

# **Holistic Approach for Authoring Immersive and Smart Environments for the Integration in Engineering Education**

Zur Erlangung des akademischen Grades einer

**Doktorin der Ingenieurwissenschaften**

(Dr.-Ing.)

von der KIT-Fakultät für Maschinenbau

des Karlsruher Instituts für Technologie (KIT)

angenommene

**Dissertation**

von

Dipl.-Inform. Polina Häfner

Tag der mündlichen Prüfung: 16. September 2020

Referent: Prof. Dr. Dr.-Ing. Dr. h. c. Jivka Ovtcharova

Korreferent: Asso. Prof. Jean-Rémy Chardonnet (MCF)



This document is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0): <https://creativecommons.org/licenses/by/4.0/deed.en>

## **Abstract**

The fourth industrial revolution and the rapid technological advances challenge the established educational structures and traditional educational practices. Especially, the engineering fields require that one has to continually improve his/her knowledge and skills in order to be competitive on the labour market. There is a need for a paradigm shift in education and training towards novel technologies like virtual reality and artificial intelligence. However, the incorporation of those technologies in an educational program is not as simple as investing in new devices or software. New educational programs have to be created or old ones reshaped from the ground up. Those are complex and extensive processes that involve decision-making, design and development. These are considerable challenges that require overcoming many obstacles.

This thesis presents a methodology that deals with the challenges of applying virtual reality and artificial intelligence as key technologies in engineering education. Its main goal is to guide key stakeholder groups to improve the way of learning and provide new and efficient learning experiences. Since each educational program is unique, the methodology follows a holistic approach to support the creation of customised courses or trainings.

For this purpose, it considers the interplay between various aspects and summarise them in three layers - educational, technology and management. The triple-layered methodology emphasises the influence of the technologies on the instructional design and the management processes. It provides methods for decision-making based on an extensive educational, technological and economic analysis. Furthermore, it supports the instruction design process by providing an exhaustive categorisation of the benefits and downsides of immersive learning environments and shows which of their characteristics can improve the learning process. A particular focus lies on the systematic design of immersive systems and the efficient authoring of immersive applications by using methods from the area of artificial intelligence.

The methodology is validated based on four validation use cases with different educational program. Each educational program has its unique goals and in combination, they cover the validation of all layers of the methodology. The methodology iteratively evolves with each validation project. The results show that the methodology is reliable and applicable for various scenarios for most educational levels and domains.

Applying the provided methods in this thesis, stakeholder groups can effectively and efficiently incorporate the immersive technologies in their educational practice. Furthermore, they can save effort, time and costs for the planning, development and maintenance of immersive systems based on the proposed approach. The technology shifts the educator's role in a facilitator role. Moreover, educators can provide individual support to the learners and concentrate on higher order cognitive skills. As a main result, learners receive an adequate, high-quality, state-of-the-art education, which makes them more skilled, successful and satisfied.

## Kurzfassung

Die vierte industrielle Revolution und der rasante technologische Fortschritt stellen die etablierten Bildungsstrukturen und traditionellen Bildungspraktiken in Frage. Besonders in der Ingenieurausbildung erfordert das lebenslange Lernen, dass man sein Wissen und seine Fähigkeiten ständig verbessern muss, um auf dem Arbeitsmarkt wettbewerbsfähig zu sein. Es besteht die Notwendigkeit eines Paradigmenwechsels in der Bildung und Ausbildung hin zu neuen Technologien wie virtueller Realität und künstlicher Intelligenz. Die Einbeziehung dieser Technologien in ein Bildungsprogramm ist jedoch nicht so einfach wie die Investition in neue Geräte oder Software. Es müssen neue Bildungsprogramme geschaffen oder alte von Grund auf umgestaltet werden. Dabei handelt es sich um komplexe und umfangreiche Prozesse, die Entscheidungsfindung, Design und Entwicklung umfassen. Diese sind mit erheblichen Herausforderungen verbunden, die die Überwindung vieler Hindernisse erfordert.

Diese Arbeit stellt eine Methodologie vor, die sich mit den Herausforderungen der Nutzung von Virtueller Realität und Künstlicher Intelligenz als Schlüsseltechnologien in der Ingenieurausbildung befasst. Die Methodologie hat zum Ziel, die Hauptakteure anzuleiten, um den Lernprozess zu verbessern, sowie neuartige und effiziente Lernerfahrungen zu ermöglichen. Da jedes Bildungsprogramm einzigartig ist, folgt die Methodik einem ganzheitlichen Ansatz, um die Erstellung maßgeschneiderter Kurse oder Ausbildungen zu unterstützen. Zu diesem Zweck werden die Wechselwirkung zwischen verschiedenen Aspekten berücksichtigt. Diese werden in den drei Ebenen - Bildung, Technologie und Management zusammengefasst. Die Methodik betont den Einfluss der Technologien auf die Unterrichtsgestaltung und die Managementprozesse. Sie liefert Methoden zur Entscheidungsfindung auf der Grundlage einer umfassenden pädagogischen, technologischen und wirtschaftlichen Analyse. Darüber hinaus unterstützt sie den Prozess der didaktischen Gestaltung durch eine umfassende Kategorisierung der Vor- und Nachteile immersiver Lernumgebungen und zeigt auf, welche ihrer Eigenschaften den Lernprozess verbessern können. Ein besonderer Schwerpunkt liegt auf der systematischen Gestaltung immersiver Systeme und der effizienten Erstellung immersiver Anwendungen unter Verwendung von Methoden aus dem Bereich der künstlichen Intelligenz.

Es werden vier Anwendungsfälle mit verschiedenen Ausbildungsprogrammen vorgestellt, um die Methodik zu validieren. Jedes Bildungsprogramm hat seine eigenen Ziele und in Kombi-

nation decken sie die Validierung aller Ebenen der Methodik ab. Die Methodik wurde iterativ mit jedem Validierungsprojekt weiterentwickelt und verbessert. Die Ergebnisse zeigen, dass die Methodik zuverlässig und auf viele Szenarien sowie auf die meisten Bildungsstufen und Bereiche übertragbar ist.

Durch die Anwendung der in dieser Arbeit vorgestellten Methoden können Interessengruppen immersiven Technologien effektiv und effizient in ihre Unterrichtspraxis integrieren. Darüber hinaus können sie auf der Grundlage der vorgeschlagenen Ansätze Aufwand, Zeit und Kosten für die Planung, Entwicklung und Wartung der immersiven Systeme sparen.

Die Technologie verlagert die Rolle des Lehrenden in eine Moderatorrolle. Außerdem bekommen die Lehrkräfte die Möglichkeit die Lernenden individuell zu unterstützen und sich auf deren kognitive Fähigkeiten höherer Ordnung zu konzentrieren. Als Hauptergebnis erhalten die Lernenden eine angemessene, qualitativ hochwertige und zeitgemäße Ausbildung, die sie qualifizierter, erfolgreicher und zufriedener macht.

# Acknowledgements

Even though a central domain of this work is the human-machine interaction, it is the human-human interaction that drives innovation. We are what we are because of the interaction with all the many people who have influenced us in our lives. Thus I would like to thank everyone who supported me directly and indirectly in creating this work.

I would like to express my sincere gratitude to Prof. Dr. Dr.-Ing. Dr. h. c. Jivka Ovtcharova for the given opportunities and support during my time as a student and research assistant at the Institute for Information Management in Engineering at the Karlsruhe Institute of Technology. I am very grateful for the trust placed in me and the provision of an environment for personal and professional development.

My sincere thanks go to the Asst. Prof. Jean-Rémy Chardonnet for his excellent cooperation and support as well as his willingness to co-supervise this thesis.

Special thanks to my current and former colleagues, including all research assistants, for the friendly and productive working environment and especially for their excellent collaboration on the joint projects presented in this work.

I wish to thank also all students, who took part in the virtual reality practical course or have written their theses under my supervision. Together we could work on exciting topics and developed so many virtual reality applications. It was a process of shared learning experience that helped me to improve and validate the methodology of this work.

I would like to use these acknowledgements to thank my family for the invaluable help and boundless love and I want them to know that I appreciate all that they have done for me throughout the years.

I cannot give enough thanks to my beloved husband, friend and colleague Victor Häfner. He has always supported and encouraged me, especially in times of doubt. Last but not least, I want to thank my daughter Leonie, who was born during the writing of this thesis. This event has boosted my motivation to complete this work. Without both my husband and my daughter, this dissertation will not have been a fact. Thus I would like to dedicate it to both of them.

Karlsruhe, September 2020

*Polina Häfner*



# Table of Contents

<b>Abstract</b> . . . . .	<b>i</b>
<b>Table of Contents</b> . . . . .	<b>x</b>
<b>List of Figures</b> . . . . .	<b>xiv</b>
<b>List of Tables</b> . . . . .	<b>xvi</b>
<b>List of Abbreviations</b> . . . . .	<b>xvii</b>
<b>1 Introduction</b> . . . . .	<b>1</b>
1.1 Motivation . . . . .	1
1.2 Objectives and Research Questions . . . . .	4
1.3 Thesis Structure . . . . .	8
<b>2 Theoretical Background</b> . . . . .	<b>11</b>
2.1 Educational Theories and Methods . . . . .	11
2.1.1 Learning Theories . . . . .	11
2.1.2 Didactic Methods and Instructional Design Models . . . . .	13
2.2 Immersive Technologies . . . . .	20
2.2.1 Interaction . . . . .	22
2.2.2 Immersion . . . . .	23
2.2.3 Presence and Imagination . . . . .	25
2.2.4 Intelligence . . . . .	25
2.3 Artificial Intelligence . . . . .	26
2.3.1 Definition . . . . .	26
2.3.2 Logic- and knowledge-based AI . . . . .	27
2.3.3 Data-based AI - Machine Learning . . . . .	29
2.4 Business Analysis . . . . .	30
2.4.1 Strategic Planning Tools . . . . .	30
2.4.2 Requirements Engineering . . . . .	30
2.4.3 Costs Estimation and Economic Efficiency Analysis . . . . .	31

---

<b>3</b>	<b>State of the Art</b>	<b>35</b>
3.1	Technological Advances of Immersive Technologies	35
3.1.1	Virtual Reality Hardware	35
3.1.2	Virtual Reality Software	42
3.1.3	Frameworks for Authoring of Virtual Reality Environments	44
3.1.4	Augmented Reality Hardware and Software	48
3.2	Immersive Technologies in Education	50
3.2.1	Immersive Learning Applications	51
3.2.2	Immersive Technologies in Engineering Education	53
3.2.3	Teaching Virtual Reality in Higher Education	54
3.2.4	Methods for Feasibility Analysis of Immersive Technologies	55
3.3	Other Educational Technologies	57
3.3.1	Multimedia	57
3.3.2	Serious Games	58
3.3.3	Artificial Intelligence in Education	58
3.3.4	E-Learning Tools	60
<b>4</b>	<b>Methodology</b>	<b>63</b>
4.1	Educational Layer	70
4.1.1	Analysis	70
4.1.2	Instructional Design	73
4.1.3	Preparation and Development	90
4.1.4	Delivery of Instructions	95
4.1.5	Evaluation and Optimisation	101
4.2	Technology Layer	105
4.2.1	Analysis of Immersive Technologies for Education	106
4.2.2	Design of Immersive Applications	125
4.2.3	Immersive IT Resources	136
4.2.4	Development of Immersive Applications	141
4.2.5	Evaluation of Immersive Systems	152
4.2.6	Optimisation of Authoring Process through the Use of Artificial Intelligence	154
4.3	Management Layer	161
4.3.1	Decision Support Method	161
4.3.2	Business Analysis and Strategic Planning	168
4.3.3	Economical Analysis	170
4.3.4	Management of the Project Development and Deployment	173
4.3.5	Overall Project Evaluation	175

---

<b>5</b>	<b>Validation</b>	<b>179</b>
5.1	Immersive Driving Simulator with Intelligent Tutoring System	181
5.1.1	Analysis	181
5.1.2	Design of the Immersive Learning Environment	187
5.1.3	Authoring of the Immersive Driving Simulator	192
5.1.4	Implementation of the Semantic Layer	203
5.1.5	Tutoring System	207
5.2	Teaching Authoring of Immersive Applications in Higher Education	226
5.2.1	Initial Analysis	226
5.2.2	Analysis of the Target Group	228
5.2.3	Design of the Virtual Reality Practical Course	229
5.2.4	Preparation Activities and Development of Educational Resources	237
5.2.5	Delivery of Instructions and Project Examples	245
5.2.6	Students and Course Evaluation	256
5.3	Virtual Reality for Teaching STEM in Secondary Education	265
5.3.1	Analysis and School Workshop Design	265
5.3.2	Project Development	272
5.3.3	Workshop Delivery	275
5.4	Sewing Machine Training with Haptic Simulation	280
5.4.1	Analysis and Design	280
5.4.2	Cost and Benefit Evaluation	285
5.4.3	Prototype Development	288
<b>6</b>	<b>Conclusion</b>	<b>293</b>
	<b>Bibliography</b>	<b>323</b>
<b>A</b>	<b>Appendix</b>	<b>325</b>
A.1	Methodology	325
A.1.1	Roles and Teams	325
A.2	Decision Support Method	326
A.2.1	Benefit Analysis Questionnaire	326
A.3	DriveSim Project	334
A.3.1	Current Situation Driving Lessons	334
A.3.2	DriveSim Requirements	336
A.4	Virtual Reality Practical Course - Educational Materials	338
A.4.1	Introductory Questionnaire	338
A.4.2	Timetable	340
A.4.3	Immersive Technology Topics for Students' Presentations	341

A.4.4	Project Work Evaluation . . . . .	342
A.4.5	Evaluation of Presentation . . . . .	343
A.4.6	Feedback Sheet . . . . .	344
A.4.7	VRPC Project Examples . . . . .	346
A.5	MINT BOX Project . . . . .	352
A.5.1	Example of an assignment . . . . .	352

## List of Figures

1.1	Forecast for the market size of virtual reality hardware and software from 2016 to 2020, by platform [Arm18] . . . . .	3
1.2	Thesis structure . . . . .	9
2.1	Cognitive theory of multimedia learning [May09] . . . . .	12
2.2	Berlin Model according to [Hei76, QWCH16] . . . . .	15
2.3	ADDIE Model for instructional design according to [Kur15a] . . . . .	16
2.4	Bloom's taxonomy (revised) according to [Wil16] . . . . .	16
2.5	Taxonomy of significant learning according to Fink [Fin13] . . . . .	18
2.6	Reality-Virtuality Continuum by Milgram [MTUK95] . . . . .	20
2.7	The three axes of the virtual reality term [Ovt20] . . . . .	21
2.8	Types of AI systems: Analytical, human-inspired, humanised artificial intelligence [KH19] . . . . .	27
2.9	SWOT analysis matrix adapted by [Xhi07] . . . . .	30
2.10	Approach for economic efficiency analysis according to [BMF11] . . . . .	32
3.1	Overview of the Human-Machine-Interface (HMI) [Ovt20] . . . . .	36
3.2	Three-sided CAVE system at <i>LESC</i> [Sch11] (left) and Powerwall with six passive stereo displays presented at Hannover Messe 2015 by <i>KIT and Bechtle AG</i> (right) .	37
3.3	<i>Google</i> Cardboard (a) [Goo19], <i>Samsung Gear</i> (b) [Sam19] and <i>HTC Vive</i> (c) [New19]	38
3.4	Target for glasses and the interaction device <i>Flystick 3</i> by <i>ART</i> company [Adv19] .	39
3.5	Omnidirectional treadmills <i>CyberWalk</i> [RGSM <sup>+</sup> 08] and <i>Virtuix Omni</i> [Vir20] . . .	40
3.6	<i>Haption's Virtuose 6D</i> and <i>Scale1</i> [Hap18a] . . . . .	41
3.7	<i>PolyVR</i> software architecture [Hä19] . . . . .	48
3.8	<i>Microsoft HoloLens</i> AR headset [Mic20] . . . . .	49
3.9	Virtual reality training for industrial plants [Lin18] . . . . .	51
3.10	Electrostatic playground for experimentation with the principles of electrostatics [GCM <sup>+</sup> 19] . . . . .	52
3.11	<i>VRTEX</i> Virtual reality welding training simulators [Lin17] . . . . .	53
4.1	The three layers and main task areas covered by the methodology . . . . .	63
4.2	Identified roles and key stakeholder groups . . . . .	64

---

4.3	Educational Layer - tasks and roles . . . . .	67
4.4	Technology Layer - tasks and roles . . . . .	68
4.5	Management Layer - tasks and roles . . . . .	68
4.6	Overview of the instruction design process adapted by [Kur15a] . . . . .	70
4.7	Structure of the “Instructional Design” section . . . . .	74
4.8	Structure of an immersive technology course with three overlapping phases . . . . .	76
4.9	Administration and development activities . . . . .	91
4.10	Project organisation and communication between educators and learners . . . . .	98
4.11	Structure of the “Technology Layer” subsection . . . . .	105
4.12	Example of learning application user interface with gamification elements, designed by [Wer16] . . . . .	132
4.13	Example of learners statistics based on gamification elements, designed by [Wer16] . . . . .	133
4.14	An iteration step of the immersive application development process . . . . .	143
4.15	Reasoning workflow of <i>PolyVR</i> adopted by [Häf17] . . . . .	157
4.16	The semantic layer and its interaction with the other components . . . . .	158
4.17	Structure of the “Management Layer” section . . . . .	161
4.18	Decision support method for embedding immersive technology in educational program, adapted from [HDSO18] . . . . .	162
4.19	An example of spider diagram of different solutions and their benefits . . . . .	172
4.20	The tasks covered by the methodology . . . . .	178
5.1	Overview of the methodology validation . . . . .	179
5.2	China total vehicle sales for the period 1997 - 2016 [TE20] . . . . .	182
5.3	SWOT analysis for the <i>DriveSim</i> project . . . . .	184
5.4	Working areas of a virtual reality driving simulator . . . . .	190
5.5	Concept diagram of the intelligent immersive driving simulation . . . . .	191
5.6	<i>DriveSim</i> hardware setup with front projection and rear-view displays [Kal18] . . . . .	192
5.7	<i>DriveSim</i> CAVE environment . . . . .	193
5.8	View from the vehicle inside to the outside virtual world [Kal18] . . . . .	194
5.9	Student driver with shutter glasses [Kal18] . . . . .	194
5.10	Virtual validation of the areas visible from the vehicle . . . . .	194
5.11	CAN-USB interface box . . . . .	195
5.12	CAN-USB interface platine . . . . .	195
5.13	Vehicle cockpit receives data from the simulation over the interface . . . . .	196
5.14	OpenStreetMap 2D editor vs generated 3D world . . . . .	197
5.15	Visualisation of height data for a particular chunk . . . . .	198
5.16	Generated topography with atmospheric effects . . . . .	198
5.17	Generated buildings . . . . .	199

5.18	Level of Details for the generation of trees . . . . .	199
5.19	Rain simulation . . . . .	200
5.20	Headlights lightening . . . . .	201
5.21	Street lighting . . . . .	201
5.22	Traffic simulation [Mic19] . . . . .	202
5.23	Urban infrastructure ontology displayed in <i>Web Protégé</i> . . . . .	205
5.24	Visualisation of the semantics paths . . . . .	207
5.25	<i>DriveSim</i> skill levels presented on an web user interface . . . . .	209
5.26	Driving events - rotation of the steering wheel, while turning right . . . . .	213
5.27	Driving events - speed and acceleration, while turning right . . . . .	214
5.28	Tutoring ontology . . . . .	215
5.29	Driving skills ontology . . . . .	216
5.30	View on the training ground data with the online editor of <i>OpenStreetMap</i> . . . . .	221
5.31	Fuyang training ground, uphill training exercise - real vs. virtual . . . . .	221
5.32	Starting scene for the uphill exercise . . . . .	222
5.33	User interface for the tutoring system via tablet . . . . .	222
5.34	GUI with recent events and users feedback on errors . . . . .	223
5.35	Infrastructure of the <i>Lifecycle Engineering Solution Centre</i> at KIT, stand 2018 . . . . .	232
5.36	Institute's Youtube channel with the project result videos [Ins20] . . . . .	238
5.37	An example for <i>ILIAS</i> course contents in summer semester 2018 . . . . .	239
5.38	First semester of VRPC in 2010 and the first prototype of the immersive driving simulator . . . . .	247
5.39	The immersive driving simulator in 2013 [HSG <sup>+</sup> 13] . . . . .	248
5.40	<i>VR Space</i> project . . . . .	249
5.41	Students from the <i>VR Space</i> project 2018 in the CAVE . . . . .	251
5.42	<i>Virtual Twin</i> project definition of a milling profile via the touch interface and the result . . . . .	252
5.43	The real and virtual environment of the <i>Energy Experience Lab</i> . . . . .	254
5.44	<i>Energy Experience</i> gameplay . . . . .	255
5.45	First version of students' assessment [HHO13] . . . . .	256
5.46	Sample solution for the automatic car light control . . . . .	274
5.47	Virtual world of the free jump exercise . . . . .	274
5.48	Storage and analysis of parameters . . . . .	275
5.49	Students working on assignments at the computer lab . . . . .	277
5.50	Students test their results on the immersive driving simulator . . . . .	278
5.51	Potential benefits deduced from the questionnaire [HDSO18] . . . . .	282
5.52	Weightings of the benefit categories for each interest group resulted from the questionnaire [Sch18] . . . . .	283

5.53	Hardware architecture of the technology concept [Hei18]	284
5.54	Benefit evaluation of the ILE according to experts (for one solution)	287
5.55	Prototype of the <i>Haptic Sewing</i> Solution [Hei18]	289
5.56	Virtual sewing simulator	289
5.57	Hardware interface of sewing simulator	290
A.1	Roles and teams of the methodology	325
A.2	Virtual reality practical course timetable for the winter term 2017/2018	340

## List of Tables

2.1	The nine W-questions of didactics [AWP19] . . . . .	14
2.2	Nine events of instruction by Gagne [Kru09] . . . . .	17
2.3	Eight instructional principles for problem-based learning (PBL) [SD95] . . . . .	19
2.4	One time costs adapted from [Dü15] . . . . .	31
2.5	Running costs adapted from [Dü15] . . . . .	31
2.6	Methods for economic efficiency analysis [BMF11] . . . . .	32
4.1	Guiding questions for target group analysis based on Berlin Model [HOS70] . . . . .	72
4.2	Guiding questions for analysis of the educational requirements and boundary conditions [LL13] . . . . .	73
4.3	Six kinds of significant learning by Fink [Fin13] . . . . .	75
4.4	Guiding questions for the overall introduction . . . . .	76
4.5	Structure for project-based learning on authoring virtual worlds . . . . .	78
4.6	Guiding questions for design of the learning activities during the theoretical introduction . . . . .	81
4.7	Guiding questions for design of the learning activities during the practical introduction . . . . .	84
4.8	Guiding questions for the design of the PBL activities . . . . .	85
4.9	Guidelines for the organisation of the necessary facilities . . . . .	88
4.10	Guidelines for determining time constraints . . . . .	89
4.11	Guidelines for identifying key personal and roles . . . . .	90
4.12	Administrative activities . . . . .	91
4.13	Categorisation of the benefits of Immersive Learning Systems (ILS) adapted by [Häf20] . . . . .	107
4.14	Categorisation of the downsides and limitations of immersive technologies adapted by [Häf20] . . . . .	120
4.15	Design criteria for immersive systems . . . . .	129
4.16	Requirements for immersive systems . . . . .	134
4.17	Criteria for selection of immersive system components . . . . .	138
4.18	Identification of the necessary resources . . . . .	171
5.1	Main benefits for the driving students . . . . .	185

5.2	Benefits for driving instructors and other key stakeholders . . . . .	186
5.3	Termination criteria for the <i>DriveSim</i> project . . . . .	187
5.4	Sample of driving skills and their related tasks and events . . . . .	217
5.5	Learning goals of the virtual reality practical course and their classification into the six kinds of learning by [Fin13] . . . . .	231
5.6	Requirements on the tasks description in the documentation . . . . .	241
5.7	Virtual reality practical course grading system . . . . .	244
5.8	Overview of evaluation criteria and weighting . . . . .	257
5.9	Criteria for evaluation of the students' presentations on immersive technology topics	258
5.10	Results of the KIT evaluation of the VRPC from 2010 up to 2018 . . . . .	262
5.11	Results of the VRPC evaluation from 2010 up to 2018 . . . . .	263
5.12	Detailed schedule of the workshop . . . . .	276
5.13	Acquisition costs estimation for the project . . . . .	285
5.14	Running costs estimation for the project . . . . .	286
A.1	Homework - preparation of a presentation on an immersive technology topic . . . .	341

## List of Abbreviations

3D	Three-dimensional
ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ADDIE	Analysis, Design, Development, Implementation, and Evaluation
ADL	Architecture Description Languages
AI	Artificial Intelligence
API	Application Program Interface
AR	Augmented Reality
ART	Advanced Real-Time Tracking
ASCII	American Standard Code for Information Interchange
BTS	French acronym: Brevet de technicien supérieur
CAD	Computer Aided Design
CAIT	Centre for Artificial Intelligence Talents
CAL	Computer Aided Learning
CAM	Computer Aided Manufacturing
CAN	Controller Area Network
CAVE	Cave Automatic Virtual Environment
CBT	Cognitive Behavioral Therapy
CEF	Chromium Embedded Framework
CNY	Chinese Yuan
COTS	Commodity Off The Shelf
CT	Computed tomography
DFG	German acronym: Deutsche Forschungsgemeinschaft
ECTS	European Credit Transfer and Accumulation System
ECU	Electronic Control Unit

ESA	European Space Agency
EU	European Union
GIS	Geographic Information System
GIT	Git is the name of a distributed version-control system
GPS	Global Positioning System
GTA	Grand Theft Auto
GUI	Graphical User Interface
HMD	Head-mounted Display
HMI	Human-machine Interface or Interaction
HRTF	Head-related Transfer Function
IC	Initial Conditions
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
ILE	Immersive Learning Environment
ILS	Immersive Learning System
IMI	Institute for Information Management in Engineering
IPD	InterPupillary Distance
IR	Infrared
IT	Information Technology
JOSM	Java OpenStreetMap geodata
KIT	Karlsruhe Institute of Technology
LCMS	Learning Content Management Systems
LESC	Lifecycle Engineering Solution Center
LMS	Learning Management System
LOD	Level of Details
LQI	Learning/Teaching Quality Index
MCF	French acronym: Maître de conférences
MINT	German acronym: Mathematik, Informatik, Naturwissenschaft und Technik
MIT	Massachusetts Institute of Technology
MM	Multimedia

NASA	National Aeronautics and Space Administration
NIRS	Near-infrared Spectroscopy
NLP	Neuro-linguistic programming
NPV	Net Present Value
OSM	OpenStreetMap
OWL	Web Ontology Language
PBL	Project-based or problem-based Learning
PC	Personal Computer
PDF	Portable Document Format
PLM	Product Lifecycle Management
PNG	Portable Network Graphics
POI	Point of Interest
PPT	Microsoft PowerPoint Presentation Format
RDF	Resource Description Framework
RGB	Red, Green, Blue
ROI	Return on Investment
RPM	Revolutions per Minute
SOA	Service-oriented Architecture
SQL	Structured Query Language
SS	Summer Semester
SVN	Apache Subversion
SWOT	Strengths, Weaknesses, Opportunities, Threats
TV	Television
UML	Unified Modelling Language
URL	Uniform Resource Locator
US	United States
USA	United States of America
USD	United States Dollar
UV	Ultraviolet
VE	Virtual Engineering
VLE	Virtual Learning Environments

VPN	Virtual Private Network
VR	Virtual Reality
VRDS	Virtual Reality Driving Simulator
VRPC	Virtual Reality Practical Course
VU	Virtual Universities
WARS	German acronym: WirtschaftlichkeitsAnalyse mit RisikoStufen
WAVE	German acronym: Wirtschaftlichkeitsanalyse für Virtual Engineering
WIMP	Windows, Icons, Menus, Pointer
WS	Winter Semester
XR	Extended Reality
STEM	Science, Technology, Engineering and Mathematics

# 1 Introduction

## 1.1 Motivation

Computers and the Internet drastically changed the way we approach learning. One of the essential changes in education was that memorisation of concepts was shifted to meaningful learning, where it is important to find the right information and apply it to solve problems. To know facts is not enough today, it is crucial to apply knowledge in order to solve problems, to be creative and to make decisions. Along with the development and improvement of the computer technologies, we can witness the improvement of how we learn. The availability and accessibility of information was never so high as today, and it will grow in quantity and quality in the future. With the help of more advanced technologies like virtual reality and artificial intelligence, the limitations of learning such as physical teacher or geographical location are vanishing, and students can learn individually at their own pace.

### **Demand for Specialists**

In addition to the changes associated with the way we learn through new technologies, at the same time these technologies require new experts. The digital revolution transforms businesses and creates new jobs. It entails increased demand for suitably qualified professionals. On the one hand, the IT-businesses are growing, but on the other hand, the lack of available specialists is becoming an increasingly negative factor in the overall market situation. A survey on talent shortage, made by *Manpower Group* in 2018 indicates that 45 per cent of the companies globally cannot find skilled job candidates [Man18].

In the time of globalisation and technical advances, companies want to remain competitive on national and international markets. This objective requires a qualified workforce with a corresponding level of education, especially in the STEM fields [OHH<sup>+</sup>15]. STEM is an acronym that stands for the fields of study Science, Technology, Engineering and Mathematics. These fields are critical concerning technology and workforce development, which directly relates to the national economic competitiveness [oPitGEotsC07]. Graduate numbers in STEM fields have seen an increase in the past few years, but the demand still has not been met by a large

margin. The corporate sector is urgently looking for graduates from the faculties of mathematics, computer science, natural sciences and technology, resulting in excellent opportunities for students with degrees related to the subjects as mentioned earlier. To address the STEM skills shortage, policy makers take measures and launch campaigns to promote interest in those fields further [Exe20].

*Forbes* summarises some top technical skills that are recently in high demand, and most of them are based on the STEM fields. The skills include experience in artificial intelligence, applied machine learning, data science talent, excellence in cybersecurity, talent for SaaS (Software as a Service) in the cloud, mobile application development. Further needed skills are those to envision design and develop Augmented reality apps, programming knowledge as well as coding and engineering experience [For18]. Next to the technical knowledge and experience, companies search employees who also possess soft skills and who have the ability to communicate with others and be approachable in their demeanour. *Forbes* lists as soft skills those related to analytics, cross-team functionality and communication as well as the ability to adapt fast to new technology [For18].

Looking at contemporary products, for example, from electronic or automotive industries, we witness a rapidly growing complexity. Handling this new complexity requires well-prepared engineers, able to investigate and solve engineering problems efficiently and in interdisciplinary teams.

### **Demand on Immersive Technology Specialists**

Speaking concretely of the immersive technologies market represented by virtual (VR) and augmented reality (AR), we witness a rapid growth. Compared to the previous VR and AR hypes in the 90s, the hype in the 21st century seems to transform into a rapidly evolving industry. According to *Statista*, the market size of immersive technology doubled in 2018 compared to 2016 (see Fig. 1.1). It was predicted to be worth approximately 18.8 billion US dollars in 2020. The forecast should be corrected because of the currently negative effect by the 2020 coronavirus pandemic. Nevertheless, the market is expected to expand dramatically in the coming years.

Nevertheless, if the IT market is growing, the VR industry will grow with it. The current demand for virtual and augmented reality jobs increases rapidly. The job search site indeed.com writes that the job postings for VR, AR and game development skill sets has risen by 93% since 2015 [ind18]. Professional game developers and designers must upgrade their skills related to the novel immersive technologies. However, more crucial still is the need to educate the new developer generation as early as possible by integrating VR courses in the university education.

## Challenges of Immersive Technology in Education

Virtual and augmented reality technologies have a high potential when used as a learning medium. Next to the integration of immersive learning applications in educational programs, another task should be the teaching of implementing immersive virtual environments. One of the challenges is to develop an appropriate and sustainable instructional design which utilises VR/AR learning environments. They are usually not meant to replace existing training but to complement it. Therefore, new didactic methods like blended learning are needed. For example, many educators rely on the learners' motivation and engagement as a feature of new learning media, but after the initial euphoria, motivation diminishes with the use of this technology. It is essential to methodically use the integration of new media technologies and develop appropriate and sustainable didactic methodologies.

Another problem in using immersive technologies from the perspective of the education and training practice arises from the high complexity of the learning environment and the higher efforts and costs for its implementation. These are the most common reasons for failing to introduce immersive training, despite the proven high potential. As VR/AR devices become more and more affordable due to the hype on the market, the question remains on how to reduce the effort involved in authoring an immersive training application. Efforts and costs are comparable to those of computer games.

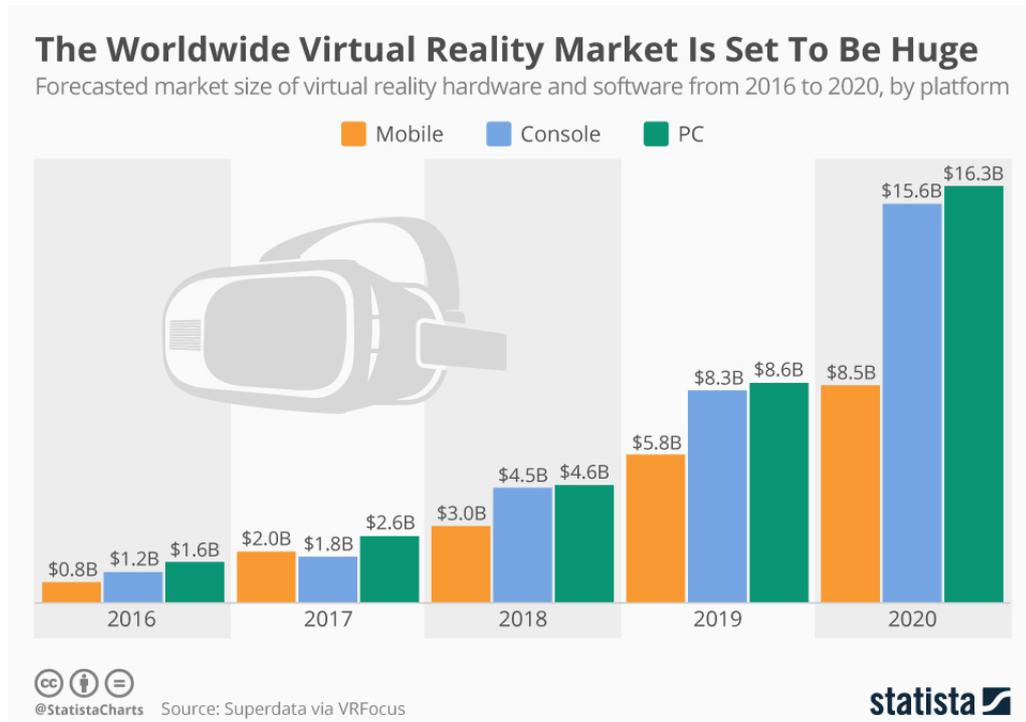


Fig. 1.1: Forecast for the market size of virtual reality hardware and software from 2016 to 2020, by platform [Arm18]

The implementation effort from today's perspective is very time and cost-intensive and requires expert knowledge in many areas. Fundamental technology expertise is necessary in computer graphics, 3D modelling, programming, system interfaces and immersive hardware. Furthermore, it is essential to have experts in learning psychology and instruction design, as well as experts in the domain of each training application.

Seeing the high potential, companies start hastily the adoption of this technology based on small-scale and low-budget pilot projects without considering the sustainability. Often, these projects cannot reveal the full potential because of the implementation of a small virtual world, low-level tutoring logic (if any) and low-cost hardware setups. Furthermore, the incorporation into the company culture and processes can be difficult due to many reasons. For instance, the quality of the learning environment is crucial for its acceptance. The moment the interaction proves to be difficult, inaccurate or complicated or the VR/AR headsets are felt to be heavy, uncomfortable or unhygienic, users do not accept the system. Therefore, the well-thought-out realisation of a suitable and sustainable immersive learning environment system is crucial for successful use.

Another problem with creating an immersive learning environment is the 3D and VR software. There are many proprietary and open-source VR/AR tools currently available. Each tool has its focus and often lacks some additional features. Significant proof of this is that researchers have failed to classify and compare these software tools. Often, there is a lack of user interfaces that allow educators to develop 3D interactive training materials intuitively. One of the most significant drawbacks is the compatibility. The transfer of the resulting application into another tool is not possible. It requires the import of the assets and programming of the application logic from scratch.

At least additional implementation or integration effort for a tutoring system or logic is necessary to create an immersive learning application. One of the problems of the implementation of a tutoring system is the “absence of adequate models of lifecycles of educational programs, resources and skill levels of trainees that allow automating the processes of synthesis and configuration of personal learning environments“ [GKGBPS16].

## 1.2 Objectives and Research Questions

Novel technologies like virtual reality and artificial intelligence promise great potential and bring many advantages in the area of education. That is why there is a need for a paradigm shift in education and training towards those technologies. Investing in new devices and software is not enough for their adoption in an educational program. There are complex and extensive

processes that involve decision-making, design and implementation of solutions and require overcoming many obstacles.

The main objective of this thesis is to guide key stakeholder groups to improve the way of learning and provide new and efficient learning experiences through the application of novel technologies such as virtual and augmented reality and artificial intelligence. Further goals are to develop methods and tools, which should support the integration of immersive technologies in educational programs. These methods should consider all connections between the related aspects and should be bundled into a holistic methodology.

The methodology of this thesis aims to develop the methods based on the externalisation of expert knowledge. Experts who have experience in integrating immersive technologies in educational programs as well as in the implementation of immersive applications. Usually, this knowledge is implicit for experts or organisations, is non-transparent, and it is a challenge to assess its amount. Non-experts, like educators, who want to use those technologies have no access to this information. This makes it urgently necessary to model systematically the processes and workflows involved. The objectives of this thesis will be achieved if it provides a holistic and sound foundation for all key stakeholder groups and enables the successful adoption of the novel technologies in the education sector.

**Main Objectives:**

- Development of a reliable methodology that supports the effective and sustainable integration of new technologies such as virtual reality and artificial intelligence into engineering education.
  - Externalisation of expert knowledge in the area of immersive and intelligent application development;
  - Systematic modelling of the associated processes and workflows;
  - Development of methods and tools that support the associated processes in order to develop the full educational potential of the novel technologies;
- Providing a holistic approach that considers all aspects with their interdependencies and all major stakeholders;
- Creating a flexible and adaptable methodology for use across most educational levels, disciplines and settings;

The thesis goals are to provide solutions for the challenges mentioned above and can be expressed by formulating the following questions on the application of immersive technologies in education, especially in engineering education.

The first set of questions relates to the primary purpose of immersive technologies in teaching and learning processes. Since each educational program or learning process is unique, it should be analysed if such technologies can be beneficial for the particular educational initiative or not.

**Research Question I: How can immersive technologies support the teaching and learning processes?**

1. What are the benefits of immersive technologies for education?
2. Which characteristics of immersive systems manifest those benefits?
3. What are the limitations and downsides of immersive technologies for education?
4. How to decide when to use or not to use immersive technologies for the specific educational initiative?

The next set of questions is about systematically designing or redesigning an educational program in order to reach the assessed potential. For this goal, all related aspects and processes, as well as their interconnections, should be exposed to all key stakeholder groups. The instructional designers need to know which specific learning theories and methods can be applied using immersive technologies. The management requires information on the cost-benefit ratio, and the educators have to redefine their role from delivering instructions to facilitating the learning process.

**Research Question II: How to systematically design an educational program that should use immersive technologies?**

1. What are the main aspects that should be considered when designing an educational program or unit?
2. How to manage the analysis, design, development, deployment and evaluation of an immersive learning application?
3. How to optimise the outcomes for all stakeholder groups (managers, educators, learners)?
4. Which learning theories and methods can be applied using immersive technologies?
5. How to teach authoring of immersive technologies in engineering education?

The last set of questions is about creating virtual environments. When it comes to developing an immersive environment, it is essential to know what effort and cost it requires. Developers should know how the authoring process looks like and whether there are ways to automate this process and make it more efficient.

**Research Question III: How to increase the efficiency of the authoring of immersive learning applications?**

1. What are the processes and tools needed to create an immersive (learning) environment?
2. How can the development effort of an immersive learning environment be reduced to achieve an optimal effort/gain ratio?
3. Which advanced tools and methods can further automate the authoring process of the immersive learning application?

The methodology described in this work tries to answer all these questions in a systematical manner. Furthermore, it proposes different methods and approaches to support incorporating immersive technologies in education. The methodology does not only cover how to learn with immersive learning applications, but also how to improve the skills of the learners by teaching the authoring of immersive technologies.

## 1.3 Thesis Structure

The thesis is divided into six main chapters and includes an introduction, a description of the theoretical background and state of the art, followed by the presentation of the methodology and the validation and finishes with the conclusion and outlook chapters (see Fig. 1.2).

In the introductory chapter, the current challenges for the integration of immersive technologies in education are presented. It further motivates the goals of the dissertation and summarises the objectives in the form of research questions.

The chapter “Theoretical Background” explains to the readers essential concepts in three domains. As a central part, the pedagogical theories and methods, then the business analysis methods and tools, and last but not least, the immersive technologies and artificial intelligence. The content of this chapter should provide the necessary foundation for understanding the methodology of the thesis.

The “State of the Art” chapter situates this work in the current state of research and technology in all areas considered in this thesis. The focus lies on advances in the field of immersive technologies and their use for educational purposes. The main question addressed in that chapter is the use of software and hardware for virtual and augmented reality in different areas and at different levels of education. Other presented technologies used intensively in education are presented, such as multimedia, serious games, e-learning tools and artificial intelligence.

The central chapter of this thesis is the “Methodology”, which presents the holistic approach to the integration of intelligent and immersive technologies in engineering education. Each section covers one of the methodology layers, starting with the educational layer, going through the technology layer and finishing with the management layer. The educational layer builds the foundation for the methodology and is organised along the traditional instructional design process. It delivers guidelines for the tasks such as analysis of the target group, the design of an educational program such as its development, deployment and evaluation. All technical aspects are covered in the technology layer section. The first part of this section handles the technical analysis based on an exhaustive categorisation of the benefits and downsides of virtual reality for education. The following subsections present the necessary technical resources, the design criteria, as well as the development process for virtual reality applications. The last part proposes a method for the authoring of intelligent immersive environments. The management layer includes the tasks around strategic planning, decision-making, benefit analysis, economic analysis and project management. It presents an extensive decision-making process to provide support when stakeholders have to judge whether immersive technologies should be applied in a particular educational program or not.

Each section of the “Validation” chapter is dedicated to one of the validation use cases. The first section presents the project *DriveSim*, where we developed a prototype of an immersive driving simulator with an intelligent tutoring system. The second use case pertains how to teach *authoring of immersive applications* in higher education and discusses the results of the virtual reality practical course at *KIT*. The next project is called *MINT-Box* and presents how virtual reality technology can support the teaching process in the secondary education. The last section validates the developed decision-making process based on a *haptic simulation* for sewing machine training.

The appendices provide the original documents described in the use cases. Such documents are the questionnaire for benefit analysis of the immersive technologies in education as well as the evaluation materials of the virtual reality practical course. Furthermore, some project examples of the practical course are presented in the form of flyers designed by the students.

The “Conclusion and Outlook” chapter summarises the results and proposes directions for future research and development in all aspects of the methodology.

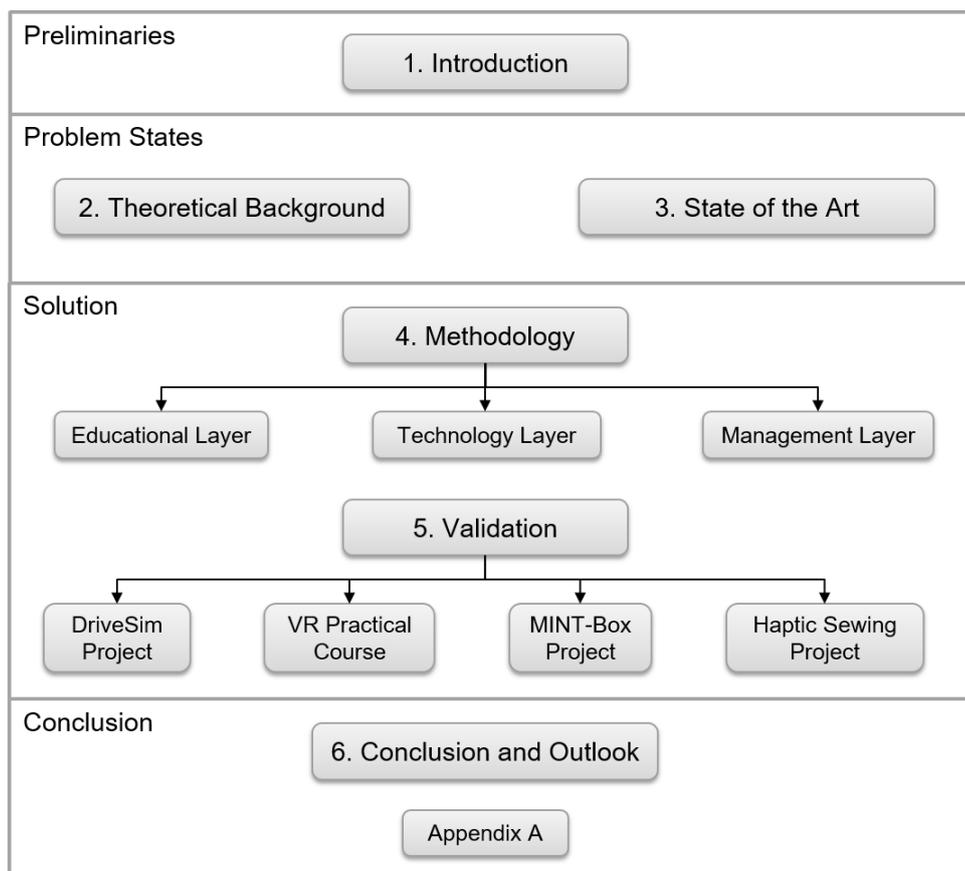


Fig. 1.2: Thesis structure



## 2 Theoretical Background

This chapter presents the key concepts and technologies introduced in the methodology. It includes the educational theories and methods as a central part. Furthermore, the chapter gives insights in the main characteristics of immersive technologies and basic types of artificial intelligence systems. Some methods and tools of the business analysis domain are also explained.

### 2.1 Educational Theories and Methods

Regardless of which technology is used for training, it is crucial to understand what learning is in order to develop successful teaching methods. This section introduces the learning theories that seek to answer the question of how people learn. Furthermore, it presents several didactic methods and instructional design models, that are applied by educators to design and develop educational programs.

#### 2.1.1 Learning Theories

Learning theories are known as conceptual frameworks, which describe how knowledge is absorbed, processed, and retained during learning [Sim13]. They describe how people learn and what exactly happens during the learning process. The most important learning theories are behaviourism, cognitivism, and constructivism [Red06].

#### **Behaviourism**

John Watson and B.F Skinner specify the behaviourism theory as a learning process, which is caused by a change in behaviour [PS04, Ski11]. In its purest form, the behaviour changes through a response to certain stimuli in the environment. The learner starts from scratch, and his behaviour is shaped through positive or negative reinforcement [Dav07]. Watson and Skinner ignored the mental aspects like thoughts and feelings, because they are not observable and handle them as a “black box”. There are three main types of learning in the behaviourism theory: the classical conditioning, the operant conditioning and the social learning theory.

The behavioural learning can be applied as verbal reinforcement, repetitive practice, bonus or participation points. The instructional methods based on the behaviourism theory help learners to recall basic facts or perform repetitive tasks. Those methods have the limitation that learners do not try to improve things when executing their tasks. Skills like creative thinking and problem-solving cannot be taught using behaviourist approaches [Kel12]. The transfer as a learning concept also derives from the behaviourism theory, but not everything we learn can be transferred to a real-world problem.

## Cognitivism

In contrast to behaviourism the cognitivism looks at the thoughts and feelings in mind as an essential processing unit for the learning process and not as a “black box”. Cognition is defined as the exploration of mental processes such as thinking, memory, knowing, and problem-solving. The process is viewed similar to the computer processing unit. The cognitive processes in the brain convert an input into an output. In the process, existing and new knowledge are related to each other, which ultimately constitutes learning. The process of thinking is, therefore, a process of cognitive information processing [KP12]. Cognitive learning theory can be applied when learners classify or chunk information, provide the structure of the lesson or lecture, link new concepts with old ones, give real-world examples and analogies, conduct discussions, use memorisation techniques as well as strive for problem-solving skills [Kel12].

A fundamental cognitive theory used in this thesis is the multimedia learning. It is extensively researched by Richard Meyer, who describes three main assumptions as its basis [May09]. First assumption is that for multimedia learning, there are two separate channels for processing information, the auditory and the visual (see Fig. 2.1). The second assumption said that there is limited channel capacity and the third that learning is an active process of filtering, selecting, organising and integrating information [May09]. He states that more knowledge is retained if both channels are presented with information. Using multimedia for learning should be applied

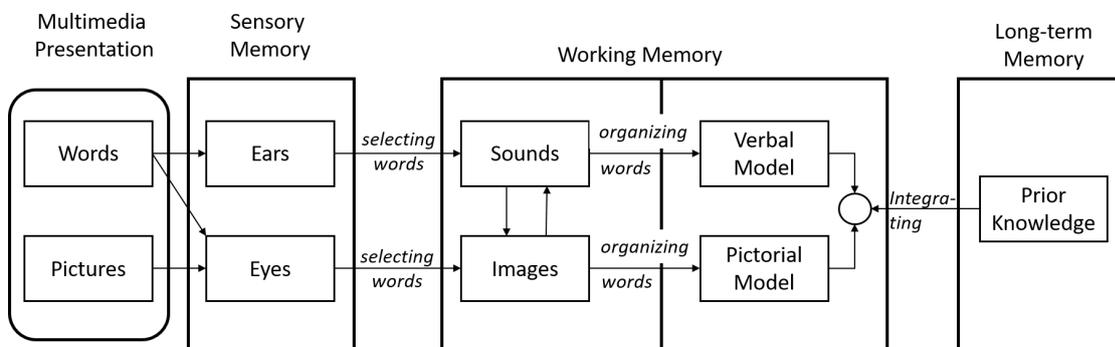


Fig. 2.1: Cognitive theory of multimedia learning [May09]

carefully, because there is a risk of delivering too much information, which cannot be processed and memorised [May09]. Teaching materials can be, for example, presentations, videos or computer applications.

## **Constructivism**

Constructivism is the third leading learning theory which states that learning is always a constructive process in which new information is linked with prior knowledge. Each individual interprets and creates the meaning based on his experiences and his internal knowledge. Learning always requires an activity of the learner and an active engagement with a learning offer [KP12]. There are two types of constructivism: individual and social. According to the social constructivism theory, the learning is a social activity and has collaborative nature. Learning occurs when learners work together in a group in order to solve problems [Che10]. The role of the teacher is to provide learning opportunities, guidance and to create a prepared (social) environment, for example with the help of learning tasks, which should encourage the learners to process as intensively and deeply as possible [KP12]. Educators must consider the prior knowledge and experiences of the learners when designing instructional methods. Some applications of the constructivism theory can be case studies, research projects, problem-based learning, project-based learning and inquiry-based learning, which include collaborative learning or teamwork, brainstorming as well as (simulations of ) real-world problems [Bob18].

### **2.1.2 Didactic Methods and Instructional Design Models**

#### **Didactic and Didactic Methods**

The word didactics means teaching and comes from the Greek word διδάσκειν (*didáskein*) [Arn12]. The scientific term didactics stems from the German tradition of theorising classroom learning and teaching [Arn12]. The didactics should provide the theoretical frame for the selection and justification of the teaching content and its structure. It should support teachers planning new teaching activities and improve existing ones. If the didactic asks what and why should be learned, the didactic methods answer the questions how and with what.

The didactic as a subject can be explained with the so-called nine W-questions (in German, all questions start with the letter W). The answers to the questions should help to formulate teaching goals, resources and times and other aspects of the educational unit. All questions should be examined in the context of the others to achieve a consistent and qualitative teaching concept [JM94]. The nine questions of didactics are presented in Tab. 2.1.

W-Question	Details
<b>Who</b> should learn?	This question addresses the target group. Which age, gender, profession, education or background the learners have.
<b>What</b> is to be learned?	What is the learning content? In what width and depth should it be treated? What previous knowledge can be assumed?
<b>Who</b> should learn <b>from</b> ?	Here is addressed the role of the educators, their qualifications, experiences and interests.
<b>When</b> should learning take place?	This question should define the time for the course, not only the time of the day or season, but also in which phase of life should the course be offered. Another critical time issue is how much course time is required to achieve the goals.
<b>With whom</b> should learning take place?	Here is essential to define if the learning is taking place in a class with other students, in small groups or individually. Some social issues like interests, performance level, gender, language and background of the other participants should be considered.
<b>Where</b> should learning take place?	The learning places like facilities, rooms and laboratories are here the usual answer, but it can also refer to an institution in which the course will be designed and held.
<b>How</b> should we learn?	This question should define the learning activities. Additionally, which places of learning, learning methods, learning techniques are preferred and which are suitable for the learning matter?
<b>With which media</b> , how should we learn?	Which media and tools, i.e. computer, overhead projector, texts, expert systems are appropriate and available to support the learning process?
<b>What</b> is there to learn <b>for</b> or <b>Why</b> ?	This question should answer what are the reasons for attending a course.

Tab. 2.1: The nine W-questions of didactics [AWP19]

While the learning theories are trying to answer the question of how people learn, the didactic models contain the teaching and learning goals, contents and methods. They are focussed on the systematic approach of a course [JM94]. A didactic model should help to ask the right questions and to cover the right aspects that are relevant for an excellent didactic decision.

There are many didactic models known such as “Berlin Model”, “Hamburger Model” and others, which offer guidance for analysis and planning of single steps for subsequent reflection and evaluation of educational units [Fur09]. The Berlin model, for example, provides two levels of didactic reflection and analysis (see Fig. 2.2). The first level of reflection is based on the

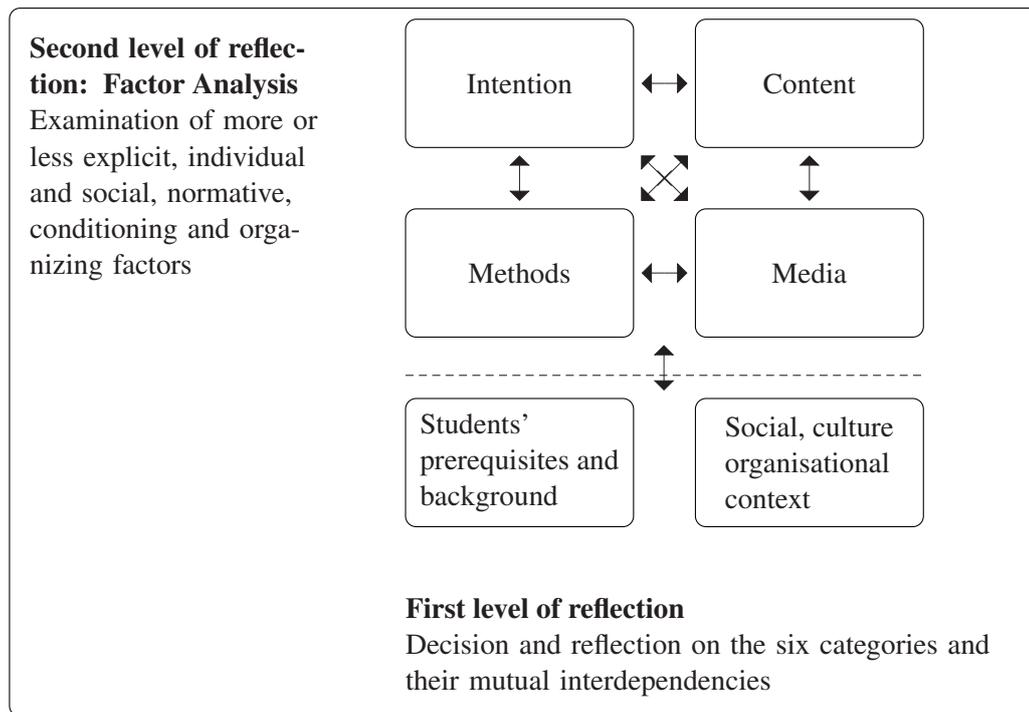


Fig. 2.2: Berlin Model according to [Hei76, QWCH16]

aims, content, media and the methods, and the second takes into account the conditioning and organising factors [QWCH16].

## Instructional Design

Instructional design is the process for creating curricula systematically and effectively. Merrill et al. [MDL<sup>+</sup>96] define instructional design as “a technology for the development of learning experiences and environments which promote the acquisition of specific knowledge and skill by students” and further promote the following instructional activities: “... directing students to appropriate learning activities; guiding students to appropriate knowledge; helping students rehearse, encode, and process information; monitoring student performance; and providing feedback as to the appropriateness of the student’s learning activities and practice performance.”

There are many instructional design models like ADDIE, ASSURE, Rapid prototyping, the systems approach model by Dick and Carey and many others, but the ADDIE model found full acceptance by instructional designers and many other models derive from it [Kur15b]. The ADDIE model has five steps: Analysis, Design, Development, Implementation, and Evaluation, hence the abbreviation (see Fig. 2.3). Each step has further sub-steps and can be used hierarchically, one step after another or in an interactive and dynamic manner [Kur15a].

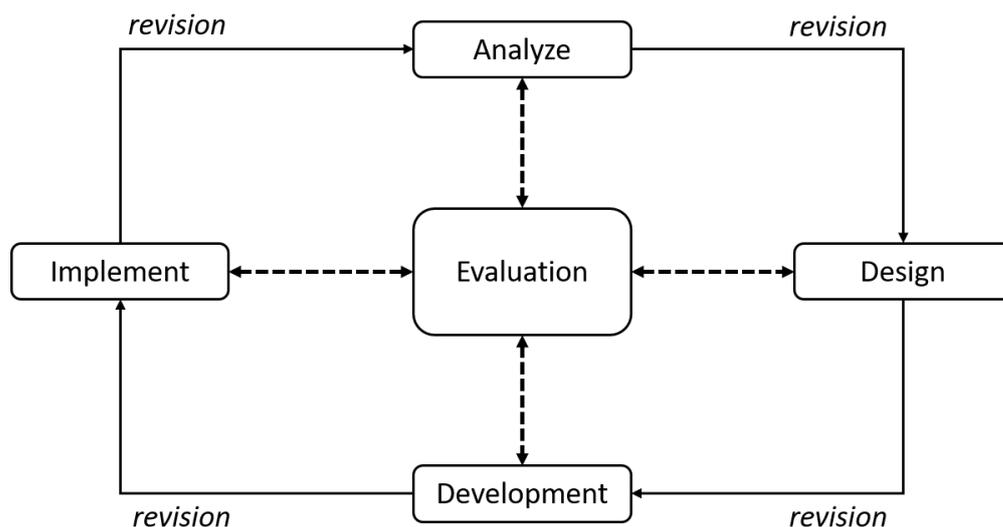


Fig. 2.3: ADDIE Model for instructional design according to [Kur15a]

When designing instructions, an important task is to identify the desired outcomes. To make a definition of the course goals as well as later decisions about testing students learning, educators can utilise the so-called taxonomies of learning and teaching. Those taxonomies helped to shift the curricula from content-oriented to outcome-oriented. An example of such taxonomy is the one developed by Bloom and revised later by Anderson and Krathwohl [Wil16, B<sup>+</sup>56]. Bloom defines three taxonomies for the cognitive, affective, and psychomotor domains of learning. The most used one, the cognitive taxonomy, has six levels of cognitive learning objectives and orders them hierarchically, depending on the complexity (see Fig. 2.4).

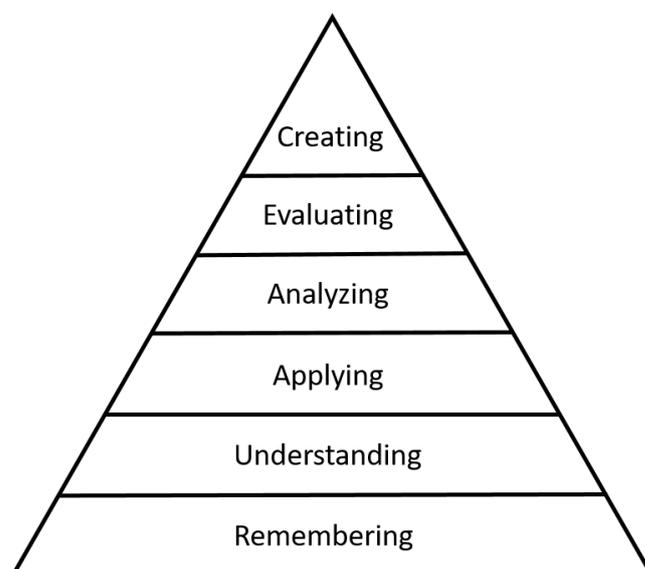


Fig. 2.4: Bloom's taxonomy (revised) according to [Wil16]

Another instructional tool was presented by Gagne and is known as “Nine Events of Instruction” [Kru09]. It is based on the behaviourist theory and addresses the conditions of learning of adults as shown in Tab. 2.2.

✓	Gain the student’s attention.	✓	Elicit performance.
✓	Inform students of the objectives.	✓	Provide feedback.
✓	Stimulate recall of prior learning.	✓	Assess performance.
✓	Present the content.	✓	Enhance retention and transfer to the job.
✓	Provide learner guidance.		

Tab. 2.2: Nine events of instruction by Gagne [Kru09]

For the goals in the context of higher education and college courses Fink created a taxonomy based on six kinds of significant learning [Fin13]. The six kinds of significant learning are as follows (see Fig. 2.5): Foundational knowledge, application, integration, human dimension, caring, learn how to learn [Fin13]. He combines the lower levels of Blooms taxonomy as foundational knowledge. The foundational knowledge should provide a basic understanding of information, concepts and ideas, that should further help the learning for the next levels. For the application kind of learning, it is important to learn how to think critical, creative and practical and to develop different skills. The application is about the usefulness of the knowledge. The integration is about the intellectual power given by the understanding of connections between things. The human dimension considers the learning about oneself, and the others and what personal and social implication have their new knowledge and skills. While learning, people develop feelings, interests and values. They care more about the learning matter and have the motivation to learn more about it and to apply it. The last category of significant learning refers to the metacognitive skills to learn more about the process of learning, which should lead to greater effectiveness [Fin13, p. 31].

### **Problem-based learning**

An important learning theory for this thesis, which derives from the constructivist learning theory is the problem-based learning (PBL). Problem-based learning is an instructional model, that can be implemented by applying different educational methods and instructional strategies. Dickie and Jay propose the following definition: “Problem-based learning is a teaching methodology that develops knowledge, abilities and skills through participation, collaborative investigation and the resolution of authentic problems” [DJ10, p. 32]. Derivatives of this model can be found in the literature also as project-based learning or team-based learning strategies [Fin13]. To facilitate the selection of the right implementation Barrows proposes a taxonomy

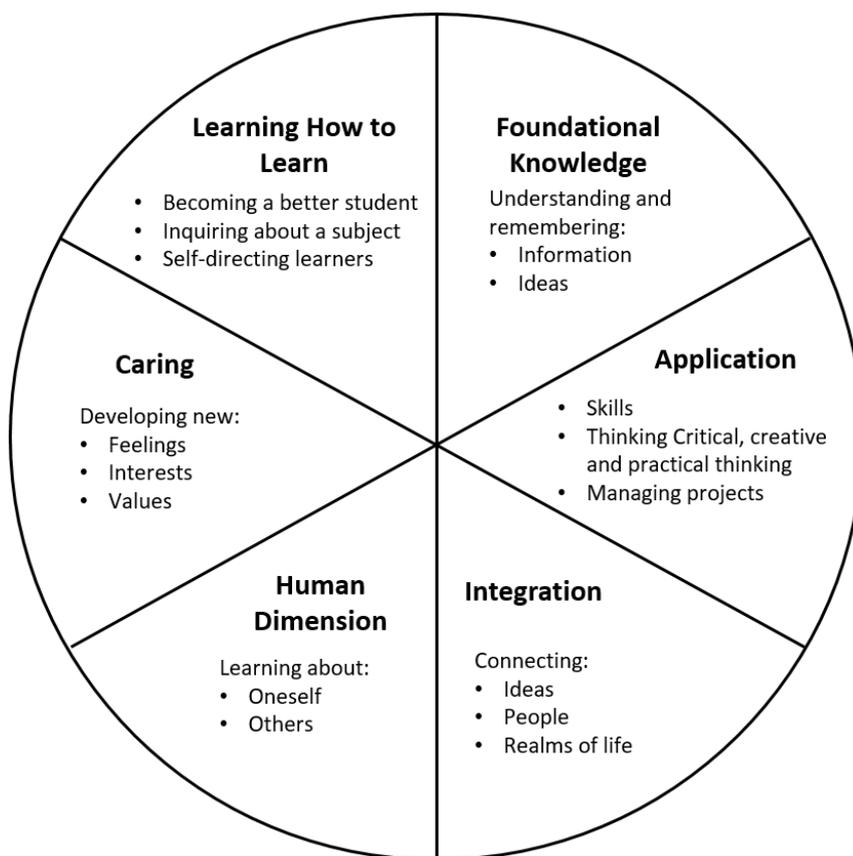


Fig. 2.5: Taxonomy of significant learning according to Fink [Fin13]

of problem-based learning methods [Bar86]. The goals to be achieved by the learners while implementing PBL according to [Bar96, HSB06, SD95, DSVdBG03] are to:

- construct flexible knowledge while applying the course content;
- develop effective problem-solving skills through engagement with an authentic problem;
- construct flexible knowledge while applying the course content;
- develop effective problem-solving skills through engagement with an authentic problem;
- develop self-directed learning skills, where learners take ownership of their learning, and the educator takes the role of facilitator;
- become effective collaborators due to the proposition that knowledge evolves through social negotiation;

- become intrinsic motivation to learn, through engagement in the learning process and ownership for the overall problem;
- develop metacognitive skills i.e. evaluation of their learning and performance;
- learn through awareness of their knowledge limitations;
- conduct research and gain new knowledge in order to solve the given problem (to apply it to the solution development);
- learn to use technology meaningfully;
- learn to present their findings and results;

The successful implementation of the PBL method can be ensured if the eight instructional principles provided by Savery and Duffy [SD95] are followed (see Tab 2.3).

✓	A larger problem should be defined, where all learning activities are embedded.
✓	The learner should develop ownership for the overall problem, in order to engage with the problem.
✓	There should be defined as a real-world, authentic problem.
✓	The complexity of the learning environment should be possibly authentic and not simplified.
✓	The problem-solving process should not be prescribed by the educator (i.e. assignment of precise readings or pre-specification of activities).
✓	The learning environment should be designed to support and challenge the learners thinking. Here the role of the teacher as a facilitator (consultant or coach) is crucial.
✓	Collaborative learning should be used so that the ideas can be tested against alternative views and contexts.
✓	The reflection on both the content and learning process should be encouraged.

Tab. 2.3: Eight instructional principles for problem-based learning (PBL) [SD95]

## 2.2 Immersive Technologies

In this section, the definitions, characteristics and applications of immersive technologies will be discussed. Those theoretical foundations are essential for the understanding of the presented methodologies as well as its benefits and potentials. The validation of the proposed methodologies is mainly based on the virtual reality technology, but can also be applied (with some adjustments) to the augmented reality. That is why virtual reality will be the main topic in the following sections and will be completed by some additional information on augmented and mixed reality for better understanding.

As a concept, virtual reality (VR) has been known for many years now, and there were several hypes in the last decades. Virtual reality has a long history and was first a privilege of research institutes and some companies. Jaron Lanier coined the term “virtual reality” in 1987 and developed several virtual reality devices, one of which was the DataGlove [Vir17]. First developments of head-mounted display known are those created by Ivan Sutherland in 1968 and NASA’s virtual reality headset called VIEW in 1985 [Bri09].

The term became widely known by the science fiction entertainment, once in the 80s as *cyberspace* in the novel “Neuromancer” by William Gibson [Wil84] and as *matrix* in the 2000s with the action film trilogy “The Matrix”. The last virtual and augmented reality hype was triggered in 2012 by the *Oculus* VR glasses kick-starter campaign [Kum14] and the *Google* AR glasses concept video [Bet15], and still continues, pushed by big companies like *Google*, *Microsoft*, *Facebook*, *NVIDIA* and many others. All immersive technologies emerged rapidly over the last years. The applications are not only of experimental or research character but already deployed and intensively used by companies.

Milgram et al. clarify the different terms for the immersive technologies with a simple diagram called reality-virtuality continuum [MTUK95]. Fig. 2.6 situates the virtual, augmented and mixed reality in this continuum. Between the two extremes, real and virtual environment, there are endless combinations under the generic term “mixed reality”. Particular form of mixed reality are thus “augmented reality” and “augmented virtuality”. Augmented reality is defined as

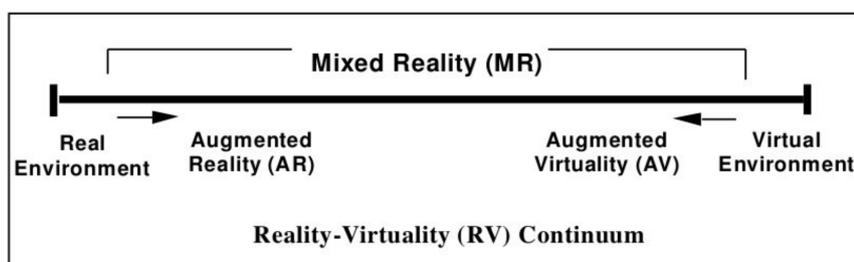


Fig. 2.6: Reality-Virtuality Continuum by Milgram [MTUK95]

a computer-assisted completion of the perception of reality through overlaying virtual objects or additional information. Augmented virtuality, on the contrary, is when the developer enriches the artificial world with real information. The virtual reality is defined according to this continuum by its fully simulated environment. There are many definitions of virtual reality.

According to Burdea VR refers to a “...high-end user interface that involves real-time simulation and interactions through multiple sensorial channels allowing the user to be effectively immersed in a responsive virtual world” [BC03]”.

Sherman and Craig [SC18] define virtual reality as: “... a medium composed of interactive computer simulations that sense the participant’s position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation”.

Both definitions give the essential properties of virtual reality, which are the immersion, interaction, imagination ( also called as “3 I’s of VR” by Burdea and Coifett [BC03] ) and presence. Another view of the virtual reality term brings Ovtcharova in her lectures on virtual engineering and adds the “intelligence” as an additional axis (see Fig. 2.7) next to interaction and immersion to represent their dependencies [Ovt20].

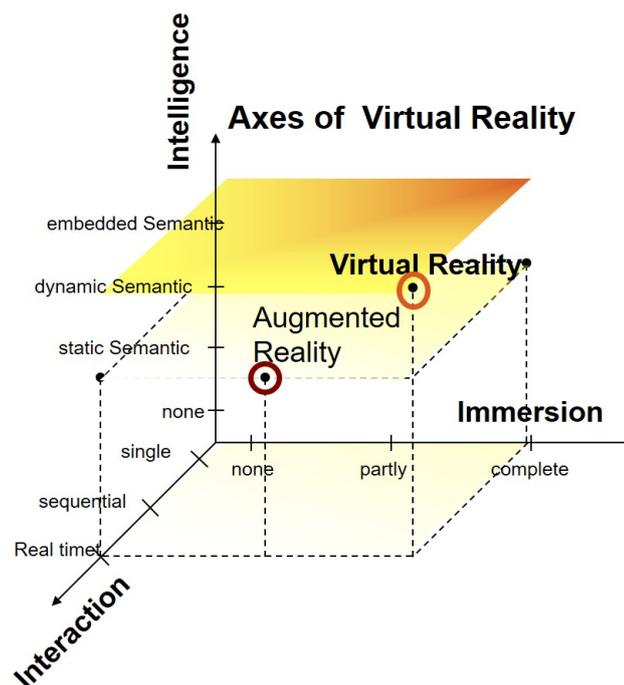


Fig. 2.7: The three axes of the virtual reality term [Ovt20]

In this thesis, the term “*immersive technologies*” is used as a collective term for all technologies like virtual, augmented and mixed reality, which simulates a virtual environment and create an

immersive experience. A new synonym for immersive technologies is the term “ $xR$ ”, which stands for Extended Reality [FBGL18].

Virtual reality produces a digital environment in which visual perception, sense of hearing, and sense of touch are highly similar to those of the real world. Virtual reality aims at creating the perfect illusion of being in a computer-simulated environment and allows the user to experience this environment with all his five senses. In the literature, many synonyms exist for VR depending on the field of application such as “*virtual environment*”, “*virtual world*”, “*artificial reality*”, “*realistic sensation*” or the term “*virtuality*”. Interesting is the use of an oxymoron for the concept of virtual reality, which means “not real reality”.

### 2.2.1 Interaction

Today everyone can enjoy a stereo movie in the cinema. The difference between a 3D movie and the VR experience is the possibility to interact in real-time with the virtual environment. Furthermore, it is possible to see the changes of the environment when manipulating an object or navigating in the scene.

Heeter defines in general an interaction as “an episode or series of episodes of physical actions and reactions of an embodied human with the world, including the environment and objects and beings in the world. These actions and reactions are actual interactions, a subset of the range of potential interactions of the human and the world at that time and place” [Hee00].

In the domain of virtual reality, the interaction is realised through multiple input and output devices, which enable the bidirectional information flow between the user and the virtual world and this in real-time.

Steuer considers the interaction in virtual environments as dynamic simulation [Ste92]. In his model, he describes three relevant features of the interaction in VR: Speed, range and mapping. The speed is the response time of the virtual world to an action by the user. It is vital for the vividness of the virtual environment and thus for immersion. The range depends on the number of objects with which the user can interact. The mapping is the connection between the actions of the user and actions in the virtual world.

An essential component of VR interaction is the navigation. The optimal navigation should be an intuitive and natural walking in the virtual world. However, there are physical limitations, because of cables connected to the HMD, limited space in a CAVE and the head tracking

range. Therefore different paradigms and devices were developed to simulate physical or virtual navigation in virtual environments (see also section *Virtual Reality Hardware* 3.1.1 on page 3.1.1).

A crucial element for the interaction is the position tracking or also known as head-tracking, which enables the perspective adjustment of the virtual environment in real-time. The tracking system that takes care of the head-tracking is also used for hand-tracking, implementation of gesture control and object manipulation.

The interaction with virtual objects is usually achieved by using hand-tracking and hand-held devices like game controllers or similar. They allow an extension of the real hand in the virtual world, where features like selecting, drag and drop can be triggered.

Gabbard classified those tasks in a virtual environment into three groups [Gab97]: navigation and locomotion, object selection, and object manipulation. Mainly, selection is an important one because it precedes most other manipulation and navigation actions. In the virtual environments, users need to select a target object. Then, they can manipulate the object and have other interactions with it.

### 2.2.2 Immersion

Immersion is measured with the quality of the user interface and hardware. We can talk about an immersive system only if it provides high-resolution stereoscopic presentations of objects and this in real-time as well as it implements head-tracking of the user [Ovt20]. Some key aspects are the stereo vision, the field of view of the user, the resolution of the display, the head-tracking, the intuitive interaction as well as the acoustic feedback.

According to Slater “immersion describes the technical capabilities of a system, it is the physics of the system [SSV16]. He defines immersion “as an objective property of a system, and higher or lower immersion as the extent to which a VR system can support natural sensorimotor contingencies for perception including the response to a perceptual action [Sla18].”

Virtual reality aims the stimulation of the human senses to increase the degree of immersion. Sight, hearing and touch are the senses with which people perceive most of the information in their environment. Smell and taste are addressed less frequently. Various techniques are used to deceive people’s visual perception. Stereoscopic vision is the ability of human perception to judge spatial depth. We have two eyes, and we get two different pictures that are slightly shifted from each other. The difference is due to the distance between the eyes, the so-called inter-pupillary distance (IPD). As a result, the brain can efficiently allocate a distance to all objects

viewed and gain a spatial picture of its surroundings. There are several methods for generating the stereoscopy, and each requires the generation of two different two-dimensional images for the left and right eye and with two slightly different viewing angles. Stereoscopic vision helps to understand complex geometries more intuitively than conventional images. Since humans perceive about 70% of the information from their environment through the eyes, stereoscopy is a key element of immersion.

Additionally, the implementation of the rich content of the scene as well as physical laws and realistic simulations can also raise the degree of immersion. The main aim of an immersive environment is to enhance a feeling of presence by controlling the immersion. Position tracking (head tracking) adjusts the perspective to the viewer's point of view. The effect that plays an important role is the motion parallax. The brain can gain information from the different movement speeds of the objects about which objects are further away than others. This effect can be used to obtain information which serves the depth perception. Other methods for the generation of depth perception are the central perspective, the relative size, the occlusion of objects (interposition), and the atmospheric depth (air perspective) [Bri09].

In order to increase immersion, image and sound can be combined. It is crucial to generate suitable sounds, also in stereo and to match them with the representation. The human can recognise and localise the distance of noises, due to the ears position on the head. Researchers at NASA are trying to model the filter properties of the outer ear and head using HRTF (head-related transfer function) [PPC92]. It must be taken into account that the sounds perceived by the human ear depend on the personal hearing ability and the filtering properties of the ear region and the body. Furthermore, it depends on the acoustic reflection properties of objects that are located in their surroundings.

Another way to experience a fully immersive environment is to stimulate the sense of touch. This sense includes the sensation of surface textures as well as forces applied to the user in the simulated world. Currently is haptic feedback very restricted by hardware limitations.

An essential component for good immersion is the computer system and network. A powerful computer graphic hardware should be capable of rendering complex scenes in real-time (frame rate should be at least 25 fps). At the same time, there should be no latency in the overall system and network. For instance, the time between the moment the user turns his head and the time the immersive system responds and renders the right image should be short; else it lacks immersion.

### 2.2.3 Presence and Imagination

An individual who feels highly present in a VR environment ultimately gives in to the illusion of that environment and thinks, acts and decides precisely as if he were actually in that environment. Although the individual knows and recognises that an immersive technology is generating his current experience, he perceives objects, events, environments, and entities as if technology were not involved. The knowledge of the virtual character, therefore no longer influences the perception.

Slater describes presence as the subjective state of consciousness of actually being in the virtual reality environment at a specific time, giving the feeling of “being there” [SU93]. With other words presence “is a mental state in which a user feels physically present within the computer-mediated environment” [DKU98].

According to Lombard, a critical element of presence is the quality of the social interaction [LD97]. Durlach and Slater also claim that the sense of being with someone, or the sense of togetherness, increases the sense of presence [DS00]. The concept of social virtual reality environment is defined with the ability of the users to interact not only with the virtual world, but also with each other. VR environments can provide an ideal platform for collaboration. Meeting in a virtual environment can improve the communication, help to discover mistakes, avoid misjudgments and support the decision making process.

The imagination supports the presence and augment it. It constitutes the ability of the mind to produce and simulate novel objects and ideas, without any direct input of the senses.

### 2.2.4 Intelligence

There is another essential characteristic of an immersive environment, and this is the level of human-like intelligence it provides. Burden and Fliesen define the artificial intelligence that exists within a virtual world as virtual intelligence [BF10]. The intelligence increases with the quality of interaction and immersion of the virtual environment as depicted on Fig. 2.7 on page 21. If a static virtual world is given, where only 3d models are loaded and only navigation as an interaction paradigm is possible, the world will be characterised as not intelligent. A responsive virtual environment with rich interaction is then considered as more intelligent. For instance, using physics engine and laws, allowing the objects to fall on the floor, just as we expect they will fall in real life, makes a virtual environment more intelligent and intuitive. Further, a highly interactive and intelligent virtual environment will be where not only objects, but also human capabilities (i.e. virtual assistant) are implemented. This can be achieved with the help of artificial intelligence methods and algorithms that are embedded in the virtual scene.

## 2.3 Artificial Intelligence

### 2.3.1 Definition

In the first section of the theoretical background the learning theories were described, giving an idea of how people learn. The following section will show how computers learn and which methods are applied to create an artificial intelligence system. Interestingly, the AI research uses the same learning theories to make computers to learn.

Artificial intelligence is a complex science due to the numerous disciplines involved. Mathematics, statistics, neurology, cognitive science, robotics are only some of them. The advances in one field lead to progress in AI research. The bottom line is that AI is a patchwork of algorithms from many domains, each of them has its advantages and disadvantages for specific tasks and they are usually used in combination for better performance (for instance speech recognition solutions).

Originally, artificial intelligence was defined as a human-like intelligence that is performed by a computer system. Russell and Norvig make a distinction in their book between two dimensions of AI: a computer system that thinks and acts like a human and such that thinks or acts rationally [RN16].

Here rational is defined as the measurement against an ideal performance measure. Some of the tasks that AI should accomplish are learning, reasoning, planning, problem-solving, decision-making as well as speech recognition, (visual) perception and many others.

Kaplan and Haenlein define AI as “a system’s ability to interpret external data correctly, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation.”[KH19]

The history of AI has its roots back in the 50s, and there are many systems developed that claim to be intelligent. Nevertheless, what is intelligence, and when is a system intelligent? To answer this question, Alan Turing proposed a test for an intelligent machine, where a human can not make the difference between a human and an intelligent agent. In order to pass the test, an intelligent agent should have those four capabilities [RN16]:

- natural language processing,
- knowledge representation,
- automated reasoning,
- machine learning.

Kaplan and Haenlein categorise the AI systems in three types to differentiate the intelligent from the non-intelligent systems (see Fig. 2.8) [KH19]. The three types are analytical, human-inspired and humanised. They compare them to expert systems and human beings. The expert systems are non-intelligent from today's technology perspective. The human beings are seen as the reference for intelligence. Each AI system type is characterised by cognitive, emotional and social intelligence.

	Expert Systems	Analytical AI	Human-Inspired AI	Humanized AI	Human Beings
Cognitive Intelligence	x	✓	✓	✓	✓
Emotional Intelligence	x	x	✓	✓	✓
Social Intelligence	x	x	x	✓	✓
Artistic Creativity	x	x	x	x	✓
		Supervised Learning, Unsupervised Learning, Reinforcement Learning			

Fig. 2.8: Types of AI systems: Analytical, human-inspired, humanised artificial intelligence [KH19]

The analytical AI is specified with the characteristic of the cognitive intelligence, where cognition is “the mental action or process of acquiring knowledge and understanding through thought, experience, and the sense” [Oxf19]. The cognitive intelligence is characterised by “the ability to handle reasoning, solving problems, applying tricks, think abstractly, comprehend complex ideas, learn quickly and learn from experience” [Quo19]. The analytical AI systems “generate a cognitive representation of the world and do learning based on past experience to inform future decisions” [KH19]. The human-inspired AI systems have both cognitive and emotional intelligence and use emotion detection and the emotional states for reasoning and decision-making [KH19]. Humanised AI systems should combine all three types of intelligence (cognitive, emotional and social) and would be able to be self-conscious and self-aware in their interactions with others. The humanised AI type does not exist yet [KH19].

### 2.3.2 Logic- and knowledge-based AI

Another categorisation of AI systems is based on the technologies used. There are three types logic-based, knowledge-based and data-based artificial intelligence systems. The logic-based systems have a focus on general problem-solving with the help of a set of symbols and rules [Ilk18]. They were first used for proving theorems using formal models like First Order Logic.

Knowledge-based systems also use logic for inference, but instead of solving general problems they rely on domain knowledge to solve more specific problems. This makes them applicable

for real-world problems, i.e. implemented in the form of expert systems. A knowledge-based system is composed of two sub-systems: A knowledge base and inference engine.

The knowledge base can be formally represented with the help of an ontology.

Gruber defines an ontology as “... an explicit, formal specification of a shared conceptualisation” [Gru93].

The conceptualisation is the creation of a model about a domain and the modelling of the relations between the concepts inside this domain. It is essential to define the meaning of all concepts in order to be explicit. The formal specification refers to the feature that the conceptualisation should be machine-understandable. The ontology should be shared between users, and in order to avoid misunderstandings, there should be a consensus about the ontology components and models. In the informatics, ontologies are modelled with the help of classes, relations, constraints and instances. Classes, relations, and constraints can be put together to form statements or assertions in the form of axioms, where the usage of constraints or simpler statements are not possible. The instances describe the individuals of an ontology, which means the concrete objects or abstract terms.

Ontologies are used to describe in a formal way the knowledge in a specific domain. Inference engines, also called semantic reasoners, are used to draw conclusions in an automatic way, making the implicit knowledge explicit [Sla14]. They use logical techniques, such as deduction and induction, to generate conclusions. There can be two types of reasoning systems: interactive and batch systems. The interactive systems ask the user additional questions, if there are uncertainties, in order to improve the reasoning process. The batch systems do not use user feedback but only the available knowledge for doing the reasoning [WOLB84]. A reasoner can infer based on a closed or an open-world assumption. The closed world assumption is used mostly when the knowledge base is known to be complete. The open-world assumption means that the lack of knowledge does not imply falsity and is mostly used for the knowledge representation with ontologies like in Semantic Web language OWL. It is more practical and useful because knowledge is never complete.

The ontology and the rules are machine and human-readable, which makes knowledge-based systems more intuitive for the domain experts. They do not need programming skills to expand the domain and add new rules. One main benefit of knowledge-based AI (compared to machine learning) is that the deduction can be tracked in details, so the result has its explanation. That means that each logical step of the reasoner is comprehensible. Another benefit of the knowledge-based systems is the decoupling of the knowledge from the reasoning engines, which brings the development of more general-purpose inference engines [HRWL83].

There is one established tool that supports the development of knowledge-based AI. Protégé is a free, open-source ontology editor and framework for building intelligent systems [Mus15]. It provides a graphical user interface to model the ontologies, which makes this task easier for domain experts.

### **2.3.3 Data-based AI - Machine Learning**

Data-based AI includes all machine learning algorithms that need a high amount of data to learn and later to perform reasoning. Methods and algorithms use training data to learn from previous experience, and to create new knowledge (e.g. analysis of genomic data), to make predictions (such as weather prediction) or take decisions (filtering of e-mails) [SSBD14]. Some examples of machine learning models are artificial neural networks, decision trees, support vector machines and Bayesian networks.

The machine learning approaches are categorised in supervised, unsupervised and reinforcement learning [Alp20]. While the supervised learning approach uses prior known inputs and outputs, with the unsupervised learning, the system should find out on its own, which are the input feature patterns or logic inside the data. The reinforcement learning uses external feedback as a reward and tries to maximise its output based on this feedback.

The technology drivers of machine learning in recent years are the increase of processing power with the development of specialised hardware, the creation of specialised software and tools as well as the digitisation of images, videos, voice and text. The specialised AI processors allow parallel programming and the machine learning algorithms can run faster. Some applications that should be processed in real-time became possible. In addition to the hardware advances, many libraries and specialised software, especially open source were developed, abstracting the complexity of lower-level programming, which entails growing research and developers community. The social media, crowdsourcing and cloud computing solutions motivated and facilitated the creation, storage and labelling of images, videos, voice and text and made them available as training data for machine learning applications. All these technologies make possible the creation and test of machine learning algorithms with a high level of complexity.

## 2.4 Business Analysis

### 2.4.1 Strategic Planning Tools

One of several strategic planning tools that are used by businesses and other organisations is called SWOT. The acronym SWOT refers to the strengths and weaknesses of a company and the opportunities and threats which it faces [OOJ14]. The goal of such tools is “to ensure that there is a clear objective defined for the project or venture, and that all factors related to the effort, both positive and negative, are identified and addressed” [OOJ14]. A typical matrix that describes the SWOT analysis is represented on Fig. 2.9.

SWOT Analysis	Helpful to achieving the objective	Harmful to achieving the objective
Internal attributes of the organization	<b>Strengths</b>	<b>Weaknesses</b>
External attributes of the environment	<b>Opportunities</b>	<b>Threats</b>

Fig. 2.9: SWOT analysis matrix adapted by [Xhi07]

### 2.4.2 Requirements Engineering

Often projects fail due to inadequate or incomplete requirements or changing of requirements during the development. That is why requirement engineering is critical for the success of a system development project.

A requirement is defined by IEEE [IEE99] as “a statement that identifies a product or process operational, functional, or design characteristics or constraint, which is unambiguous, testable, measurable, and necessary for product or process acceptability (by consumers or internal quality assurance guidelines).”

There can be different requirements categories like customer, architectural, structural, design, functional, non-functional, performance requirements and others [Def01]. The systematic approach to deal with requirements is known as requirement engineering.

Dick et al. define requirement engineering as “the subset of systems engineering concerned with discovering, developing, tracing, analysing, qualifying, communicating and managing requirements that define the system at successive levels of abstraction” [DHJ17].

The requirements analysis is usually a process consisting of the identification of stakeholders, the elicitation of requirements and their documentation. The goal is to produce requirements that are complete, consistent, relevant and reflect what the customer needs [SS97].

### 2.4.3 Costs Estimation and Economic Efficiency Analysis

The costs are defined as the value of goods consumed and services used to produce goods and services. Whether money is spent or not is irrelevant for the cost estimate [BMF11]. Furthermore, costs can be divided into running and one-time costs. The one-time costs are usually made at the beginning of an investment project and running costs refer to those which occur repeatedly. Tables 2.4 and 2.5 show examples for one-time and running costs.

One-Time Costs		
Project Costs	System Costs	System Deployment Costs
Consulting	Hardware	Hardware Configuration
Analysis, Feasibility Studies	Software	Software Installation
Decision Making		Support and Consulting
Reorganisation Measures		Employee Deployment
Evaluation and Acceptance		Training

Tab. 2.4: One time costs adapted from [Dü15]

Running Costs		
Direct Operating Costs	Indirect Operating Costs	Overhead Costs
Personnel costs	Maintenance	Amortization
Material costs	Ongoing adaptation of business processes	Interest Rate
	Further education/training	Rent
	Attending conferences and trade fairs	Insurance
		Energy costs

Tab. 2.5: Running costs adapted from [Dü15]

## Economic Efficiency Analysis

There are many methods and tools to conduct an economic efficiency study, also called profitability analysis. The selection of the method depends on several factors. One factor can be the type of measure. Other factors are the objective pursued by the measure, and the effects of the measure. In the table 2.6 are presented several methods. They are categorised according to monetary and non-monetary evaluation as well as the microeconomic or macroeconomic view of the analysis.

Methods	Microeconomic View	Macroeconomic View
Monetary Evaluation	Net Present Value Method	Cost-Benefit Analysis
Non-monetary Evaluation	Cost-utility analysis	Cost-utility analysis within the framework of the Cost-Benefit Analysis

Tab. 2.6: Methods for economic efficiency analysis [BMF11]

The Federal Ministry of Finance recommends a systematical approach based on a six step procedure for conducting an economic efficiency analysis [BMF11] as illustrated in Fig. 2.10. The first step includes the analysis of the actual situation, followed by the analysis and definition of the objectives and requirements. In a further step, the costs and the benefit factors are analysed and put in relation. After one has made a decision, it is recommended to perform a sensitivity analysis, to control the success of the measures. For this purpose, first, the criteria for evaluation of success should be determined at the planning stage, and later the achievement of objectives, effectiveness and efficiency should be monitored.

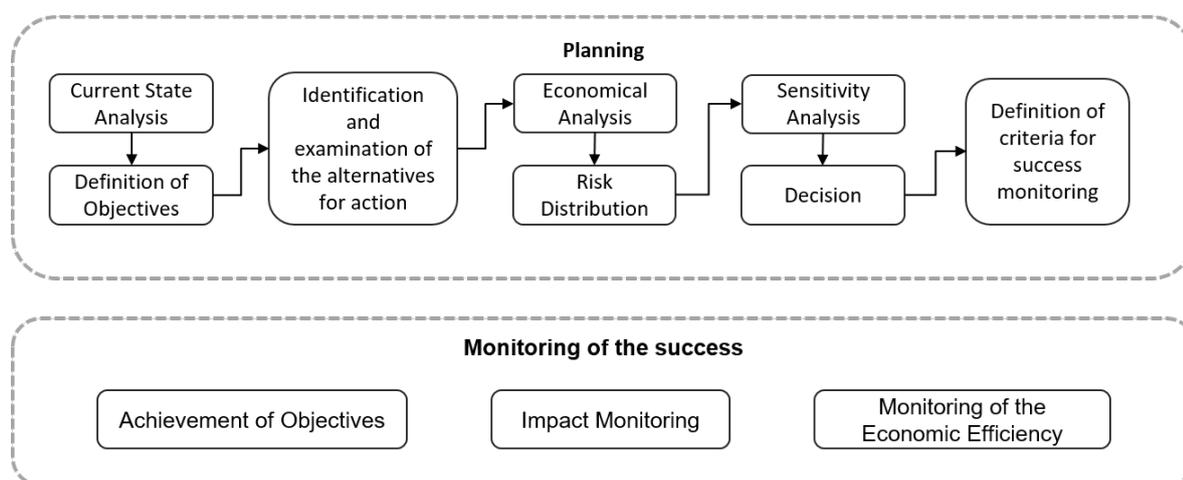


Fig. 2.10: Approach for economic efficiency analysis according to [BMF11]

The profitability analysis is therefore based on the relationship between the benefits achieved and the costs incurred. It should be considered that the cost efficiency analysis is mainly based on estimates. Thus, there is a high degree of uncertainty attached to the results. The cost-efficiency analysis supports the decision-making process when there is no experience with the envisioned project matter.

## **Summary**

The chapter “Theoretical Background” explains to the readers essential concepts in three domains. The first topic is on didactics and instructional design and presents the current understanding of how people learn and the established pedagogical theories and methods. The next domain is this of both immersive and artificial intelligence technologies. The section on immersive technologies presents the definition of virtual and augmented reality and their main characteristics such as interaction, immersion and presence and imagination and intelligence. The following section explains the term artificial intelligence and presents its three main types logic-based, knowledge-based and data-based AI. The last section of this chapter introduces some methods and tools from the area of business analysis and strategic planning. The content of this chapter should provide the necessary foundation for understanding the methodology of the thesis.



## 3 State of the Art

### 3.1 Technological Advances of Immersive Technologies

Although computing power tends to grow exponentially over time as an indirect implication of Moore's law, the capabilities of immersive systems have suffered from a long stagnation period in the last 30 years. This was due to the costs associated with IT equipment for virtual reality and its rapid obsolescence. The incorporation of VR and AR in learning processes was quite tricky. The former mainstream implementations of virtual reality systems were commonly deployed on high-end hardware like CAVEs that were both expensive and immobile. In the last years, profound changes in the way people communicate, learn, work and play were observed. The expansion of cellular networks during the last 20-25 years paved the way for the introduction of new affordable mobile devices such as smartphones or tablet computers, with capabilities that were once typical for large mainframe systems. In the same time, the gaming industry has established itself as one of the most critical technology drivers of the VR and AR technologies.

#### 3.1.1 Virtual Reality Hardware

Games usually provide real-time and 3D virtual scenes. Game products continuously pursue larger and larger scale of user access, more and more multi-modal audio and visual effects and more and more natural human-machine interactions, which brought about continuously new requirements for the research and development of technology, system and equipment of VR. Recently they can support active and cooperative participation from users in network environments and enhance the naturalness of interaction for multi-users games utilising high precision interactive equipment. The gaming industry has developed many affordable, high-quality interaction devices and graphic accelerators and displays with high performance. This class of virtual reality systems has been inspired by the pioneering work of Belleman et al. and Pape et al. which utilises Commodity Off The Shelf (COTS) hardware and gaming interface devices to reduce the cost of the system down to a minimum [BSdV<sup>+</sup>01, PAD02]. The development was pushed extremely in recent years by big companies like *Facebook*, *Google*, *Microsoft* and

*NVIDIA*. As a result, a new emerging class of virtual reality systems has emerged and gained quick acceptance.

The necessary hardware for virtual reality experience can be explained easily based on the human-machine interface (HMI) depicted in Fig. 3.1. The interaction starts with the capturing of the user's input with sensors for position tracking, interaction controllers or microphone. The data from the sensors are sent to and processed by the computer infrastructure. The result of the processing is provided to the user with the help of the visual, acoustic or haptic output devices. This HMI cycle repeats very fast to deliver real-time performance and provide a good level of immersion.

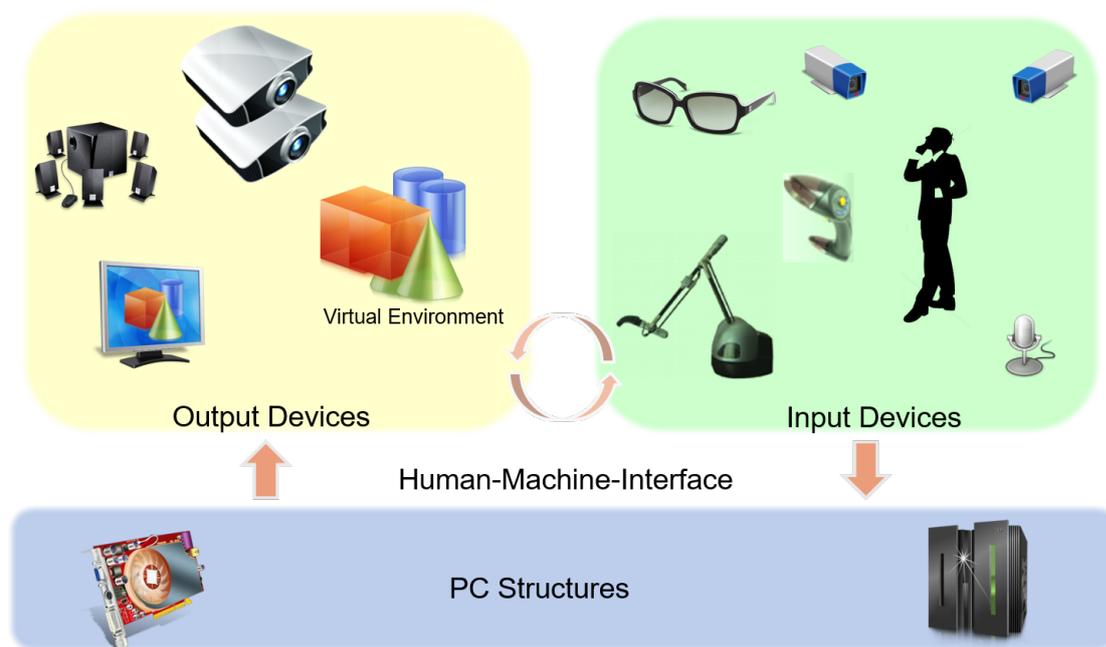


Fig. 3.1: Overview of the Human-Machine-Interface (HMI) [Ovt20]

## Virtual Reality Output Devices

### Visual Output Devices

As mentioned earlier, approx. 70% of the information for the environment people get through the eyes. Therefore, the visual output devices are a fundamental component of a virtual reality system. A crucial element of the visual output devices for the immersion is the stereoscopic view.

Stereoscopy is the capability of a system to generate and display two slightly shifted images, that are perceived as a depth image by a human being [Mph20].

Stereoscopy can be achieved through different techniques, but the most used for virtual reality are the active stereoscopy with shutter glasses and a passive one with polarising filters in front of projectors and the glasses. Some technologies do not require wearing of glasses like the autostereoscopic or holographic displays [HDFP11, Mph20, Hol20].

Sherman and Craig differentiate between the categories stationary and head-based visual output systems [SC18]. The first category uses fixed stereo projections or displays (see Fig. 3.2). The second is using devices that are worn on the user's head, where displays are directly embedded in glasses. Both categories have their advantages and disadvantages.

Highly immersive virtual environments can be built using passive or active stereo projectors and large screens. There can be different set-ups of the projection systems in the form of a cube and cuboid like a CAVE or one-sided system called powerwall (see Fig. 3.2) or a curved projection up to 360 degrees. There are configurations only with a front and a floor projection, which are called Powerbench or Workbench. Further configurations of the projection walls are also possible.

A CAVE is a highly immersive system and stands for CAVE Automated (sometimes Aided) Virtual Reality Environment and is defined as a projection system which has three to six projection sides building a cube or cuboid [CNSD<sup>+</sup>92].

In the CAVE, the user can physically move, wearing stereo glasses and is tracked by a tracking system. The interaction and navigation are done on the one side through the own body, and there can be different interaction devices for manipulation of the virtual scene.



Fig. 3.2: Three-sided CAVE system at *LESC* [Sch11] (left) and Powerwall with six passive stereo displays presented at Hannover Messe 2015 by *KIT and Bechtle AG* (right)

In case of a head-mounted display (HMD) system or also called virtual reality headset, two displays are installed inside the helmet near to eyes. Each display shows one of the stereo image pairs to achieve stereoscopy. The position tracker follows the position and direction of the head and a computer renders the scenes under the current viewpoint on the displays.

Typical representatives of HMDs in this segment which meet the requirement for affordability are *Oculus Rift* and *HTC Vive* (see Fig. 3.3 a and b).

Virtual reality headsets are designed specifically for video games and provide a moderate field of view (e.g. 110 degrees), high resolution (such as  $1080 \times 1200$ ,  $1280 \times 1440$ ,  $1440 \times 1440$  pixel per eye), and integrated latency head tracking for providing an immersive experience. The complete shading of the real world, when wearing the headsets intensify the feeling of presence in the virtual environment. Headsets like *Oculus Rift* and *HTC Vive* are delivered with controllers for navigation and manipulation of the virtual scene, cameras for tracking of the headset and controllers as well as headphones for stereo sound output (see Fig. 3.3 c).

Another kind of low-cost head-mounted displays are the *Googles Cardboard* and *Daydream* or *Samsung Gear* (see Fig. 3.3 a and b), where a smartphone is inserted into the headset and is used as a display, tracking and rendering at the same time. The smartphone screen is divided into two pictures for the left, and right eye and the lenses embedded in the case magnifies the images to achieve the moderate field of view. The accelerometer and the gyroscope are used to change the orientation of the screen and head-tracking. Additionally, headphones can be used for stereo sound output. Interaction is often achieved by pressing on the smartphone's buttons, which is not very intuitive. This technology is more suitable for 360-degrees virtual reality videos, where interaction does not have an important role.



Fig. 3.3: *Google Cardboard* (a) [Goo19], *Samsung Gear* (b) [Sam19] and *HTC Vive* (c) [New19]

### Auditory Output Devices

The auditory output and in particular, the playing of interaction or background noises is an essential part of the immersive experience in a virtual reality system. It increases the feeling of presence significantly and is used to complement the visual output. The visual and acoustic impressions should correspond to avoid confusion for the user [Bri09].

The hardware setup for the sound output can be differentiated between via headphones or loudspeakers (such as surround sound systems). Usually, the VR headsets are equipped with stereo headphones.

## Virtual Reality Input Devices

### Head Tracking

A tracking system is defined as the set of peripherals which is affected by interaction with the digital scene, and it tracks the position of the user in the physical environment so that the virtual environment is kept up to date according to their movements. The position tracking should track very precisely and without latency, the head and hands of the user, so the virtual reality system renders the changes of the virtual scene done by the user movements in real-time. The real-time capability of the system is from crucial importance, because the lag in the head tracking can induce motion sickness. The current tracking systems provide optical and wireless tracking. The tracking systems technologies differ from one another in that they can track with markers or markerless.

Mostly virtual reality tracking systems use tracking with markers or also known as tracking bodies. Such bodies are usually mounted on the passive or shutter glasses and the interaction device (see Fig. 3.4). Several new gaming interface devices based on computer vision techniques like *Microsoft Kinect* and *Playstation EyeToy* have been introduced in order to perform tracking in the low-cost segment. Their capabilities can be significantly expanded by using the respective software development kits provided by the vendor. The depth-sensing cameras of these new devices provide with the most natural, but also the most flexible way to interact with rehabilitation applications. The user is not required to wear any markers or carry any additional devices to interact with a system. Full-body tracking provides the opportunity to select any combination of gestures and limbs for interaction with a software application at an affordable price.

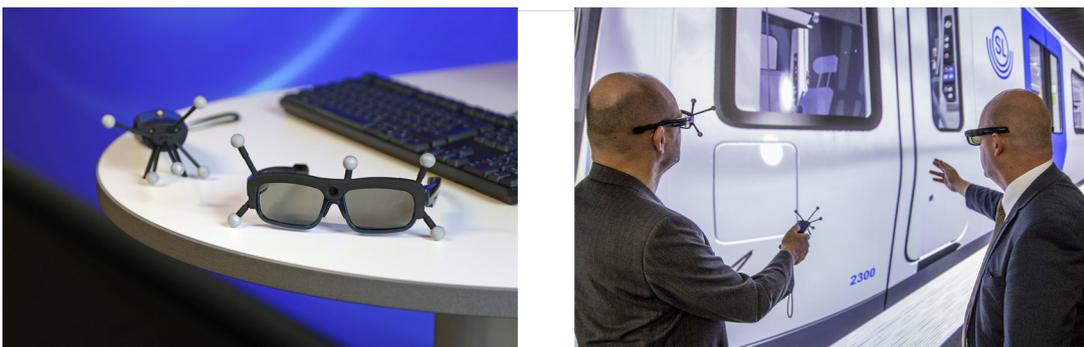


Fig. 3.4: Target for glasses and the interaction device *Flystick 3* by ART company [Adv19]

## Interaction Devices

In its simplest form, interactivity provides the user with the capability to extend his hand into the virtual environment and undertake a set of possible actions with virtual objects. That is why most of the offered interaction devices are in some way related to the hand: it is a natural manipulation element of humans.

Classical solutions usually depend on a specific device that has special markers attached, which can be recognised and tracked by the tracking system. Although such products have evolved from wired to wireless, from magnetic to optical tracking, a significant drawback of this approach is that they do not feel natural to the user since they have to hold the device and use predefined buttons to activate special functions specific to the current scene. Examples of such devices are the controllers of the HMDs (see Fig. 3.3 c on page 38) in the low-cost field and the *Flystick* devices by the *ART* company (see Fig. 3.4 on page 39) in the high-end segment, which all are unnatural extensions to the hand.

An essential role of the interaction in a virtual environment is the navigation. Usually, the user has limited physical space to walk naturally and thus translate in the scene. To allow intuitive navigation in vast virtual spaces, some devices such as omnidirectional treadmills were developed. The user walks at one place and is translated virtually in the scene. An example for a low-cost treadmill is the *Virtuix Omni* [Vir20], and further example for big-scale omnidirectional treadmill system for the unconstrained walking in VR is the *CyberWalk* developed at TU Munich [RGSM<sup>+</sup>08] (see Fig. 3.5).



Fig. 3.5: Omnidirectional treadmills *CyberWalk* [RGSM<sup>+</sup>08] and *Virtuix Omni* [Vir20]

There are devices called data glove, which contain sensors that allow the tracking of the hand and finger positions. A gesture recognition is used to provide gestures control in the immersive application [Bri09].

More recent research focuses on eliminating the controllers and achieving direct hand tracking and manipulation using gestures. Such devices are *Leap Motion* and *MS Kinect*). This eliminates the need for markers which tend to suffer from wear-out over time. For instance, the

*Thalmic Myo* gesture control armband does not require any additional elements except from a wristband which is attached to the hand. It uses muscle activity sensors, a three-axis gyroscope, accelerometer and magnetometer to intercept the movements of the hand. Despite the complexity of the sensor, the product is offered with disruptive pricing which can actively contribute to low-cost virtual reality solutions.

### Force and Touch feedback

A further development of the data glove is a glove that has actuators and sensors, which makes it possible to give tactile feedback to the user. In this way, the users can feel an object they touch or collide with [Bri09]. Haptic gloves can have small exoskeletons wrapped around fingers, and applying forces to simulate the grabbing of objects. Still, the weight of the grabbed virtual object cannot be felt, unless it is extended by some arm or any other mechanical support [Hei18].

The used technologies depend on the gloves. Some embark pressure actuators for a tactile experience, others apply temperature, and some advanced ones like *HaptX*, have enough actuators to simulate raindrops or a beetle walking on the hand [Hap18b].

A haptic arm is a dedicated robot, measuring movements and able to give force-feedback in real-time (see *Virtuose6D* from *Haption* company Fig. 3.6). The user controls the end effector of a kinematic chain. Thereby the position and orientation of the end effector can be tracked. The driver for the device controls the resistance as the device moves, which makes it possible to make collisions palpable [Bri09]. To get enough degrees of freedom and a sufficient workspace, *Haption* offers the *Scale1* system. It is a motorised platform which allows to extend the workspace of a *Virtuose6D* haptic device (see Fig. 3.6).

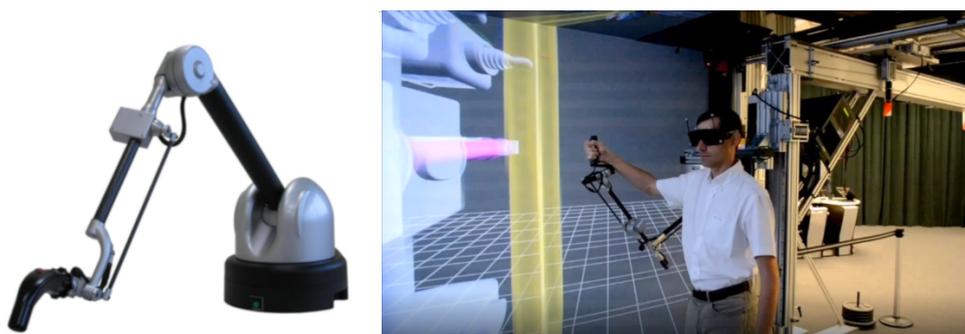


Fig. 3.6: *Haption's Virtuose 6D* and *Scale1* [Hap18a]

### 3.1.2 Virtual Reality Software

As virtual reality hardware gets more affordable, reliable, and efficient, there is a need for mature software packages that facilitate the development of virtual reality applications. Many tools disappeared from the market, and new tools are developed or adjusted to meet the requirements of the new VR hype.

#### Authoring of Immersive Applications

The development of virtual reality applications, which are highly interactive, usually overlaps with the development of interactive 3d computer games. There are numerous tasks which are distributed to several developer roles: A programmer, a 3D designer and (3D) sound designer and others. Depending on the project, the software used and the team size, next to the 3D designer there can be a graphic designer (for the textures) necessary or the programmer tasks can be divided into core-programming and application logic programming. A new role in the development of VR applications can be the interaction designer, who designs the interaction as navigation and manipulation in the virtual environment depending on the interaction devices used for the project. The general procedure for creating virtual worlds is the preparation of the content, the addition of the application logic and the deployment on advanced VR hardware setup.

#### Content Creation and Generation

The main assets needed for the development of VR and AR applications include 3D models, textures and materials and sounds. There are two main ways to create a virtual scene. The first way is the manual modelling of 3d models, and the second is the generation of the three-dimensional geometry with the help of algorithms. Both methods can be used in combination. In their basics, 3D models can be described mathematically in a different way, for instance, polygon mesh and boundary representation models, volumetric data or point clouds, depending on the tool with which they are designed.

#### 3D Modelling

Several types of software solutions come into question when creating 3D models depending on the applications area and their mathematical description. A universal type are the 3d modelling tools like *Blender*, *Maya*, *3ds Max*, *SketchUp* and similar, with the help of which, 3d models and worlds can be created and exported [APB<sup>+</sup>09]. During the modelling process, one needs

some additional tools like *Photoshop* or *GIMP* for creating some textures, that can be mapped on the 3D model [Sol09].

Another software solution for creating 3d models are the CAD systems that derive from the engineering area. In the area of building management, popular CAD tools are *AutoCAD* and *Revit* [Khe04] and in machine engineering tools like *CATIA*, *SolidWorks*, *PTC Creo*, *Siemens NX* and many others [MAAAA17].

### **Generation of 3D Assets**

The second way to create virtual environments is the implementation of algorithms for the generation of the world assets. Some methods to create 3d geometries by algorithms are the creation of sweep models, tessellation of polygons or Boolean operations on meshes [Hä19]. Next to the generation of the geometries, the textures should also be generated. There are several benefits of the virtual world generation. A benefit of the generated world is the possibility to parameterise the world elements and enrich the world with semantic. Another benefit is that, when once the algorithms are created, they can easily be reused. This approach saves costs compared to the costs for the modelling of an entirely new virtual scene. At the same time, the programming of such algorithms requires excellent experience in computer graphic and software implementation.

When creating virtual worlds, it is usually the assets that are the most time-consuming part. The assets also determine how appealing the scene will be. Detailed, high polygon and nicely textured objects, can also be very expensive for the overall performance, compared to simple scenes. Here, the trade-off between the performance and the scene quality should be considered. There are some features of the real-time computer graphics, where the performance can be improved using tricks like Level Of Details (LOD), shaders and others.

### **Data Interfaces**

There are often issues during the data exchange process. When CAD tools do not support exchange formats or vice versa or there is a loss of geometric precision, topology and metadata after import in the virtual reality framework. Often there is data loss due to format conversion. For instance, most exchange formats export the hull model, but dynamic information like kinematic and constraints are missing [LSR<sup>+</sup>16]. There are companies specialised in writing software, so-called converters, for seamless export from the 3d modelling or CAD tools to the virtual reality authoring software. There are free tools such as *Open Cascade* [Ope20] and paid converters like *CAD Exchanger* [CAD20]. Such tools can differ strongly in the quality of the

implementation and lead to different results. For example, the quality depends if the implementation of the converter for a specific file format is done with the official library or based on the defined specifications. Several issues can happen during conversions like a crash of the software, no termination of the converting process (especially by big datasets), the occurrence of errors in the process, or in the resulted files.

## **Application Logic and Interaction**

The implementation of an application starts with the import of the assets and their setup in the scene. The arrangement of those assets in the 3d space and the relations between them are usually realised with a scenegraph. Virtual reality software uses scripts or programming languages (such as *Python*, *C#* or *C++*) to add logic. The application logic determines the behaviour of the virtual world, reacting on the user interaction. The virtual object behaviour can be programmed as animations or simulations by using physics engines.

### **3.1.3 Frameworks for Authoring of Virtual Reality Environments**

There are different approaches to author an immersive application. A low-level approach is when combining available libraries (usually *C++* or *C#* based) like game engines, scene graphs and VR device libraries, which is very time consuming and reserved for developers with excellent programming and computer graphics experience. *OpenSG* is such a scene graph library, but with a focus on clustering and threading as well as numerous advanced features for VR applications. *OpenSG* by itself is enough for developing a VR application, only small libraries for communicating with VR devices have to be added. Those libraries are very powerful and flexible, but the drawback is that using them directly is very time consuming and needs much expertise in coding and VR technologies. Without those experiences, it will take much time even only to set up the *C++* project. For pupils projects, it also means that the supervisor will have much work when refactoring the project, for example, for the next pupils that have to work on it. Thus reuse becomes difficult, and the work is not sustainable.

Nowadays, there are high-level virtual reality authoring frameworks, which abstract the low-level libraries and the user can develop the application using an intuitive graphical user interface or scripts for advanced application logic.

## Gaming Engines

As mentioned above, virtual reality development was pushed by the game industry. The available game engines should be retrofitted with the support of virtual reality hardware. This works well for head-mounted displays, but not so suitable for complex VR systems like CAVEs, because of the tracking system types used and the synchronisation of all projection screens. Instead, additional middle-ware libraries should be used in order to deploy a virtual reality application written with a game engine like *Unity* on high-end VR hardware. In this work, the two most used game engines are shortly presented to give the reader an overview and some good examples.

### Unity 3D

One of the most famous virtual and augmented reality engines today is *Unity* by the company *Unity Technologies* [Gau15]. *Unity* supports currently the creation of games and other applications for more than 25 platforms, which also includes AR and VR platforms. It is necessary to use the middle-ware *MiddleVR* to interface the simulation and the various devices to work with VR applications created in *Unity*. *MiddleVR* supports HMDs, multi-user collaboration and distributed visualisation, which may be necessary for CAVE systems. While *Unity* runs on a *Linux* operating system, *MiddleVR* is limited to *Windows*, which can be a limitation [Kun18].

## Proprietary Virtual Reality Software

Compared to game engines, other virtual reality tools are created to serve engineering applications, like machine and building engineering. The designed machines can be exported from the CAD tools and imported in a virtual scene to be presented or examined. Such tools are, for instance, *ICI.DO* by *ESI* or *Visionary Renderer* by *Virtalis*. Some other virtual reality tools use different approaches to interface the 3d data. They use a direct access of the data on low-level API and visualise this graphic data stream on an immersive display. Here examples are *TechVizXL* by *TechViz* and *MoreViz* by *More3D*.

### ICI.DO

The software *ICI.DO* currently provided by the company *ESI Group* is usually used for virtual engineering use cases. Engineering companies often apply this software for design reviews or products and services, ergonomics investigations with human models and many others [ESI19]. This software can also be used for training in a company context, for instance, to provide initial training on a machine that is still in production and not delivered to the customer yet. It enables

the deployment of CAD and some simulations data on immersive hardware, including high-end visualisation systems, distributed cluster environments, tracking systems as well as VR headsets. To create a virtual scene with *ICI.DO* 3D tools should first export the 3D data, mostly CAD tools in the supported formats and then import and further prepare them for visualisation. Animations and kinematics should also be developed manually using the graphical user interface. It also provides a scripting language for further programming. Some of the limitations of the program for training is the higher price and the lack of available detailed technical information before first company contact, consulting and buying of the product. There is a small community compared to the game engines, and the source code is wholly closed [Hä19]. Training applications are usually developed in the clients specific ecosystem and are limited to the engineering context.

#### **Visionary Render**

The *Visionary Renderer* by *Virtalis* is another example of a virtual reality application for engineering context. The visualisation platform allows users to create dynamic, interactive virtual environments and simulations [Vir19]. According to *Virtalis*, the same models can be used to improve safety and compliance by training operators, engineers and users with immersive, experiential training that links to learning management systems [Vir19]. The *Visionary Renderer* has the same advantages and disadvantages as the *ICI.DO* software mentioned above.

#### **TechViz XL**

The *TechViz* company's product *TechVizXL* works like a hardware driver for immersive environments and can natively visualise the data from more than 200 3D applications [Tec19]. The support of so many applications makes this VR software applicable in numerous application areas [BVHO15]. As described above the software uses special technology to grab the 3D data stream that is sent from the 3D application to the *OpenGL* API and allows *TechVizXL* to transmit this data over a network to a rendering node and visualise it on an immersive screen. The benefits of this approach are that there is no data loss due to conversion of data formats and supports natively a high amount of 3d applications. Next to the support of different immersive systems like HMD and CAVEs, *TechVizXL* provides support for many tracking system and interaction devices. The user has a bundle of features at hand to inspect the virtual environment like cutting plane, hide and show parts, set annotations, take measurements and many more. With this solution, most of the benefits of exploring interactively 3d environments described in this work (see 4.2.1 on page 106) can be achieved. Static 3D objects or large scale scenes that are not available in real can be displayed and explored by the students using the generic exploration and manipulation features. There are some limitations of the technology like the one-way data

is being transferred, which limits the possible features, like the implementation of additional application logic [Hä19]. This limitation means that no additional programming of features for teaching like automatic tasks verification or special animations that are not supported by the original 3D software are possible. Another drawback of *TechVizXL* for an educational setup is the higher price.

## Open Source Solutions

### COVISE

*COVISE* is an immersive visualisation software developed in a university context initially for scientific visualisation. It became open source in 2015 and can be used for training. *COVISE* supports immersive hardware like CAVEs, HMDs, standard tracking system and interaction devices. The software was designed for collaborative working and should allow engineers and scientists from different locations to work together over the network [HLR16]. The *Visenso* company used the *COVISE* software for building a training application called *cyber-classroom*. The *cyber-classroom* product consisted of a low-cost virtual reality display and interaction device. It provided several learning modules on topics like anatomy, chemistry, maths and others intending to use it as a complement media in schools [Mad12]. Today's successor of the *Visenso* company is called *Imsimity* and offers the *cyber-classroom* products, based on the *Unity* game engine [Ims19].

### PolyVR

*PolyVR* is a virtual reality authoring framework, which main focus is to provide the scalability of hardware setups and scene authoring and management [HH20]. *PolyVR* is open source and was developed at the IMI Institute of KIT since 2009. It is based on open-source libraries like *OpenSG* and *OpenGL* and uses the *C++* programming language and *Python* scripting. *OpenSG* is the backbone and features a scene graph management with the focus on clustering and threading. The modular architecture of the VR framework facilitates the extension with new features, while the engine grows with every new project. *PolyVR* has many application modules, which can be seen on Fig. 3.7.

*PolyVR* allows the flexible software configuration of different hardware systems for distributed visualisation on computer clusters. It can thus be deployed on visualisation clusters for CAVE environments as well as on desktop VR environments, HMDs and recently in web [HH20].

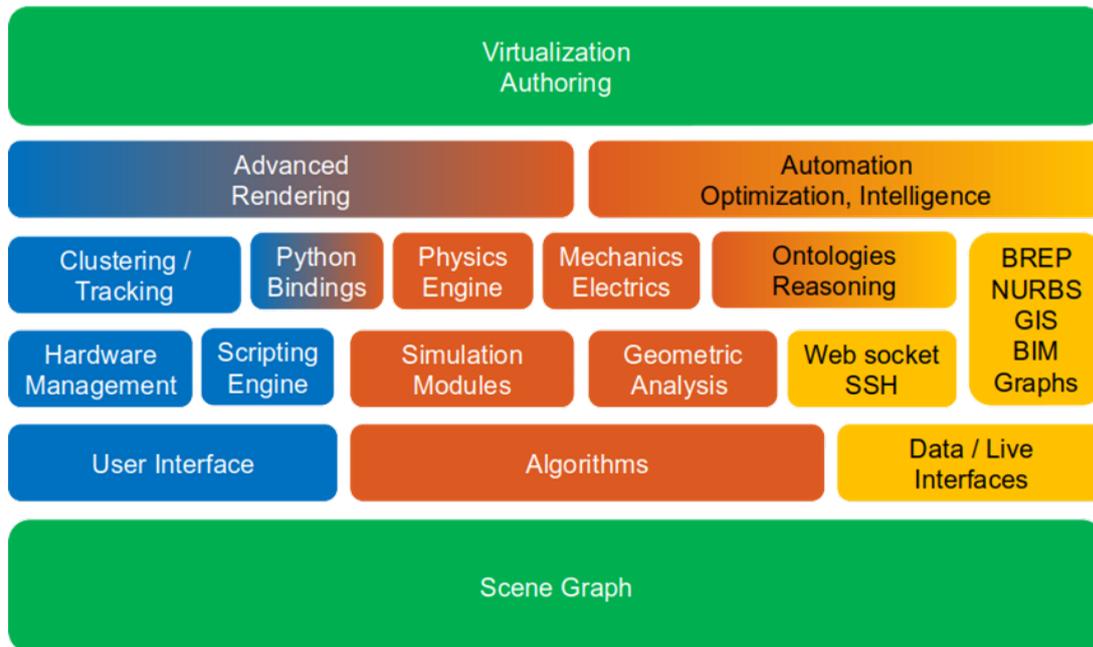


Fig. 3.7: *PolyVR* software architecture [Hä19]

### 3.1.4 Augmented Reality Hardware and Software

One other possibility for the implementation of low-cost systems for presentation and learning in virtual environments is Augmented reality (AR). Augmented reality refers to a broad spectrum of technologies that project computer-generated materials, such as text, images, and video, onto users' perceptions of the real world.

AR is defined as a technology “which allows computer-generated virtual imagery to exactly overlay physical objects in real-time” [ZDB08].

AR systems are usually visual and revolve around a display. The most common concept for display in the systems for AR is the head-mounted display. It provides freedom of movement of the users. Current HMDs implement either video or optical see-through technologies and optionally provide audio feedback. GPS and image recognition are widely used for the tracking function of the AR systems. Both of them are affordable in the sense of price and availability on the market. Nowadays, every smartphone or other mobile device has a high-resolution camera and GPS, which can turn it in an efficient tracking device for use in the AR presentation system.

The typical representative of the contemporary AR headsets is *Microsoft Hololens*. It is one of the first real AR displays, closer to what one can expect from *Google Glasses* [She15]. The head tracking and surface detection are convincing, enabling virtual objects displayed on the glass to appear laying on the floor or table [Mic18]. However, the field of view is narrow, so

that the virtual objects can only be seen in a limited square [Pal17]. Some current commercial, industrial augmented reality systems are *Vuforia* and *ARToolkit* [BNFCFLVM18].



Fig. 3.8: *Microsoft HoloLens* AR headset [Mic20]

## Summary

Despite the current momentum of the virtual and augmented reality market, the user adoption of the technology has not reached the critical mass, that should force standardisation. Especially, the standardisation of the development environment like tools, interfaces, or programming languages. We witnessed in the past many proprietary as well as open-source toolsets, applications and hardware solutions for VR and AR, that lasted only a couple of years. This forced developers to change the development environment, the accompanying processes and maybe additional created interfaces for those tools, which is a costly process. Usually applications should be developed from scratch, because most VR tools do not provide export possibilities, especially of the application logic. Developers of immersive environments should perform careful and extensive process on decision making, which platform, tools and hardware are suitable for their project. This methodology provides support for this process, which is described in section *Technology Layer 4.2* (see page 105).

## 3.2 Immersive Technologies in Education

Immersive technologies can achieve the next level of interactive learning software after serious games. Virtual reality as interactive media opens new possibilities for instructional approaches like situated learning and methods based on experiential education [Ded09]. At the same time, teachers can use the flexibility of a virtual learning environment to embed gamification elements in the training [Ric12]. Many studies have been conducted on the applications and effectiveness of virtual reality in education and training since 1980. For example, it is often used as a training platform, where VR offers safe environments for experiencing real situations such as surgeries or coal mining [Blo18, GAPD09].

Immersion and presence in the VR experience are determined as the key elements in the cognitive variables associated with the processes of learning. Immersion and presence seem to be facilitated by the ability to control attention and focus on the new VR by excluding the real world. Using VR as a learning environment has great potential through the provision of a realistic, immersive environment in which the trainee can be motivated, can practice skills repeatedly, can be optimally challenged and receive immediate feedback and can be mentored via best practice. Some of the benefits of using immersive technologies in learning presented by Pantelidis and Yuen [Pan10, YYJ11] are that virtual reality:

- provides new forms and methods of presentation of learning material, drawing on the strengths of multimodal representations.
- motivates students as it requires interaction and encourages active participation rather than passivity.
- allows the learner to proceed through experience during an extended period not fixed by a regular class schedule, at their own pace.
- allows disabled persons to participate in an experiment or learning environment when they cannot do so otherwise.
- transcends language barriers and provides equal opportunity for communication with students in other cultures.
- helps to teach subjects where students cannot feasibly gain real-world first-hand experience.
- helps recreate an authentic learning environment suitable for various learning styles.

### 3.2.1 Immersive Learning Applications

In the following paragraphs, we present different types and examples of immersive technology applications for learning. Lutz categorises four immersive learning environment types: Exploratory, experimental, training and constructional virtual worlds [Lut05].

#### Exploratory Worlds

Exploratory worlds allow a walk or flight through the virtual environment where the user can freely explore the visualised information. The learner can decide which objects he wants to view, in which order and speed as well as perspective. Employing pictorial representation, specifics of objects can be shown in order to promote the development of a clear pictorial imagination [Lut05]. Those worlds usually use low-level interaction paradigms like virtual walking, flying, teleporting as well as point and select features to display additional information. Examples for such applications are virtual museums, that can show contemporary or past cultural assets or the exploration of the space as presented in the example of VR Space project in section 5.2.5. The exploratory worlds usually have no complex simulations. They are built with 3d models and can provide some animations for a better presentation of the concepts. An example of a learning application using a walk-through in an industrial plant is this presented by *Linde Engineering* [Lin18] (see Fig. 3.9). The operating personnel can get familiar with the plant topology and train critical procedures, based on the plant's digital twin, before it is really built.



Fig. 3.9: Virtual reality training for industrial plants [Lin18]

#### Experimental Worlds

Lutz describes the experimental virtual worlds as learning environments where the learners can set up and check hypotheses through integrated simulations [Lut05]. Interacting with the virtual world or changing simulation parameters have an immediate effect. In this way, the learner is

supposed to gain an understanding of the cause-and-effect relationship in dynamic processes with the help of visual representation in the sense of discovery learning and to develop an adequate mental model [Lut05]. The experimental immersive environments are much complex compared to the exploratory ones regarding their implementation. Furthermore, they provide a higher level of interaction and feedback based on the learners' action. Their actions influence the course of the presentation and thus enable the learner to approach the problem to be solved by trial and error [Lut05]. Examples of the experimental world are those applying to physics and chemical simulations (see Fig. 3.10). An excellent example is the *Virtual Reality Physics Lab* that allows students to understand concepts such as force, acceleration, velocity, position and others in a playful manner [MLB<sup>+</sup>19]. In such applications, students can both observe physical phenomena at macroscopic and microscopic levels or can control the time.

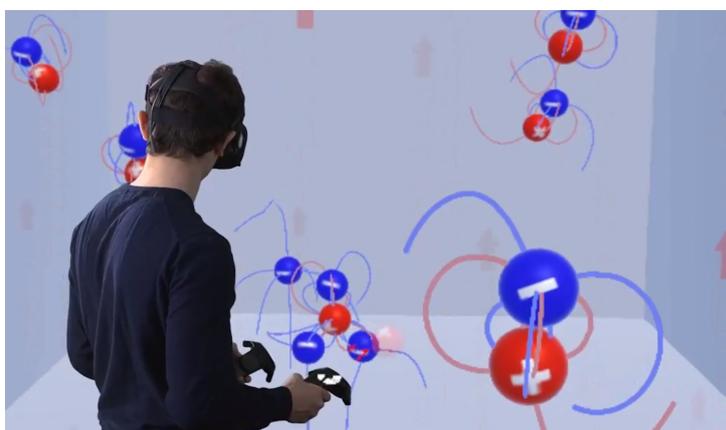


Fig. 3.10: Electrostatic playground for experimentation with the principles of electrostatics [GCM<sup>+</sup>19]

### Training Worlds

Training virtual worlds are one of the most popular and examined ones. Many VR simulators were built to enhance motor-coordination and related physical skills and provide a safe training environment (see welding simulation on Fig. 3.11). Training worlds are mostly used to learn complex action sequences [Lut05]. A typical example of this kind of immersive environments are flight or vehicle simulators as well as medical procedures such as surgeries [PPM<sup>+</sup>14]. Such immersive simulators usually demand a high level of interaction and complex immersive systems. The interaction with the virtual environment can be built based on the real-world interaction which provides specific haptic elements. For instance, an immersive driving simulator requires real vehicle controls like steering wheel, pedals and gear lever (see *Immersive Driving Simulator with Intelligent Tutoring System* 5.1 on page 181). Furthermore, acoustic, vibration and force feedback are crucial for the immersive experience.

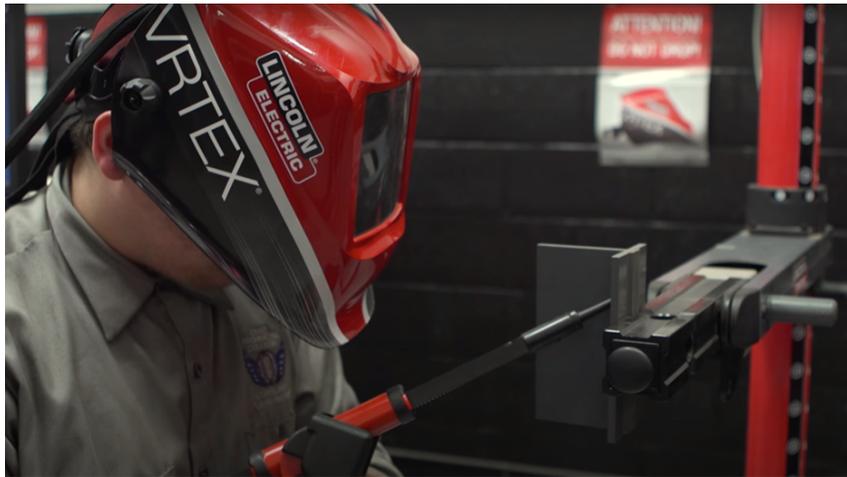


Fig. 3.11: VRTEX Virtual reality welding training simulators [Lin17]

### Construction Worlds

The construction worlds are a particular case, and the transfer of knowledge takes place through the creation of the virtual world itself [Lut05]. In order to create a convincing immersive environment, the learners must have an exact knowledge of the contents and the essential rules of the topic to be presented. The learners have to understand well the contents before they can start to implement the related concepts in the virtual world. An example of construction worlds are the projects created by the virtual reality practical course students (see *Delivery of Instructions and Project Examples* 5.2.5 on page 245) [HSD<sup>+</sup>14, HHO13]. Another example is the *MINT-Box* project, where an immersive driving system exists, and students can learn while programming STEM concepts as additional system features [HHO14].

### 3.2.2 Immersive Technologies in Engineering Education

Virtual reality finds broad application in the industry, especially in automotive for more than 30 years. Ovtcharova considers the usage of virtual reality technologies by the industry in the product life cycle as *Virtual Engineering* (VE).

Ovtcharova defines virtual engineering as a “holistic, continuous, cross-linked (process view) and integrated (IT - system perspective) support of the entire product life cycle concerning coordination, evaluation and verification of results of all partners with the use of immersive technologies [Ovt20]”.

Compared to digital engineering where the work is done on a single workstation by the engineer and is task-specific, virtual engineering uses immersive technologies to create teamwork and to support decision making [Ovt20]. For instance, an engineer in a company designs a specific

component of a machine in a CAD system individually, after assembling all single components in one product, all engineers together with management or customers can experience and validate the whole product as “it is real” in a virtual environment and discuss all the interfaces and features. The benefits of resulted iterative team sessions and discussions are, for example, finding design or usability errors as well as the making of decisions easily. Further, this approach improves product quality, save money (for prototypes or by early found mistakes), enables earlier product release also called “frontloading” and gives companies a big advantage over the competition.

In the industry and engineering fields, virtual and augmented reality technologies are often used for vocational and on-the-job training [STVT<sup>+</sup>19]. The employees can learn how to assemble a product [CFO17, EON20a] or maintain a machine [EON20b]. The existing virtual twins of plants, production lines or machines facilitate the implementation of an immersive training [Ovt15].

### **3.2.3 Teaching Virtual Reality in Higher Education**

Looking back in the past, Burdea was one of the first authors concerned about the problems of teaching virtual reality [Bur04]. He first described the issues in teaching virtual reality such as the need for experienced lecturers and dedicated laboratories and the lack of supporting textbooks and lectures for VR courses. He focuses on a broad usage of VR technology and the need for such courses due to a growing job market for VR specialists. Burdea’s informal worldwide survey showed that only 148 (3%) universities in 2003 [Bur04] and 273 in 2008 [Bur08] offered virtual reality courses. Since then, the number of VR courses increased, but most of them take place in the form of lectures and exercises. The still relatively small amount of VR practical courses offered in academia use different teaching methodologies, various hardware and software platforms. Often the courses are offered only to computer science students as a complement to a computer graphics course [Sta05, Zar06, Cli06].

An introductory undergraduate VR course is presented by Stansfield [Sta05]. The course has both a traditional lecture-based and hands-on, experiential components and provides an opportunity for new capstone experiences. In addition, the students’ communication skills are enhanced by writing and presenting research papers.

Miyata et al. [MUH10] created an educational framework for developing VR applications. The graduate students work in interdisciplinary groups, creating VR applications as a part of a competition. The competition motivates the students to learn during the project development and to improve their collaboration skills. Each project has different content and is focused on

creativity. The ideas must be coming from the students. Most of the applications are related to entertainment topics such as games.

Zimmerman and Eber describe another interdisciplinary course with technical (computer science) and non-technical (art) students [ZE01]. The course comprises traditional lectures on both artistic and programming topics, demonstrations, research topics presentations and group labs. Each group creates an artistic virtual environment over the course, using HMDs and software WorldUp.

Fallast and Oberschmid refer to an interdisciplinary student project in the field of the product innovation process. In their work, the challenge consists in the remote collaboration between interdisciplinary, intercultural and international student teams working on tasks given by an industrial sponsor [FO09].

### **3.2.4 Methods for Feasibility Analysis of Immersive Technologies**

Some methods for evaluation of VR usability and benefits already exist but are specific for concrete application areas. Here some methods determining the feasibility and profitability of using immersive technologies are presented.

An example of the usage of strategic planning methods for virtual reality projects is that of Minocha, who makes overall SWOT analysis to study the challenges of applying virtual reality in education. He concludes that the impact of virtual reality on learning outcomes is still limited so that it can be used as an addition to traditional classrooms and standard training [Min15].

Rizzo and Kim made SWOT analysis for an application of virtual reality in the field of rehabilitation and therapy in 2005 [RK05]. They provided a structured examination of the factors relevant to the current and future status of VR rehabilitation as well as a good overview of the critical issues and concerns that are relevant for understanding and advancing this application area.

All advantages and disadvantages can be analysed and compared in detail using tools like cost-benefit analysis to decide on the profitability of a general investment [Bös16]. Kunst developed a methodology for economic analysis of VR technologies in 2005, where he focused on virtual factories [Kun06]. He recognised the problem that standard investment calculations are difficult to apply in this context.

The developed efficiency analysis of VR environments by Dücker et al., the so-called WAVE methodology, allows a step by step approximation of the complex decision on technology adaptation without the need of initial knowledge about VR technologies. It also involves many

interdisciplinary company divisions in order to obtain comprehensive statements about future VR usage. In addition to the insights on possible improvements in the company, a concrete VR solution is also identified by a risk-based efficiency analysis customised for the specific company [DHO16].

From high importance for this thesis is the work of Pantelidis, who makes recommendations on when to use and when not to use virtual reality. She proposes a 10-step model that can be applied to determine when to use virtual reality in an education or training course [Pan10].

## Summary

Immersive technology in education is an essential and growing field. The number of virtual reality courses will rise in the future because the immersive technologies become more affordable with time, and many institutions can afford them. Next to the immersive hardware and the software systems, the educators need more information on didactic approaches and technology incorporation practices to apply it successfully. However, new didactic approaches have to be developed not only for the development of constructive virtual worlds but also for the exploratory, experimental and training learning environments. This will open many possibilities to teach complex concepts in a more visual, interactive and intuitive way, especially for STEM subjects.

In the field of virtual reality for education, there are few models to determine when to use an immersive technology and no specific methods developed to identify the cost-benefit ratio of using this new media in educational programs.

In this thesis, the procedure from our preliminary work on the WAVE methodology [DHO16], where the main focus was on the adoption of the virtual reality in the industry, has been transferred to the application of immersive technologies in education. For this purpose, the questionnaires were adapted, the cost-benefit categories were supplemented, as well as the analyses were simplified and made more tangible.

### 3.3 Other Educational Technologies

This chapter covers some technological advances and how they currently support the learning process. As this thesis considers the application of advanced technologies for learning, it is of great importance to describe the available educational technologies and how they refer to the learning theories and didactic models. The description of the available educational technologies also helps to better differentiate them from the advanced technologies used in this work.

#### 3.3.1 Multimedia

The *multimedia learning* by Richard Meyer as described in the section before (see *Didactic and Didactic Methods* 2.1.2 on page 13) is based on the use of teaching materials based on both visual and auditory channels. These materials can be prepared for passive learners. They may assume the form of a multimedia presentation or video or provide more interactivity like an educational computer application, a computer game or some more sophisticated immersive applications. Educators should have in mind that there are different learning styles or modalities like visual, auditory, physical and social learning [FB06] that are important for the choice of the media to be used. Using (interactive) multimedia for learning can be most beneficial, when combined with the right didactic concepts and having proper implementation regarding software and hardware. It should be considered that some researchers claim that the success of a learning offer does not depend on the technology but on its didactic conception and the extent to which the conception precisely addresses and solves a particular educational problem [KP12]. Moreno and Meyer state that the same instructional methods have the same effects on learning regardless of whether the medium is a desktop computer, a non-immersive virtual reality or an immersive virtual reality [MM02].

*Computer-Aided Learning (CAL)* or its synonym *Computer Based Training (CBT)* is one of the first terms mentioned in the context of educational technology and enabling multimedia learning.

*CAL* are software tools that are designed to assist learning in a specific learning matter and where instructional methods are programmed, so they compensate for some teachers' tasks.

Combined with the advances of internet technologies those programs and other digital educational resources can be easily and comfortably shared online with the students (asynchronous learning) and some other transitions of synchronous learning approaches are possible for instance for the holding of online seminars or so-called webinars. Other advances like the miniaturisation of hardware brought the concept of mobile learning (also known as *m-learning*),

where learning applications can be used on portable devices such as smartphones or tablet computers.

### 3.3.2 Serious Games

Educators are searching for new and innovative ways to engage learners more in the learning process. They use computer games or so-called *serious games*.

*Serious games* are learning applications that use *gamification elements* for playful learning and try to imply intrinsic motivation and engagement with the learning matter.

Recently, there are many proofs that serious games are effective tools for training and education [MC05, WW13, vRZ17]. Computer games provide interactive virtual worlds and can be considered as a foundation of an immersive application, but have a lower interaction and immersion level. *Serious games* can provide an environment where people can learn more efficiently and sustainably through the application of knowledge.

The fun factor of the game additionally supports the learning effect. The player is not necessarily aware of the transfer of knowledge, so he learns unconsciously through active action [Mar10]. Other benefits of *serious games* are the overcoming of social and local restrictions, supporting individual learning as well as the reproduction of social, cultural and linguistic interaction. The latter is a critical factor for the consolidation of knowledge during the learning process [Mar10]. According to Dickey (serious) games can be linked to the *constructivist* methods, and the created immersion will help to motivate learners and increase learning outcomes [Dic05]. Other authors believe that computer games, looked from the perspective of instructional design, can feature all three approaches *behaviourist*, *cognitivist* and *constructivist* [PDSL17, VRW14].

### 3.3.3 Artificial Intelligence in Education

The artificial intelligence technology also finds application in education in recent years, due to the advances in this field like natural language processing, pattern recognition as well as intelligent agents and tutoring systems. The AI-based systems can mostly be found as a personal assistant of the learner or the teacher. Intelligent chatbots try to answer students questions personally, helping them solving tasks as well as keeping track of their progress [Bac17]. At the same time, embedded intelligent algorithms in the learning management systems support teachers in their administrative and organisational tasks (such as registration formalities, homework grading or measuring student responses) [Sch17a]. Using AI can help improve the quality of

learning in two ways. First, it can overtake the students' and courses' management tasks so that educators can concentrate on teaching and concrete students' needs. Second, learners can have a highly personalised learning environment [Sch19].

### **Intelligent Tutoring Systems**

Intelligent tutoring systems (ITSs) are computer learning environments, whose primary goal is to support the learning process in an adaptive and personalised manner, based on a student model.

It can incorporate computational models from the cognitive sciences, learning sciences, computational linguistics, artificial intelligence, mathematics, and other fields [GHS18]. Moreover, ITSs track many psychological characteristics of learners as well as their knowledge and skills to provide a customised learning environment [Woo10, SGHG14].

### **Knowledge Engineering Methods for Educational Systems**

Using ontologies for the implementation of intelligent educational systems are scarcely researched. Mizoguchi et al. present preliminary taxonomy of concepts to formalise intelligent educational tasks and processes with knowledge engineering methods [MSI96]. Later Ascar and Altun propose a method to design the e-learning domain concepts and cognitive skills for a personalised learning environment in the area of K-12 education [AA09]. Furthermore, researchers utilised a domain ontology and Bloom's Taxonomy in order to create learning paths and a genetic algorithm or selection of the most appropriate learning path [SKD15].

### **Combining Immersive Technologies and Artificial Intelligence for Education**

The automatic tracking of the individual learning process for adaptive learning requires more knowledge about the domain of the learning matter and the learner. Recently few researchers try to combine virtual learning environments with artificial intelligence (AI) technologies. MASCARET provides a model-based approach for the design of semantic VR environments [CTB<sup>+</sup>12]. Fricoteaux proposed an informed virtual environment (environment including knowledge-based models and providing an action/perception coupling) for fluvial navigation training. They used an automatic guide to a driving ship simulator by displaying multimodal aids adapted to human perception for trainees [FTO11]. Another development is the use of multipurpose fuzzy semantic enhanced 3D virtual reality simulator for the evaluation of maritime robot algorithms and the analysis of maritime missions. The simulator blends the digital mockup technology with semantic domain knowledge of the system to analyse the tasks remotely [BK13].

### 3.3.4 E-Learning Tools

Instead of paper textbooks, we have today digital textbooks and other multimedia learning materials that need to be stored and easily accessible. The so-called *Learning management systems (LMS)* and *learning content management systems (LCMS)* are developed to allow better management of digital learning materials and courses. Those platforms are also known as e-learning tools.

E-learning refers to “all forms of learning in which electronic or digital media are used for the presentation and distribution of learning materials and to support interpersonal communication” [Ker09].

LMS systems evolved with time from platforms for distribution and management of learning materials to complex systems that serve for management of whole courses. Their features include course administration, communication and collaboration between the users and roles (teachers and students), documentation, tracking and reporting of user activity, learner’s learning progress and feedback. Teachers can organise their course and also conduct online assessments. Those tools support novel teaching models like digital learning, blended learning and flipped classroom. Some representatives are the platforms *Moodle* and *ILIAS*.

*Moodle* is a learning management system designed to provide educators, administrators and learners with a single and integrated system to create personalised learning environments [Moo18]. Another open-source web-based learning management system is *ILIAS*, which is often deployed by German universities [ILI20].

The terms e-learning or Virtual Universities (VU) refer to computer-assisted learning scenarios in which distributed users can use networking technologies to meet at virtual learning locations, or to receive tasks and deliver solutions [Lut05]. Such platforms are also known in the literature as virtual learning environments (VLE) or virtual classrooms and can be used, for instance, for web lectures or seminars.

This thesis differentiates between the above-mentioned VLE and deals only with *immersive* virtual reality learning environments.

## Summary

Next to the immersive technologies, other technologies strive to advance and support learning processes and facilitate the work of educators. Such technologies are the learning management systems, multimedia applications, artificial intelligence methods, as well as approaches for playful learning like serious games. At this point, it is crucial to differentiate between

an *immersive environment* and multimedia applications. Interaction is considered a key factor in immersive applications. Individual users use most multimedia applications on a computer, where mouse, keyboard or joystick are used as interaction devices. In virtual reality, it looks different, where a much more extensive selection of interaction devices that enable interaction in three-dimensional space are available [Lut05]. The learner in an immersive environment experiences situations that are generated by his interaction and which allow him to explore, manipulate or contribute to the experience [PP06]. In general, a multimedia application faces the user with a situation that can be generally described as data recovery. In contrast, the VR environment confronts the user with a situation of real-time stimuli generation [PP06]. Another difference is also that immersive applications create a stronger feeling of presence which leads to many benefits such as achieving better concentration (see also *Benefits of Immersive Learning Environments* 4.2.1 on page 106).

E-learning is often described as a virtual learning environment (VLE) since learning takes place over the internet and is not physical. At the same, time immersive learning environment (ILE) are misinterpreted as a virtual learning environment (VLE) or virtual reality learning environments (VRLE), which can also be non-immersive. It is essential to differentiate, that this work deals with immersive learning environments (ILE), where systems with a high level of immersion are incorporated to achieve a high level of presence and improved learning outcome.

The AI technologies and gamification techniques serve to advance the immersive learning applications and provide highly engaging and adaptive learning environments.

## Summary

The chapter “State of the Art” provides information about the current technological advances in the area of education which are essential for the understanding of the presented methodology. The first section presented in details the current developments in the area of immersive technologies such as the virtual and augmented reality hardware and software.

The next section encompasses different aspects of the application of the immersive technologies in education. It starts with a categorisation and examples for immersive learning applications categorised in exploratory, experimental, training and construction worlds and continues with their application in the engineering fields. Another aspect that this section covers is the teaching of immersive technologies as subject matter, in particular in higher education courses. Furthermore, methods for feasibility analysis of immersive technologies are presented and concretely the WAVE method which is adapted in the developed decision-support method (see *Decision Support Method* 4.3.1 on page 161).

The last section deals with other technologies embedded in education and their recent development. Such technologies are multimedia applications or serious games as well as supporting technologies like e-learning tools and methods from artificial intelligence. At the end, a distinction between e-learning and immersive learning environments is made.

## 4 Methodology

This methodology introduced in this chapter deals with some current problems of learning and teaching with immersive technologies like how can those technologies support the learning process, how to systematically design immersive systems and how to increase the efficiency of the authoring process of immersive learning applications. The usage of immersive and artificial intelligence technologies in education promises many benefits for learners and educators. However, many studies showed that the success of every learning environment based on new technology depends on its design and integration in the learning process [May09].

The methodology presents a *holistic approach* to the integration of intelligent and immersive environments in engineering education. Its holistic characteristic allows us to look at the utilisation of immersive technology in education from different angles. The methodology deals with the interplay between the *three layers* - education, technology and management, and emphasises on how the technology influences the traditional instructional design and management processes (see Fig. 4.1). In other words, the presented methodology builds on the *educational life cycle*. It provides a framework and guidelines for educators to plan and implement an educational program based on the immersive and artificial intelligence technologies.

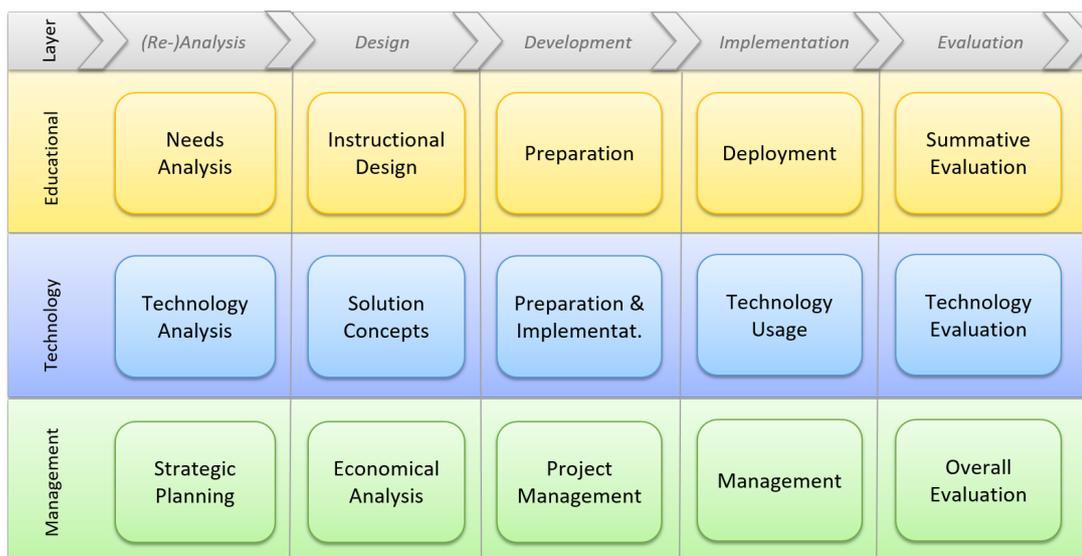


Fig. 4.1: The three layers and main task areas covered by the methodology

Furthermore, the methodology involves an extensive technological and economical analysis combined with a method for decision making support. This method is based on a detailed categorisation of the benefits and limitations of virtual reality for education and uses extensive cost-benefit analysis.

Four validation use cases are provided in order to prove that the proposed methodology can be applied in various learning setups. Together, the presented projects cover all layers with their tasks and processes, in different level of details and give examples on how to implement the methodology successfully.

## Roles

During the creation of a new educational program or the redesign of an old one, many actors and roles are involved. This methodology handles different perspectives for all key stakeholder groups, depending on their roles and responsibilities. During the development of the methodology six main roles were identified as depicted on Fig. 4.2.

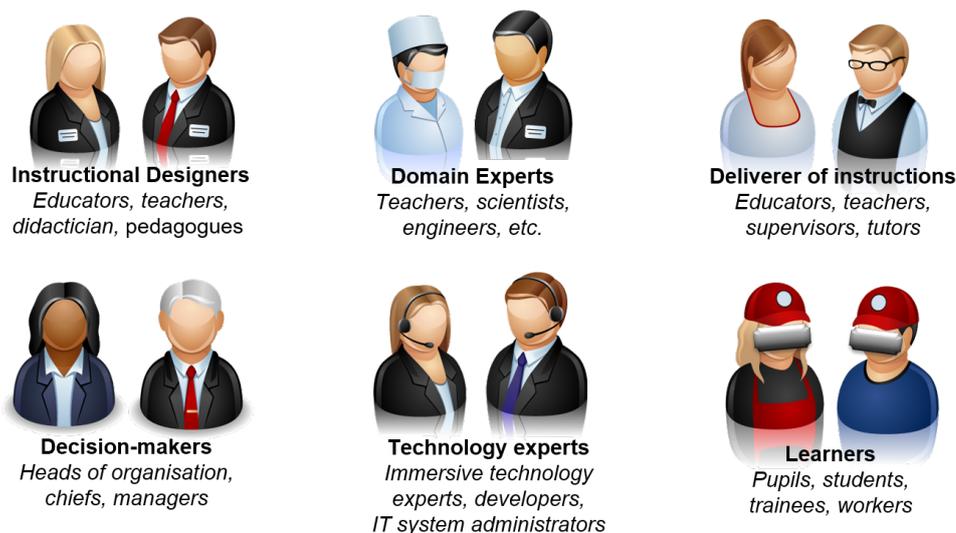


Fig. 4.2: Identified roles and key stakeholder groups

### Instructional Designers

The people who are going to create the instructions are called instructional designers. They are experts in the field of designing educational programs, such as a course or training, and will not necessarily deliver later the instructions themselves. Those people have the knowledge on didactics, how to utilise teaching strategies and activities and how to manage educational resources in order to achieve the learning goals. Furthermore, they should have experience in using different media in the instructions and are responsible for the content creation [Wor20].

---

This methodology helps instructional designers to better assess the requirements of the immersive system from a pedagogical perspective.

### **Domain Experts**

Domain experts, on the other hand, have the knowledge and experience in the subject matter and support the content development. Those are usually educators (e.g. teachers in physics) or other external experts in the specific field. Their role is to deliver information about the subject matter, which can be in the form of text, tables, diagrams, images, videos describing the environment or the related processes, training procedures and even the assets for the virtual environment like 3d models, sounds or simulations.

### **Deliverer of Instructions**

Educators or supervisors (often a teacher, trainer, instructor or tutor) play another crucial role. They deliver the instructions based on the instructional model. When immersive technologies are adopted, their traditional role shifts from implementer of the instructions to facilitator of the learning process. They intervene in the learning process when learners require their support.

### **Technology Experts**

The next role is that of the technology experts. Their tasks range from consulting, to the design and development and the training and support of immersive systems. Furthermore, the technology demands a technician or a system administrator who usually takes care of the preparation and maintenance of the IT systems.

### **Decision-makers**

Often, people who have management positions (such as heads of an organisation, chiefs, managers) and will take decisions on the future of an educational program and at the same time can have less knowledge in instructional design, are neglected in the research literature. The methodology refers to this role as decision-makers. Those stakeholders have an essential role and skills like positioning of the educational unit, strategic planning or resource management. Furthermore, management tasks have economic aspects, e.g. the budget planning or if applicable, business aspects like the creation of a business model, generation of revenue, marketing activities and many others. Those responsibilities and roles depend strongly on the organisation's size and can be distributed among different people.

## **Learners**

Last but not least, there is the role of the participants of the educational program. They are referred as the *target group* during the analysis and design phases and as the *learners* (e.g. pupils, students, trainees) later during instruction delivery. They have the privilege to gain knowledge and skills in a novel and intuitive manner, while building virtual worlds or experiencing them.

One person can perform several roles. For instance, teachers or trainers often provide the course design, the preparation as well as the delivery and the evaluation. In big organisations, it is usual to have teams, where each team member has a particular role in a particular process. Since virtual reality is a novel and sophisticated technology, it becomes even more important to have technical experts, during all phases. In the next part of this section, the single layers with the tasks and roles are explained. An overview of all roles and possible teams along the three layers and the educational life-cycle is presented on Fig. A.1 on page 325.

## **Layers**

When creating an educational program that involves new media, the right incorporation of the technology depends on numerous aspects. Those aspects are categorised in three main layers: education, technology and management.

### **Educational Layer**

The main goal of the methodology is to show how to embed novel elements (in particular technologies and methods) in the education. That is why the educational layer is so essential and provides the foundation of the methodology. All tasks are organised along the educational life-cycle and instructional methods. From the perspective of the instructional design, it is of a central importance to analyse the target groups and their needs. The resulted requirements can then be used to create the initial design or redesign an educational program which is then used as a framework for the concrete development, deployment and evaluation activities. The instructional design depends strongly on the resources necessary for the planned course to achieve the defined learning goals. Those resources include the media, and with it the technology used. At this moment, the technology aspects influence the further design, development and deployment of the educational project and should be taken into consideration. The task areas and the concrete tasks of the educational layer are presented in Fig. 4.3 and explained in details in next section *Educational Layer 4.1* on page 70.

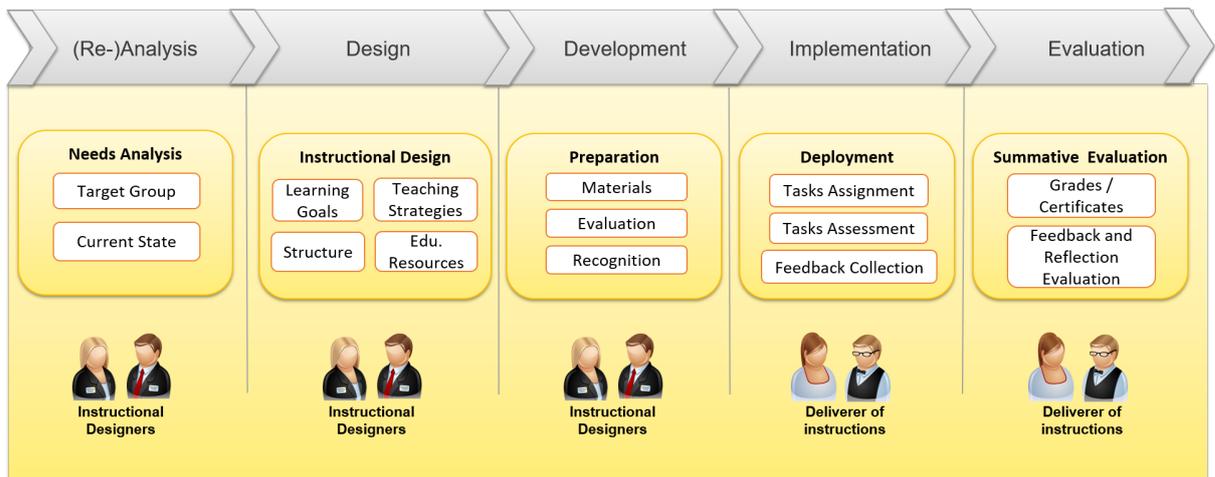


Fig. 4.3: Educational Layer - tasks and roles

## Technology Layer

The educational and management aspects influence strongly the analysis, design and implementation of the technology as they determine the overall system requirements. At the same time, the benefits and limitations of the technology can also influence the instructional design like the selection of appropriate learning activities. Furthermore, there can be conflicts between the development of the maximum potential and the budget available. There is a need to find a cost/benefit ratio for all stakeholders. Incorporating immersive technologies can require many technical experts (see Fig. 4.4), starting from immersive systems specialist, who provide hardware and software solutions and in particular have experience in the development of immersive learning environments. They should be involved as early as possible, ideally, already in the analysis phase. Moreover, the virtual reality developers need domain experts who provide the content depending on the subject matter, in parallel supported by the instructional designers, who decide about each learning step and its order. For the preparation and deployment of the immersive system, an IT administrator, as well as technical support, should not be neglected.

## Management Layer

The central tasks of the management layer depend strongly on the organisation's strategic goals. Many tasks are indirectly connected to the educational program and usually are not so present. They can be categorised into the following areas: strategic planning, analysis, decision making and project management (see Fig. 4.5). Many decisions have to be made during the whole educational life-cycle. For instance, after the analysis and initial concepts, it should be considered whether the implementation of the educational unit can take place as planned. After the successful delivery and evaluation of the educational program, it is necessary to decide whether the usage of the immersive technology should be extended to other target groups and domains

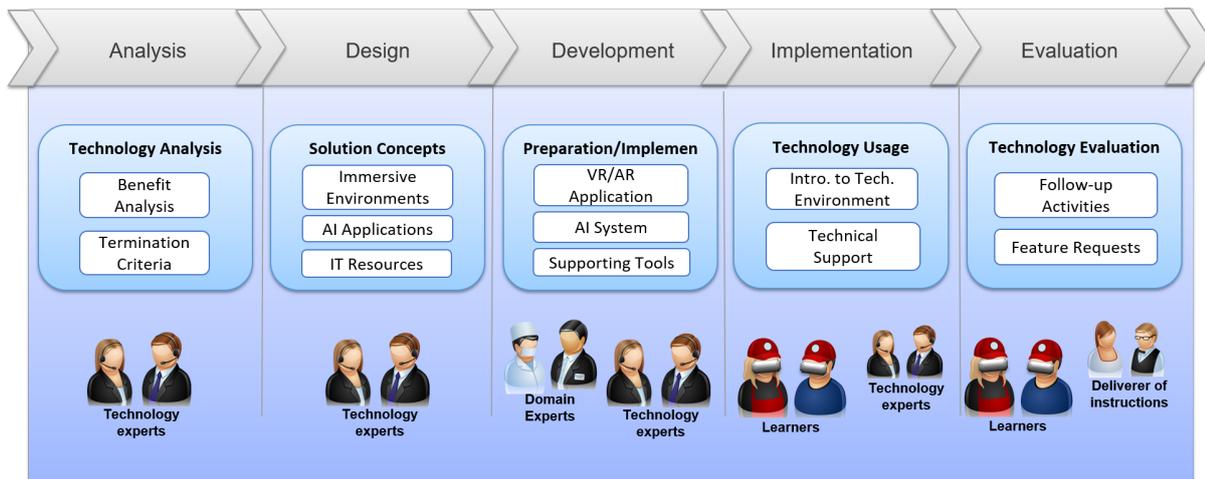


Fig. 4.4: Technology Layer - tasks and roles

or whether more learning content and helpful features should be developed for the same course. If functions only may have been beneficial for the learning outcomes, and there is a need to redesign or even cancel the project because the full potential could not be achieved. The management layer provides a framework for all tasks that cannot be assigned to the other layers and supports in parallel the educational project. Such tasks are project management and evaluation as well as management of human or other project relevant resources.

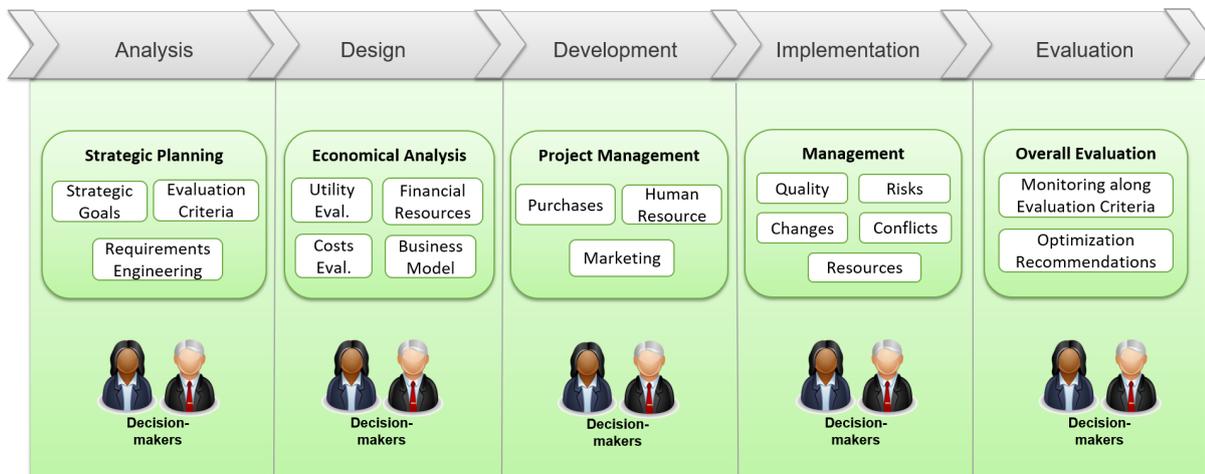


Fig. 4.5: Management Layer - tasks and roles

The interplay between the three layers is very complex and is of major significance for the success of the integration. That is why this methodology uses a holistic approach, that covers all aspects, from all perspectives and ensures sound implementation of immersive technologies in the educational program.

---

## Processes

The three layers and the corresponding tasks are organised along the *life-cycle of an educational program*. On the figure 4.1, the methodology is presented as a linear process to demonstrate all relevant, involved aspects and tasks and for better understanding of the complexity. The goal is to provide a smooth and clear entry to the educational program for all stakeholder groups, depending on their perspective and initial knowledge. Next to the life-cycle of an educational program (see Fig. 4.6) and the *instructional design process* concerning the educational layer, there are many other processes incorporated in the methodology.

The technology layer supports the educational life-cycle process and provides further processes such as an *agile system and software development*, and their many sub-processes. The immersive system life cycle, for instance, consists of many sub-processes mainly in the area of system engineering like technical analysis, design, implementation, tests and optimisation. The specifics of the *authoring of immersive applications* and the novel approach for building intelligent and interactive learning environments are the two essential processes in this methodology. Authoring of immersive environments, as most software development projects, is an agile and highly iterative process as described in *Authoring of Immersive Applications* 4.2.4 on page 142. Each software development step should be tested and evaluated with end users, since the evaluation can affect decisions taken in previous steps (e.g. requirements engineering or design). That is why the educational program life-cycle can not be considered as a linear process with fixed milestones and agile project development should be supported.

An extensive process for *decision making support* is provided in the management layer (see Fig. 4.18). This process goes through several analysis and design steps, followed by a cost-benefit evaluation in order to provide decision-makers with all necessary information to proceed or not with the realisation of the developed concepts. After a positive decision is made, a *project management process* can start.

As described above, there are many processes and sub-processes involved in the methodology. They are discussed and depicted in details in the corresponding sections for each layer.

## 4.1 Educational Layer

A curriculum gives a framework for all aspects concerning the teaching and learning processes and represents the learning context in which new technologies are going to be applied. This section gives guidance for educators on how to create an educational program (e.g. course, training) for teaching immersive technologies or embedding immersive applications in their curriculum.

The teaching methodology presents a mixture of methods and approaches along the life-cycle of an educational program ( see Fig. 4.6), helping to meet the learning goals of the course and the different needs of the learners. It should answer questions such as what should one consider when designing a new teaching program, which factors influence the education and which novel methods exist. The educational layer subsections follow the educational program life-cycle which starts with the analysis and design continues with the development and delivery of the instructions and ends with their evaluation.

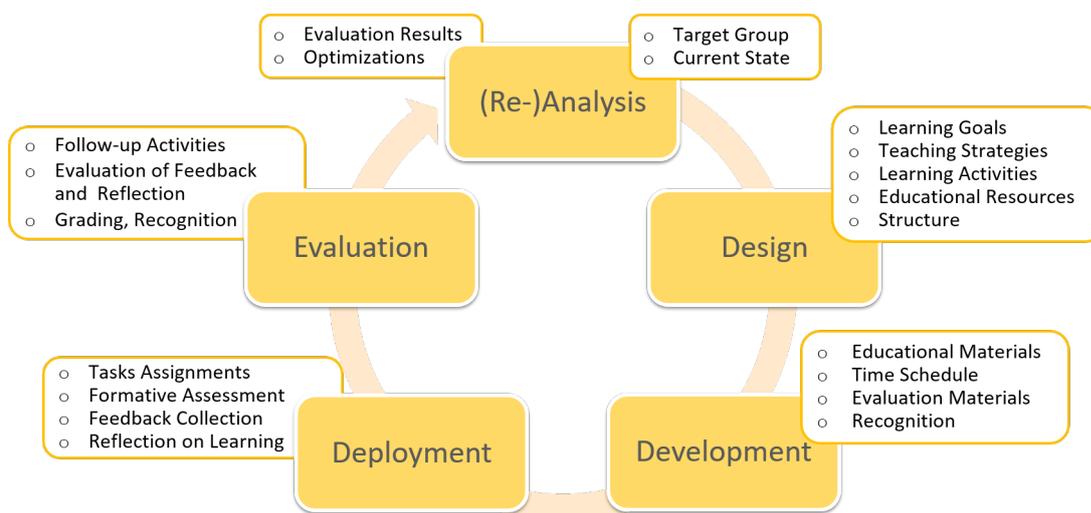


Fig. 4.6: Overview of the instruction design process adapted by [Kur15a]

### 4.1.1 Analysis

The analysis phase in the context of instructional design is the process of defining who is going to learn and what is going to be learned.

It is supposed to serve as a foundation for all subsequent phases. Hence, it is of great importance to plan it with particular care.

During this phase, the initial teaching objectives and current issues should be clarified. One important part is the analysis of the *target group*. Who is the learner and what are his existing

skills and knowledge? Additionally, the current state of the educational program should be analysed.

There are several tools and methods that can be used for this purpose like needs analysis, job analysis or task analysis. Techniques from areas like strategic planning, design thinking, business models, and methods from the area of service development can also be involved.

The results of this phase include description of the learning constraints, the learners needs, the learner's profile as well as some problem statements. The requirements are derived from these insights and lay the foundation for the design phase.

### Target Group Analysis

The learners have specific requirements, expectations, attitudes, maturity, backgrounds and skills, that need to be considered during the course creation. Analysing the learners creates an excellent foundation to define the appropriate learning methods, to choose the right content and will lead to better user satisfaction and achieving of the learning goals. For instant, adult learners compared to full-time students need to know the benefits of learning like where is the immediate value and application of the content, to use experiential learning methods and have flexibility according to time, place and pace [Ghi11].

The instructional design should align with the requirements of the target group and other key stakeholders. Alan Carrington notes that it is highly essential to know the target group, concrete the graduate attributes and capabilities, in order to achieve motivation and engagement, before going ahead with the fine-tuning of the course design, activity design or technology selection [C<sup>+</sup>16].

The thesis proposes two main methods for target group analysis, which are interviews and questionnaires.

These methods help to collect the learners' main characteristics combined with their competences, learning expectations and many others. Using interviews with potential learners is a time-consuming process, but can tremendously increase the instruction quality. Another method for studying the target group is to fill in a questionnaire. The questions can be oriented towards the anthropological-psychological and socio-cultural conditions by Heinemann (see *Didactic and Didactic Methods* 2.1.2 on page 13) and at the same time, should be customised based on the learning goals and used immersive technology. Tab. 4.1 provides questions that can guide the instructional designer through the target group analysis.

✓	Which learning background does the particular learner have?
✓	At which stage of development are the learners?
✓	Which attitude/motivation, receptivity do they have?
✓	Where do they live and what can be inferred from that? (attitudes, skills, learning styles)
✓	What knowledge and experience do they have?
✓	Which interests do they have?
✓	How old are the involved persons or at which stage of development are they? Male or female?
✓	What expectations do the parents, the society, or the institution/school have?

Tab. 4.1: Guiding questions for target group analysis based on Berlin Model [HOS70]

Next to the proposed Heinemann conditions, the technical aspects like digital literacy and availability of the education medium should be analysed. For instance, if a web-based learning is going to be provided, it should be ensured that the target group has access to computers or tablets and an internet connection. Other conditions next to the availability of the technology, the technology acceptance and the technical literacy of the user should be considered as well. The methodology is suitable for a high level of multidisciplinary in various educational contexts such as companies where the employees are usually with heterogeneous age and background. How many participants can take part in a course and how the places are distributed along the roles or fields of study depends on the goals, the learning activities and the time available for the course, which is discussed next.

Furthermore, there are different methods and instruments to analyse target audiences in the context of marketing [Cah97], which is not further considered in this work. Once done, it is also beneficial to analyse the best communication channels to promote the course (see also *Marketing* 4.3.4 on page 174).

### **Current State of the Educational Program**

The analysis of the current state includes the identification of how the learning environment looks like and what are its main constraints. If the educational program already exists, its current situation should be analysed based on the learners and educators feedback. The evaluation gives clues for current issues and optimisation potentials. At this stage the current state analysis in educational context should only be considered. It comes together in the overall current state, which will be described in the management layer ( see section 4.3 on page 161). The educational

requirements and main boundary conditions for the instructional design can be gathered based on the following questions (see Tab. 4.2).

✓	Who are the learners, and what are their characteristics? (see target group analysis 4.1.1)
✓	What is the desired new behaviour?
✓	What types of learning constraints exist? (educators, budget, time)
✓	What are the delivery options?
✓	What are the pedagogical considerations?
✓	What learning theory considerations depending on learners age apply?
✓	What is the timeline for project completion?

Tab. 4.2: Guiding questions for analysis of the educational requirements and boundary conditions [LL13]

### 4.1.2 Instructional Design

The successful application of new technology in an educational program needs sound instructional design and good backgrounds on both didactics and technology. Furthermore, the design should be based on an in-depth analysis of the boundary conditions and the requirements associated with it (as performed in the analysis phase, see 4.1.1).

During the design phase, educators should determine the main learning factors like

- what is being taught (the subject of learning),
- how it is being taught (the process of learning),
- the behavioural outcome (the object of learning) as well as
- the context and medium used [May09].

The design of a course is an iterative process and educators can work out the different aspects simultaneously. There is no task order that have to be strictly followed. It is essential that course designers should consider all aspects and have a rough idea of each aspect. This should save educators time, stress as well as additional costs during the implementation.

The section “Instructional Design” describes in details the necessary design tasks and is structured as depicted on Fig. 4.7.



Fig. 4.7: Structure of the “Instructional Design” section

## Teaching and Learning Goals

This methodology applies *two classical and proven frameworks* for the formulation of the teaching goals and the learning outcomes. Several teaching frameworks can be helpful for this purpose, but the most popular is the *Bloom’s Taxonomy of Educational Objectives*. His framework provides a practical tool for identifying the learners’ observable and measurable skills and helps to determine specific learning objectives [B<sup>+</sup>56]. According to the level of complexity, he describes six types of cognitive processes. Starting with knowledge, comprehension, application, analysis, synthesis, and ending with the most complex: the evaluation (see *Didactic and Didactic Methods* 2.1.2 on page 13). To define the goals of the learning process, the question “What should a learner have acquired after the course?”, should be posed and answered according to the six types of cognitive processes. At this point, it is important to focus on the definition of the goals and not how to achieve them. In particular, the benefit analysis of using immersive technologies like VR and AR is ignored for now.

Bloom’s Taxonomy is more general and can be applied in the most educational cases. In the area of higher education and courses for adults, this methodology recommends the usage of the *taxonomy of significant learning* proposed by Fink [Fin13]. This taxonomy helps educators formulate college course or training on the job goals. Fink also defines six kinds of learning together with the specific content types as listed in the Tab. 4.3.

Following these six kinds of learning gives an excellent guideline for the definition of the learning goals. They then should help instructional designers to identify the teaching strategy and the learning activities and with this also the necessary resources. The learning activities can in-

Kinds of Learning	Knowledge and Skills
Foundational knowledge:	Understanding of key content: facts, principles, concepts, and others.
Application:	Thinking skills, other physical and intellectual skills, managing complex projects.
Integration:	Connecting ideas, information, realms of life, and others.
Human dimension:	Knowing how to interact with oneself and with others.
Caring:	Making changes in one's feelings, interests, and values.
Learning how to learn:	Learning how to keep on learning after the course is over.

Tab. 4.3: Six kinds of significant learning by Fink [Fin13]

corporate immersive technology if it is beneficial for the improvement of the learning outcome and process.

### Curriculum or Structure of Educational Programs

The proposed methodology prescribes a division of the educational program in *three phases*, which should help to create the detailed syllabus. The first phase is the theoretical and practical introduction, followed by the application and evaluation phase. The evaluation phase encompasses both the evaluation of the learners' learning performance and the evaluation of the educational program by the learners and supervisors. The phases can overlap. The course structure can be drafted during the design process and planned in detail during the preparation. That means that all educational modules and units should be considered together with the teaching methods and learning activities in order to achieve the learning goals. The proposed structure also implies that the instructors can better manage the time they invest in preparation and follow-up activities. The three proposed phases by the methodology are presented on Fig. 4.8. The introduction and evaluation phase provide a frame for the most extended application phase.

#### Introduction Phase

The introduction can be split into three parts: Overall introduction, theoretical and practical introduction.

#### Overall Introduction

The goal of the general educational program introduction is to explain to learners all relevant information about the course organisers, structure, learning goals and activities. The questions

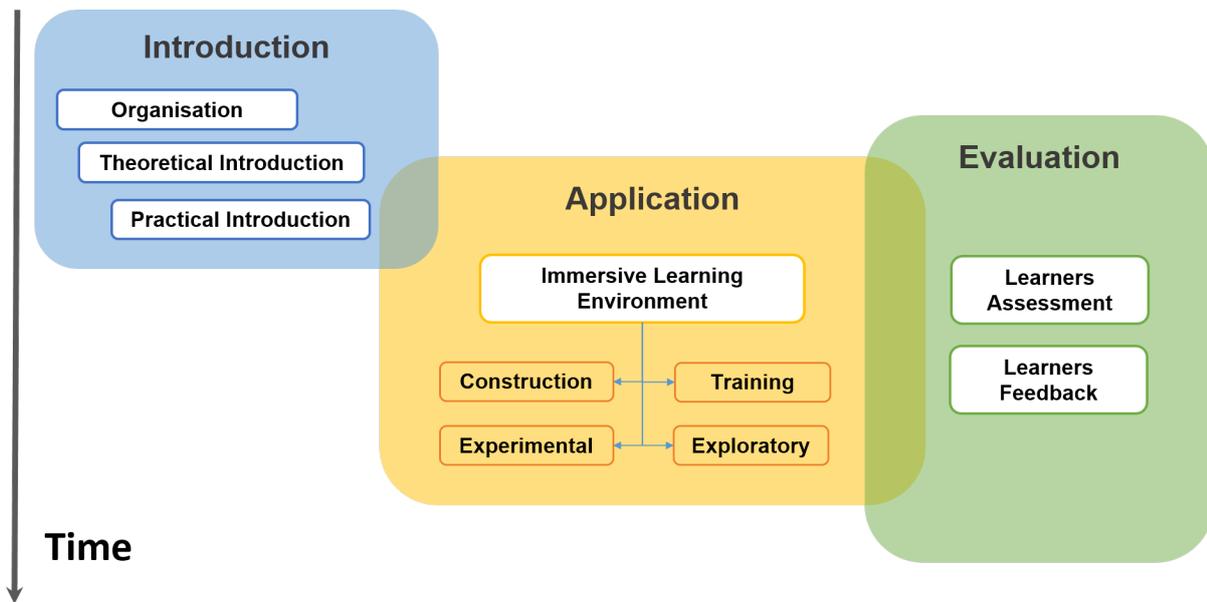


Fig. 4.8: Structure of an immersive technology course with three overlapping phases

that have arisen should be discussed in detail with the learners, so they are aware of what and how they are going to learn and misunderstandings in the future can be avoided (see Tab. 4.4). The presentation of the teaching goals is of great importance. The learners should know which skills they can learn until the end of the course.

✓	What is going to be learned or trained? What are the learning goals?
✓	How should the learning happen? Which learning activities are used? Why are all these activities necessary?
✓	When are the meetings and how long?
✓	Where are the meetings taking place?
✓	Who are the responsible supervisors? Which are their consultation hours?
✓	Which learning media and materials are going to be used?
✓	Which learning materials or readings are recommended? Is there any other relevant information like topics and results from past educational programs?
✓	Which criteria are used for the grading?
✓	Other relevant questions like important assignment dates, project deliverable or attendance should be presented.

Tab. 4.4: Guiding questions for the overall introduction

The supervisors should be presented not only with their role, experience and contact data, but also with their background in order to build a solid social base. Our experience showed that creating a casual atmosphere motivates learners to have frequent contact with the supervisors and to

ask more questions during the educational program. A short presentation of each course member to the others is also of great benefit. Furthermore, a short introduction to past educational programs statistic data (e.g. number of participants, average grades) or other achievements can provide a better overview to the learners in order to have more realistic expectations.

### **Theoretical Introduction**

The theoretical introduction is placed at the beginning of the course and has the goal to cover the *relevant theoretical background* necessary for achieving the learning activities during the application phase. The instructor should choose the relevant themes and suitable learning activities, so the course participants achieve a *common understanding* for the learning matter. In the proposed methodology, the theory introduction is concise; the goal is to give a good *thematic start* and to help the learners to find further information in order to solve their assignments. Nevertheless, the instructional designers should carefully prepare the internal structure of this introduction. As recommended by Fink, the topics should build on one another. For instance, the topics should be presented from simple to complex or from fundamental to the topics which emerge from fundamentals [Fin13, p. 128].

### **Practical Introduction**

The proposed methodology aims at the application of immersive technologies, and next to the theoretical introduction, there is a need to present the software and hardware to be used. As learning activities, some labs on a specific tool or demonstrations of hardware equipment can be provided. With the experience collected during the labs (experiments, exercise, lab scripts) the learners are introduced to the basic functionality and principles of the software tools, and this should facilitate the later use of the tool and all advanced features, based on other sources like documentation, internet forums, videos.

### **Application Phase**

The application phase is usually the longest. This methodology distinguishes *two kinds of teaching strategies* based on the utilisation of immersive technologies. The one strategy is the *teaching of authoring immersive environments* with immersive constructive worlds. Meanwhile, learners immediately learn the subject matter of the virtual world. The second strategy is the incorporation of *immersive learning applications*, which depending on the required type of knowledge, can be explorative, experimental or training worlds.

## Teaching Authoring Immersive Applications

*Project-based learning* is a suitable teaching method for the development of an immersive constructive environment. The project work starts with the tasks assignment and building working groups. The next task for the learners is to think about the possible solutions of the given problem, the available competences and task contribution in the group, needed software and hardware, about the time available for the project and they should create a project plan in a short time. After presenting the plan, learners can start working autonomously or in groups on the specific application tasks. In the middle of the project, learners present the current results and compare them to the original plan. The learners can check with the supervisors in order to see if it is realistic to stick to the plan, and if some tasks should be cancelled. The project work ends with a presentation of the final results and demonstration of the project with the dedicated immersive hardware. At the end, the learners should also submit the project documentation and other relevant project deliverables. An example of a structure of the project work together with the learning activity location, while teaching authoring of immersive environments is depicted on Tab. 4.5.

Learning Activities Structure	Delivery
Task assignment and building groups	in-class
Project planning	out-of-class
Presentation of the project plan	in-class
Autonomous and group work	out-of-class
Presentation of the intermediate results	in-class
Autonomous and group work	out-of-class
Final presentation and results demonstration	in-class

Tab. 4.5: Structure for project-based learning on authoring virtual worlds

Project tasks can be allocated at the beginning of the course, during the introduction phase. Learners can start earlier with the project work, in parallel to the theoretical and practical introduction. The advantages of an early start are that trainees can get to know each other better inside the group, have enough time to think about possible solutions, carry on first brainstorming activities and create a plan for the project work phase. *Earlier allocation of the tasks* gives learners the possibility to estimate which topics from the theoretical and which tools from the practical introduction are relevant for them so that they can concentrate on them. In the light of previous course experience, the learners have more time for the project work and are more satisfied with the results at the end of the course.

## Teaching with Immersive Learning Applications

After the introduction of the immersive system and how it should work, learners can start using it for knowledge or skill acquisition. There are different types of immersive learning environments depending on the learning goals, learning matter and the incorporated instructional methods: *Explorative, experimental or training worlds*. In many cases, the immersive learning environment can alternate with theoretical or real-life practical experiences according to the *blended learning approach*. In the driving course example, the driving in a virtual reality simulator can be combined with other learning activities like theory lessons on traffic regulations as well as driving a real car.

## Learners' Assessment and Course Evaluation

### Learners' Assessment

The evaluation of the *learning performance* can start practically from the first educational unit, depending on used learning activities and their evaluation methods. This methodology proposes an earlier evaluation of the acquired knowledge from the theoretical introduction phase as well as a continuous evaluation of the *soft skills* during the whole project work phase. At the end, all results are evaluated, and the grades can be formed from all components (see summative evaluation 4.1.5).

The immersive software application can be delivered with or without the *tutoring system*. In the first case, the tutoring system can provide automated evaluation with instant feedback to the learner and summarised evaluation for teachers on demand. In the second case, the evaluation is done continuously and manually by the educators.

### Learners' Feedback

The evaluation of the educational program based on learners' feedback can also start earlier and should not wait until the end of the educational program. The learning process can be continuously optimised by providing feedback for all technical, educational and management levels. The methodology recommends to conduct questionnaires *in the middle and at the end* of the educational program. *Direct feedback* from learners can be acquired whole the time and in any form ( i.e. in the virtual reality application, in an additional tool like forum, ticket system or communicated directly to the supervisors). The (anonymous) results can be discussed with learners, and some *corrective actions* can be taken as soon as possible.

## Teaching Strategies and Learning Activities

Designing an educational program or module is an iterative process which includes the creation of a *teaching strategy*. This strategy should contain the structure and the learning activities.

An instructional strategy is defined as 'a combination of specific learning activities in a particular sequence, usually laid out over a one- to three-week span of time' [Fin13, p. 260].

Here suitable learning activities will be presented along with the proposed structure among the theoretical, practical introduction as well as activities for the development and deployment phase. It is helpful to think about the learning activities from the perspective of the linked knowledge processes and what should be done in order to know something. A useful categorisation of those knowledge processes and different kinds of activities are presented by [VH10] as follows and can be used as a tool for designing learning modules:

- Activities that bring in the learners' own experiences and existing knowledge.
- Activities that immerse learners in new experiences or information.
- Activities that get learners to group and classify things, form concepts and define terms.
- Activities in which learners tie concepts together into generalisations or map the interconnections between concepts.
- Activities which explore cause, effects, relationships and functions.
- Activities which explore motives, purposes and interests.
- Activities that require application of knowledge to actual problems and real-world situations.
- Activities that require the transfer of knowledge to new situations and different contexts.

Some of the leading questions here are, what does an instructional designer want to achieve with a specific activity and which knowledge process is best suited to achieving the learning objectives? This question supposes the search for a *direct link between learning activities and learning objectives*. Another critical issue is that each learning activity should build on learners'

past learning activities and prepare them for future activities, in other words, they should be coherent and contribute to the learning of earlier or later activities.

As each learning module has its own goals, this methodology gives examples of best practices and proposes supporting tools for choosing the right learning activities. Furthermore, the course structure and the defined goals should function as a framework for identification of the specific learning activities. Additionally, the resulting target group requirements from the analysis phase should be considered (see section 4.1.1). The inclusion of the described benefits of immersive environments for education classified in section 4.2.1 should provide a good foundation to plan the appropriate kind of learning activities while developing immersive environments, in order to provide the desired learning outcomes.

In the following paragraphs, we present some examples of learning activities that were successfully validated. The proposed teaching strategy provides a rough framework and is built along the proposed structure.

### Learning Activities during Theoretical Introduction

Educators should provide certain theoretical background to the learners in order to achieve their tasks during the application phase. Especially if the learners have different knowledge background and experience, it becomes even more difficult to define with which topics the learners should familiarise at the beginning and which should be learned individually along the problem-solving tasks. To apply the best instructional methods and activities, some guiding questions are proposed on the Tab. 4.6.

✓	What for theoretical background and experience the learners already have?
✓	Which topics should be covered, in order, all students have sufficient background to master their learning activities?
✓	How much time is available to cover the theoretical foundations?
✓	Which learning activities should be used?
✓	Should in-class or out-of-class activities or a combination of both be applied?

Tab. 4.6: Guiding questions for design of the learning activities during the theoretical introduction

### Lectures

A common in-class method for theoretical knowledge acquisition is the lecture, held by the educator. The lecture is an ancient method for instructional teaching, and today there are many possibilities to provide modern lectures using multimedia, which means incorporating sound

and visuals. Lectures may have certain advantages such as the possibility of presenting quickly information to a large audience but present some disadvantages too since they may reveal themselves insufficient for students without auditory learning and note-taking skills. If the presenter is not skilful enough or if the lecture is too long the learners might get bored. Another drawback is that an immediate students assessment is not possible.

### **Flipped Learning Approach**

Lectures today can be recorded and made available in the form of video. This video can serve as bases for *out-of-class preparation*, also known as the flipped learning approach. Using flipped learning, the students prepare the theoretical part at home, and they can concentrate in class on some *problem-solving tasks* and other activities based on this theory. Another possible media for out-of-class preparation are written materials like books or scripts on the topics that they should read at home before the in-class activities work. Flipped learning approach has some issues, for instance, that some learners do not do the preparation at home, lacking time or motivation. Another problem is that the evaluation can be very time consuming for the instructors.

### **Presentation by Learners**

To avoid the problems of lectures and to use the benefits of the flipped learning approach, we developed an *active form of learning* activity for the theoretical introduction. Learners should prepare at home and present in class a given topic from the theoretical foundations. This learning activity has several benefits compared to a lecture. First, the learners can *autonomously work on a topic* (if it fits their interest), and learn how to search and screen the relevant information, and to sum it up in form of a presentation. The second benefit is that the learners learn how to *prepare a short presentation* with exact requirements for duration and structure, can learn how to use text, diagrams, images, tables and other multimedia elements to explain a concept.

Two kinds of *presentation skills* can be defined: Technical and non technical. The technical skills are limited to the mastering of different presentation software functionalities, for example, knowing how to embed images, text, animations or videos in a slideshow. The non technical skills are various starting with learning how to transmit the message in the form of facts, data, analysis to the audience, to interpret and understand the listeners, and finish with how to interact with and engage the audience. During the presentation, learners learn to explain concepts in front of many people.

The assessment of such a task is much easier and faster than with an oral or written exam. First, because one can be sure that one topic is learned properly by each learner (using the learning-by-teaching effect) and second, the instructor can evaluate during the presentation. The students

have the opportunity to learn all relevant theoretical concepts from the presentations of the others (*peer-to-peer learning*). At the same time, they can learn some *technical skills* relating to the presentation by comparing their work to that of the others.

Learning how to present a project or product is very important for the set of *soft skills*, in particular, of the *communication skills* a person should have. Today, presentations are deeply incorporated in the business life, and one's chances of success depend strongly on one's presentation skills. The learning of *presentation skills* itself is a long process, and the success lies in practice. Learners should learn which information is essential and expedient and how it should be presented, in order for other people who are not aware of the topic or are not experts in the field to understand well. Furthermore, learners should learn how to create an effective structure and appealing design. Next to learning facts and concepts, presentation can be used in *project-based learning* for demonstration of the project plan, status in the middle of the project and final project presentation. The evaluation of this learning activity can be carried out simultaneously. As described above, presentation helps not only to learn foundation knowledge, but also has an impact on the application, integration and human dimension of Fink's six kinds of learning [Fin13].

### Learning Activities during Practical Introduction

The practical introduction includes labs, tutorials or exercises on a specific tool or demonstrations for the usage of a hardware equipment (also called deployment environment). In both use cases, if the learners are going to use immersive learning applications or work on a project, there are specific tools for which an introduction is necessary. A practical introduction can save learners time and frustration so that they can be more productive and more engaged with their tasks. In order to choose the most appropriate learning activities for the practical introduction, some questions are provided in the Tab. 4.7 below.

An explicit introduction of a software tool is not necessary if it meets the following conditions:

- The software has a very intuitive user interface,
- the software has a small number of functions,
- the learners will use a small amount of functions,
- the software has a good and easy-to-understand documentation,
- the software has a good community

✓	Which software tools are going to be used?
✓	How intensively will a software tool be used?
✓	Which level of proficiency is necessary to achieve the learning goals?
✓	How many participants have already some experience and which level of experience with the software tool?
✓	Are there enough computers, installations and licences available for all learners?
✓	Which learning activities and methods exist for acquiring skills in applying a software tool?
✓	Which educators have the expertise in the software tools to execute the teaching activities?
✓	Are the teaching activities mandatory for all learners? (i.e. under the condition that some learners are already skilled at this software tool)
✓	Is there proper tool documentation and other resources (e.g. video tutorials) that should be applied for further autonomous work?

Tab. 4.7: Guiding questions for design of the learning activities during the practical introduction

In the case, that no practical introduction is going to be provided, the learners have the opportunity to experience autonomously or in groups the needed functions. It is advisable to check if some learners have previous experience on specific tools. They can often teach their peers how to use them during the course (peer-to-peer learning).

### Teaching Authoring of Immersive Applications

The teaching of authoring immersive applications uses selected methods of the problem-based learning as instructional strategies 2.1.2. The learning objectives that can be achieved during an authentic and meaningful project for development of an immersive application are:

- Development of deep content knowledge (in STEM or other fields),
- critical thinking and usage higher-order thinking skills,
- creativity,
- problem solving,
- collaboration and teamwork,
- communication skills.

During the design process, instruction designers should consider several questions on how to manage the project work phase. In section *Problem-based learning* 2.1.2 on page 17 *eight instructional principles* for problem-based learning are presented, the application of which should contribute to the successful design. Educators should plan the learning activities according to the project and learning goals. Furthermore, they should build the learners' groups and define further subgroups and their specific tasks. The following questions should guide course designers in the specification of the learning activities (see Tab. 4.8).

✓	Which (STEM) topics and tasks will help to achieve the learning goals?
✓	Can the specified tasks be fulfilled by the learners in the given time constraints? (balance between scope and time)
✓	How much effort is needed, and is it adequate?
✓	How to build the learning groups in order to have a good balance between the participants' learning interests and available competences?
✓	How to build the groups and assign the tasks?
✓	How should the tasks be presented to the learners, to insure that the learners can estimate the effort)?
✓	How precise the tasks should be defined (in order to provide space for creativity)

Tab. 4.8: Guiding questions for the design of the PBL activities

Some answers and recommendations for this questions are provided in the sections *Preparations for Project-Based Learning* 4.1.3 and *Teaching Authoring of Immersive Applications with Project-Based Learning* 4.1.4. A detailed workflow for development of immersive environments as well as the necessary resources are presented in section *Technology Layer* 4.2 on page 105 and should support instructional designers in defining the technical goals and pursued skills.

### Teaching with Immersive Learning Environments

The learning activities in immersive learning applications vary depending on the learning goals and the learning approach that educators have decided to follow. The type of knowledge and skill that should be learned determine whether exploratory, experiential or training worlds are going to be integrated in the educational program.

There are some learning activities which can be performed entirely in a virtual reality environment, but most trainings *alternate* between *traditional teaching activities and teaching in immersive environments*. Especially, procedural and physio-motor skills should provide both real and virtual worlds training to prevent a false sense of security and the habituation in case

the virtual environment can not provide high fidelity. Alternating between real and virtual training should ensure a better transfer of knowledge and skills.

The immersive learning applications allow to use almost *all kinds of learning theories* like behaviourism, cognitivism, constructivism or pedagogical approaches like situational learning, game-based learning, and inquiry-based learning and many others. Kerres describes how the learning theories can be implemented generically in learning software [KP12], which also applies to the immersive learning environments.

### ***Behaviourism***

For the technical implementation of the behaviourism theory in learning software, the learning material is first broken down into *small units* (also called learning nuggets) and presented to the learner *step by step*. The system *immediately checks* if the answers given are right and *praises* the student [KP12]. Usually, there are *no punishments* in the immersive environments, because there are no real adverse effects or consequences.

### ***Cognitivism***

It looks different when applying cognitivism in learning software. Here, the software gives *learners' assistance*, if it is necessary, while confronting them with specific problems. Skills in *solving complex problems* can be trained. There is not only a single answer possible, but there exist rules, where different procedures or learning paths are possible. The system controls the learning behaviour, and *adapts the learning material* to the learner's progress and level of knowledge background [KP12].

### ***Constructivism***

The implementation of the constructivist approach include features that enable *collaborative learning activities*. Those activities should help learners to organise and reflect on their learning process. The software should support learners in applying knowledge in action, where they can uncover problem situations and *develop solutions* [KP12]. Virtual reality applications, based on the constructivism approach, enable the learning by doing and putting the *knowledge into practice*.

### *Applying Bloom's domains*

Immersive learning environments support almost all domains of *Bloom's taxonomy* and their levels [Elv16, BF97]. The most obvious are the cognitive and psychomotor domains. The exploratory and experiential virtual learning applications can be associated with the *cognitive domain* and the training virtual worlds with the *psychomotor domain*. Using collaborative environments and communicating with virtual agents or other learners can cover the *affective domain* (see also 4.2.1).

### **Learners' Assessment**

In *parallel* to the selection of learning activities, the methods for *learning assessments* should be determined. Each learning activity based on its goal and effectiveness has different methods and parameters to be evaluated and transformed into a grade. More about learners assessment and evaluation, see section 4.1.5.

During the instruction design phase, designers can get some early feedback (before the delivery of the educational unit) from the target group and colleagues. The results of this evaluation can be recommendations for optimisation or a revision of the instruction design.

### **Educational Resources**

This section outlines all resources needed for a learning module from a didactical perspective. The problem is that it is not possible to differentiate the resources based on the three presented aspects instructional, technological and economical because all three are strongly connected. Despite of this fact, the details for each technological or business-related resource will be described in their dedicated chapters (see *Technology Layer 4.2* on 105 and *Management Layer 4.3* on page 161).

An essential step in the process of course design is the analysis of the necessary and available resources. Often, using new technology in class requires the purchase of new equipment, further training of the educators or more time for course preparation. In the following paragraphs, we categorise four primary resources: facility, human, time and financial resources. The available human and facility resources, the curriculum contents and the time frame are firmly interconnected, and instructional designers should consider them together. That is why this step is iterative and performed all over again.

## Facilities - Physical Space and Equipment

The facilities are further divided into two categories physical places and equipment for learning. With learning places is meant the physical space where *students and educators meet*—for instance, a building with classrooms, laboratories or other necessary places. Currently, there are many courses which are executed online, and there is no physical place needed for the meetings. Other courses, for instance validation use cases, require many places like computer laboratory, immersive or virtual reality lab, or a lecture room. In an organisational context, the physical places should be booked in advance for the course, so one main task for the educator is to be sure that all laboratories and their equipment (projector, computer and others.) are available. This task should be accomplished as early as possible in the design or preparation phase.

The *classroom size and occupation* can be a limitation for the number of trainees and duration of the course. It should be considered how and when the trainees can access the facility, i.e. if they need the *infrastructure for autonomous project work*, homework or research and the access rights should be managed. In the Tab. 4.9 are some guiding questions on the organisation of the facilities and meeting rooms.

✓	Where should the meeting or training take place?
✓	Are there more than one physical place necessary at a given time?
✓	Are there different kinds of places necessary for different learning activities?
✓	Are the necessary places available at the desired time?
✓	What is the capacity of the places and can they accommodate the desired number of the students?
✓	Which other conditions do exist, i.e. facility access rights, keys or others?

Tab. 4.9: Guidelines for the organisation of the necessary facilities

## Equipment

Modern teaching requires in most of the cases, the usage of many *IT resources*. Especially using immersive technologies for teaching and learning often needs *high-end equipment* such as computer pools with powerful *graphic workstations*, *software tools* and *immersive hardware setups*.

The IT resources in this methodology are further classified into *two main categories*. The *non-immersive* IT resources are those who are not directly connected to the immersive technologies. The hardware and software needed to build and learn with immersive environments are in the category *immersive* IT resources.

The *non-immersive IT resources* contain the infrastructure in a lecture room like projector and computer for presentations, computer pools, as well as software tools needed for course administration, student management (e.g. *Moodle*, *ILIAS*), for creation of the learning materials and software tools for project and code management.

The *immersive IT resources* are more sophisticated and include the immersive hardware, the software tools for building virtual worlds and for support of the hardware (see section *Immersive Technologies 2.2* on page 20 and *Design of Immersive Applications 4.2.2*) on page 4.2.2.

### Time Constraints

The *time constraints* can depend on the target group or *resource availability*. If the time frame is not externally fixed, the decision on time slot and duration can be fixed based on the necessary time to achieve the learning goals. Finding a free time slot in the calendar of a seminar room, computer pool or laboratory can also be challenging in some organisations and some limiting time constraints may exist for the course.

Another time constraint is connected to the planning and *preparation of the learning materials*, the evaluation sheets and other activities in the preparation phase. Additionally, the time needed for the design (collecting requirements, determination of assignments and assets) and *implementation of the immersive learning application* is often underestimated. Usually, the developers are not experts in the educational context, and collecting the needed data like concrete task assignments with detailed description of the training process can take much time. The time parameters that should be kept in view are listed in Tab. 4.10 below.

✓	Which are the restrictions to the time and length of the course?
✓	What is the global time frame, start and finish date of the course?
✓	How often should educators and learners meet? Also online, in the virtual environment or in real (intensity of course units, i.e. once a week)
✓	Which duration should each unit have?
✓	How many hours should they spend on in-class and how many on out-of-class learning activities?
✓	How many hours of the total workload should be invested in the course or the learning activities to gain the aimed knowledge and skills and to get the certificate or credits in higher education context?
✓	Are all the other needed resources like educators and equipment available for the desired time slot?

Tab. 4.10: Guidelines for determining time constraints

## Human resources

Crucial questions are connected to the *human resources* and in particular, who is going to take which role or *roles* such as the instructional designers, the developer of the immersive software or the deliverer of instructions (guideline questions see in Tab. 4.11). Each role has an *immense effect on the teaching* content and results. Both the course difficulty level and the quality of the learning outcomes depend on the qualification of the team members.

✓	How many employees are available for the design and delivery of the educational program?
✓	What are their competences and classifications?
✓	How are the teams organised based on the identified roles? (i.e. Who will do the support and administration of all the IT infrastructure necessary for the course?)
✓	Which technical competences in the field of immersive technologies are available and which competences should be acquired?
✓	Are there external persons who have influence or control rights?

Tab. 4.11: Guidelines for identifying key personal and roles

The number of participants can also depend on the number of supervisors. There can be one or a team of supervisors for one educational program, where each of the supervisors is expert in a particular area. For instance, in a course, where authoring of immersive application should be taught, the supervisors should have expertise in VR software, 3D modelling, programming, VR hardware or mechatronics. When creating the course, it is essential to have experts in the area of didactics for developing the teaching and learning methods. Usually using new technology in class does not end with the purchase of the equipment, there is experience in its usage and maintenance needed. Educational organisations should ensure they hire suitable supervisors in due time.

## Financial resources

Financial resources are a *critical factor* for the realisation of the course. There can be a need of financial support for *hiring supervisors* or training the existing ones, for *IT infrastructure* and development of *immersive applications* or budget for any other costs and specific learning activities. The financial resources are discussed in *Management Layer 4.3* on page 161.

### 4.1.3 Preparation and Development

The development phase builds on both analyse and design phases and has the purpose of doing all necessary *administrative preparations*, as well as to generate the *learning and evaluation*

*materials* (see tasks on Fig. 4.9). In the case of using immersive technology as a novel medium, the immersive learning system should be provided or developed. The preparations can be done in a different order as well as in parallel by the responsible stakeholders.

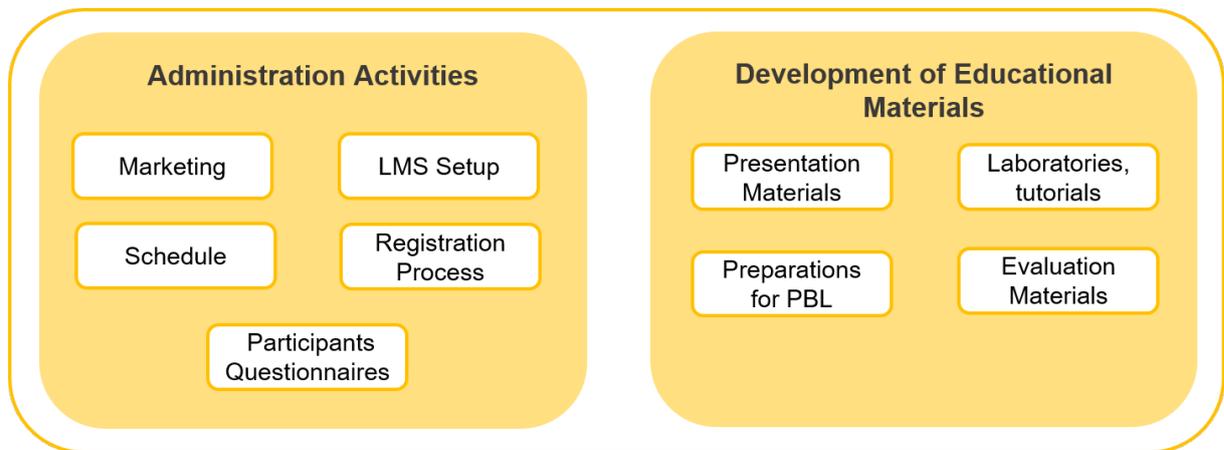


Fig. 4.9: Administration and development activities

### Administration Activities

There are some tasks like an administration that stay invisible for the others but are also essential and time-consuming. The course administration include the registration of the learners, managing the learner information, providing all information for each educational program in advance, caring out some grading tasks or examinations. Many preparation and follow-up administrative activities are accomplished with the help of the learning management system (LMS) like *Moodle* or *ILIAS*. The administrative course activities, which should be taken into account before the course starts are defined in Tab. 4.12.

✓	Select and set up a learning management system
✓	Create and update the marketing information for the upcoming course or training on the web site and or web-based learning management system
✓	Prepare the registration formalities and tools (i.e. number of participants)
✓	Prepare questionnaires and plan the time slots for preliminary talks, if provided
✓	Upload all relevant documents for the course like presentation slides, literature, documentation, examples, templates, task descriptions or others to the LMS
✓	Set all deadlines for the upload of the online tests or tasks in the learning management system

Tab. 4.12: Administrative activities

## **Registration**

The supervisor should prepare the registration for the course several weeks in advance. Among other things he should decide how many participants can take part, set the time for registration, describe all the prerequisites necessary as well as the acceptance criteria (i.e. first come first served or successful payment, if applicable).

## **Detailed Schedule**

A time plan should be provided to learners in order to enable them to combine the training with other activities like other courses or exams. The schedule should have all important milestones and events as well as elements like activity, dates, duration as well as where it should take place (room number or online). An example for milestones of PBL can be seen in Tab. 4.5 on page 78). In more prominent educational programs and settings, a curriculum with all educational modules and units should be provided.

## **Introductory Talks and Questionnaires**

During the registration process, it should be guaranteed that the supervisor has all relevant information about the learners and if necessary, some additional questionnaires or interviews can be conducted. This methodology prescribes the use of preliminary talks or a questionnaire to determine learners previous knowledge and skills, as well as their learning interests and expectations from the educational program.

Using individual introductory talks with each learner is a time-consuming process, but increases tremendously the teaching quality. Each learner should be invited to a fifteen-minute interview. If some previous questionnaires were conducted, this time can be reduced to 10 minutes. The goal of the interview is to give learners the chance to present themselves to the deliverer of instructions together with the knowledge and skills they gained until then, i.e. studies, internships, current job, as well as their learning interests and motivation for the upcoming course. Learners may use the time to ask questions on the learning outcomes and communicate their expectations or even fears to the supervisors (e.g. fear that they are not qualified for the course). The gathered information can then be used to build the learning groups, if a project-based learning approach is used. The same principle is used in the industry when a project manager sets up a team for a new project. He needs to be sure that the competences and the workload are well distributed in the team. Furthermore, this practice takes care of diversity and interdisciplinarity in a team.

## **Educational Materials**

Depending on the instructional design and planned activities, educators have to generate the learning materials. In this section, the preparation tasks of the educational resources are considered. Other preparation and development tasks concerning the development of the immersive learning systems and the other resources such as human, finance are discussed in the sections technology *Technology Layer 4.2* and management layer *Management Layer 4.3* respectively.

The proposed methodology uses several educational resources which are time-consuming in terms of preparation. This should be taken into consideration when creating a brand new educational program.

### **Presentation materials**

Those can be helpful as an introduction to the course organisation, some theoretical knowledge or other purposes. Slide shows or videos can be made available for preparation at home or presentation in class.

### **Materials for Practical Introduction**

A time-consuming task is the development of the laboratories, exercises or tutorials for the practical introduction. It includes the definition of the concrete learning goals like which tool is going to be taught. The practical introduction to a specific technology like programming language or tool also demands the provision of resources such as the software tools, the assets or source code of the solutions, as well as the accompanying documentation like scripts, presentations or videos.

### **Preparations for Project-Based Learning**

The definition of problem or topics for the PBL approach strongly depends on the learning goals, which are mainly to put the theoretical knowledge of the specific field of study (usually STEM field) into practice. The problem-based or project-based learning is very suitable for authoring immersive applications and solving engineering problems. During the project, a consistent virtual world should be created by the learners and deployed on an immersive hardware installation. The virtual world should have some useful purpose or solve a specific and authentic problem, which should care for more motivation and engagement of the project members.

This methodology differentiates three kinds of projects: non-sustainable also called one-time projects, projects with sustainable topics and sustainable projects.

- The topic and the tasks of *one-time projects* are conducted only once for a particular group of learners. The work on this topic is not continued or repeated by other learners during the next education period.
- The projects with *sustainable topic* have the same topic each time, but the project goals and subtopics differ sharply.
- The *sustainable projects* always have the same topic and goals, and it looks like the tasks are infinite. They can be carried out beyond one term or course but are more difficult and time-consuming to manage by the supervisors. The first team that works on such a project should usually make an excellent foundation for the next team. If the foundation is not useful or sufficient for further development, supervisors should decide to stop the project or to improve the results themselves, which is sometimes very time-consuming. The successor team should first understand the results, created by the former learners, which can be very difficult depending on their background.

Proper documentation of the project work and results is of high importance for the success of the sustainable project. Despite some difficulties, a sustainable project comes with many benefits for the learners. Given a broad topic, learners can choose the specific tasks and bear the responsibility for their choice. In this way, they can let their creativity unfold and work with enhanced motivation and engagement on the project. Which again brings better learning results.

### **Formative and summative evaluation materials**

Based on the learning activities, there can be different possibilities for *learners' assessment*. The assessment can be done after each task or at the end of a module. Evaluation activities can be oral or written examinations that provide the preparation of tasks, a catalogue with questions as well as a concept for grading. See also section *Evaluation and Optimisation 4.1.5* on page 101. During the preparation phase, educators should consider, which learning activities reflect which learning goals and to what extent, relatively to the whole course. On this base, they can create a *grading system* for the summative evaluation at the end of the instructions.

### **Learners' feedback**

Some *questionnaires* can be developed to assess the learners feedback regularly. The right categories and questions, as well as the evaluation concept, should be designed and provided to the learners. Learners can evaluate the educational program in many categories like management and structure, educators, facilities and equipment conditions, learners' motivation and satisfaction, quality of the provided teaching (i.e. content, media, accompanying documents, needed

efforts, achieved learning objectives). See also section *Evaluation and Optimisation* 4.1.5 on page 101.

## **Recognition**

It is beneficial if the educational program is recognised by other organisations or even accredited. The recognition shows that the course or training meets the *quality* requirements, and in the case of training that is delivered entirely in a virtual environment, it guarantees the *transfer of knowledge* in the real world. During the preparation phase, the quality assurance process for the *accreditation* can be conducted. Another task in this area is the design and preparation of the *certificates*.

### **4.1.4 Delivery of Instructions**

In the process of instruction design, what is meant by “implementing” is the process of installing the instruction in the real world context [Kur15a]. It refers to the actual delivery of the instruction to the learners after its design and preparation. In this methodology, the term “delivery” is used instead. The goal is to avoid misunderstandings and differentiate better between the implementation of a system or software and the delivery of a course.

In the delivery phase, the educational program is already designed, and all learning materials are prepared. The central cycle here consists of the task assignment and the task evaluation where the main aim is to support the learning process like learners’ understanding of the material and to ensure the transfer of knowledge. In despite of the many instruction types (such as classroom or lab-based, online or virtual reality-based), it should be ensured that the delivery of the instruction is effective and efficient. The delivery follows the educational program design and the elaborated schedule. In the following paragraph, we propose some recommendations for the delivery of teaching activities like authoring of VR applications and using immersive learning applications.

### **Teaching using Immersive Learning Application**

For the educators, the instruction delivery using immersive learning applications can vary strongly, depending on the implemented features. The educator’s tasks range from simply monitoring and *facilitating the learning process* to intensively supporting the learning process and providing the evaluation.

The minimum effort for the educators using immersive learning applications will be the *maintenance of the equipment* or platform (depending on whether organisation provides the immersive equipment or not) and the monitoring of the learning process. Furthermore, the educators should provide if necessary some theoretical introduction and explain learners how to use the immersive hardware and application.

If educators use different *off-the-shelf small virtual or augmented reality applications* with no educational features, they should provide support for the *learning context*, additional “offline” tasks and assess if the learning goal is achieved. Such applications can be exploratory virtual worlds or serious games. *Specialised immersive learning applications* usually provide *step-by-step instructions* for the learners, as well as some assessment and educators should provide a summative evaluation at the end of a course or training. The most current immersive learning applications can be put in this category. Such virtual worlds can be exploratory, experiential and training worlds as well as immersive serious games.

The *high-end immersive learning applications*, that require almost no actions from the educators, are complicated and usually have rich content, high interaction level, as well as integrated intelligent tutors. They usually can provide *individualised training* and *automated evaluation*. Such systems have *complex immersive system* with different sensors for a high level of interaction like user body tracking devices, speech recognition, virtual agents, collaboration possibilities and many other features.

Independently of the quality and content of the immersive learning applications, the educators can provide additional support to learners in areas of *higher-order cognitive skills*, which cannot possibly be acquired or trained in the virtual world.

## **Teaching Authoring of Immersive Applications with Project-Based Learning**

The usage of a *project-based approach* for learning through immersive technologies needs much more organisation and support from educators. Next to all administrative tasks during the preparation, many management tasks should be handled. This methodology provides further support in the areas of project task assignment at the beginning of the educational program, the project work phase itself and the delivery of the project results as described in the next paragraphs.

### **Project Tasks Assignment**

After the educators have fixed the topic, the concrete project tasks and sub-tasks should be defined and assigned to the learners. They should be developed according to the resources available, like the number and competences of the supervisors, the available software tool licences

and working places, the available immersive technology and others as analysed and designed in the previous phases.

Following rules are prescribed by this methodology to help building the groups in a project-based learning setup:

- The supervisor defines the project topics, the project teams structure and the sub-tasks in each group.
- The supervisor assigns the learners to a project group.
- The supervisor chooses a team member responsible for the project and technical management.
- If several projects topics are possible, the learners can rank them in order of preferences and the supervisor should take those preferences into account when building the groups.
- One project team should have about three to five team members.
- One project should have about two to four groups.
- When the supervisor assign learners to the groups, they should take into account the trainees' learning preferences, needs as well as their existing skills and knowledge.
- The supervisor should take care that the learner groups are mixed well according to their field of expertise, in order to have balanced multidisciplinary and intercultural teams.
- It should always be taken in consideration that priority has to be given to the learning process and not to the project results.

The previously proposed methods for accurate analysis of the target group help to assess the knowledge and skills the learners already have, their learning preferences and expectations. This analysis facilitates the building of the groups in order to achieve *harmonious teams* with *complementary skills* and offer the learners the possibility to learn from another (*peer-to-peer learning* and *learning-by-teaching effects*). It is imperative to arrange the tasks and the learners in a manner that they can learn the *desired skills* and can *fulfil their expectations*. Better engagement can be achieved when the learners rate the project topics (if applicable) and the learning matter according to their preferences before the task assignment. Our experience showed that it is better that supervisors assign the learners to the projects and project sub-teams, but let them assign themselves to the specific sub-tasks in the sub-teams. Learners usually need much more

time to assess what knowledge, competences and learning preferences the other team members have, and often they lack experience on the project topic, efforts in order to create subgroups and sub-tasks. This process, if done by the learners themselves, takes precious time from the project work itself and is sometimes error-prone and can lead not only to not achieving the learning goals, but also to conflicts in the groups.

It is essential to define who leads and has an influence on the project at the very beginning. Which aspects of the course are free to choose and which are to be coordinated with the supervisor. It is also advisable for supervisors to define a project manager and a technical leader. The *project manager* role is to monitor the progress and to manage the resources. He should ensure a good working climate and take care of conflict management. If the learners cannot solve the conflicts, they should communicate them to the supervisor. The *technical leader* tasks are at the operational level. He is responsible for taking care of the integration of the teams' results and ensuring that all features work after deployment on the immersive hardware. The following picture describes the *organisation and communication* ways between supervisors and learners. (see Fig. 4.10).

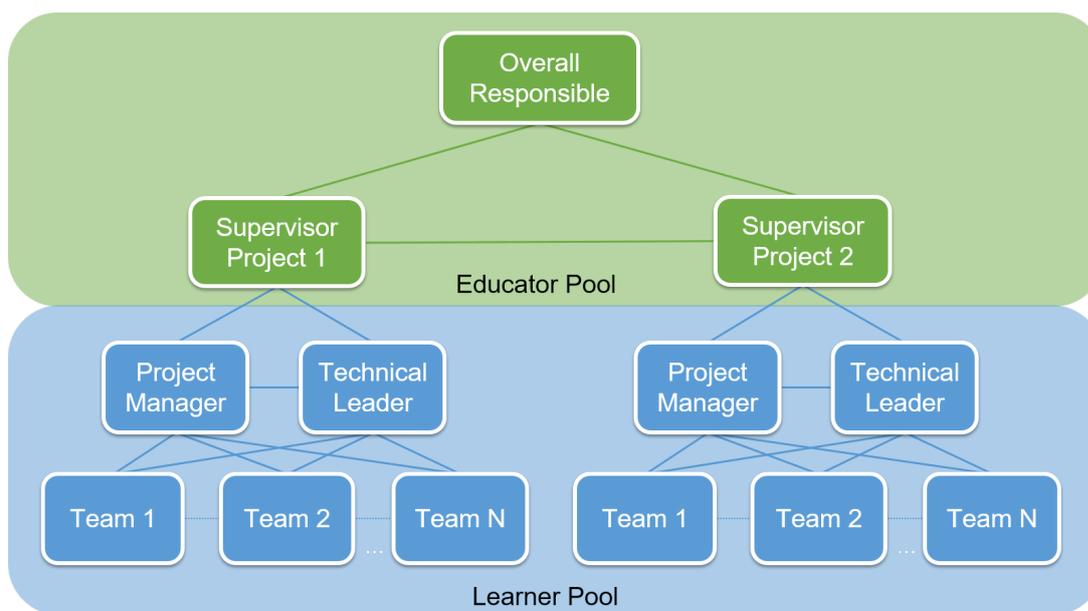


Fig. 4.10: Project organisation and communication between educators and learners

There can be an optional hierarchy layer of the *supervisors*, so that there is one superior supervisor for the whole educational program and an additional supervisor for each project or team. The supervisor in this learning setup has the *role of facilitator*, instead of a teacher. They should provide access to all needed resources at the beginning of the project and help if there are issues, that cannot be solved by the learners alone. In the case of software development issues, it is a good practice to define a period after which learners should demand help, if they can not solve a specific problem, like finding a bug or developing a specific function. This period depends on

the time learners have for the whole project or specific task. Often learners are very ambitious and want to solve their problems alone and sometimes spend days in searching unsuccessfully for a specific feature or bug. This leads to frustration and losing project time, especially if integration is planned soon and other team members are waiting for delivery from the others.

The *groups* should be carefully defined depending on the number of learners and the number of projects. For instance, a group should not exceed five members. If groups are too big, the load or effort per member can be distributed unevenly, and there is extensive communication effort in the group. If the group has less than three members, it does no longer complies to the definition of group. If a project exceeds four groups, the communication effort and time is enormous, so integrating the results in the final solution becomes a challenge. If a project has under ten members, it is recommended that the project manager should be a member of a project team and have additional tasks in it. If the project exceeds ten members, the management effort rises, and the project leader learner should take care only of project management tasks.

### **Project Work Phase**

The project work starts typically with a short discussion or brainstorming amongst the project participants about the goals, the task, first ideas and solution approaches. The learners work on the project autonomously and in groups. The sub-tasks in the groups are distributed to the team members. For the *project plan*, they need to think about the time they need to accomplish the tasks, to create small milestones, to propose first solution approaches, to plan a budget if necessary, as well as to define some group internal rules and communication tools. During the *presentation of the plan* at the beginning of the project work, the project should be validated by the supervisors. Supervisors should consider that the learners often underestimate the time for the development of the applications. Furthermore, they start with the deployment of the application on the specified immersive hardware too late. Such delays can lead to stress and bring some disappointment at the end of the educational program.

Most of the *project's work* is done in the computer pools and immersive laboratories and the supervisors should take care that the learners have all necessary working conditions. Supervisors should also set clear rules for the programming work and the use of the version control system.

Learners should have the possibility to *work independently* at home. For this purpose, they should install on their private computer the development environment or other software depending on the particular task. It should be made possible that some portable immersive devices and gadgets can be loaned to the learners.

Usually, the *work in the group* consists of regular meetings, where the current status of the task and the project are discussed. Some meetings can be held online. Some learners prefer to work in a team or tandems. *Teamwork* helps build synergies between multidisciplinary learners. They can learn from the more experienced peers.

The biggest issue making a *multidisciplinary* immersive technology-based educational program is the different background of the learners. Often most of them have no experience in programming, computer graphics paradigms or 3d modelling. This missing background makes it difficult to create a structured and properly documented codebase. Supervisors can provide code reviews to learners regularly in order to teach learners how to optimise their code and how to document it.

### **Delivery of the Project Results**

The *project report* is also one learning activity which should be delivered by learners at the end of the project or course. On the one hand, the learners should learn to describe the project results in a document, on the other hand the documentation should help the learners from the next generation to understand the results and continue the work on the project. The project work itself is pervasive, that is why educators should provide clear and *concrete requirements* as well as a *template* for the documentation, which can save time and frustration for the learners.

Next to the learning of creating and performing a presentation and demonstration of the project results, the learners have the task to create other *presentation materials* like flyers and posters. Here, as with the project documentation, some requirements that the learners should follow are beneficial. *Flyers* can be used as handouts during the final presentation of the project or later on demand. Additional benefits of the *printed materials* such as posters are that they can be hanged up in the labs and can be seen by other learners or visitors. It has proved to be very useful to show lab visitors results of previous projects which cannot currently be shown due to missing hardware or software support. The project evolvment and sustainability can be easily presented step-by-step with the help of posters, since the virtual reality environment software is the result of all steps.

The availability of a camera on each smartphone device, the advanced and intuitive tools for video editing, as well as video sharing platforms like Youtube, makes the creation of project videos accessible and desirable. The learners are motivated to share their results, and a *project video* can also be required as a project result.

## 4.1.5 Evaluation and Optimisation

### Evaluation of the Instructions

In the area of education, the evaluation process should determine if the instruction is adequate, effective and efficient. The evaluation can consist of several tasks such as the creation of a feedback survey, interpretation of test results, revision of the learning activities, measuring execution time of a task and many others. *Two different types* of evaluation can be distinguished: the formative and the summative evaluation. The *formative evaluation* should be continuous and be given between the design phases whereas the *summative evaluation* should take place after the delivery of instruction.

### Evaluation of Learners Performance

In the literature, there exist a differentiation between assessment *for* learning, assessment *of* learning and assessment *as* learning described in details below [Alb08]. The main goal of an assessment is to improve student learning and teaching effectiveness. The learners' assessment should be appropriate to the defined learning goals and skills to be gained.

#### Formative Assessment - Assessment for Learning

The formative assessment is an ongoing activity of the educators that provides a specific *feedback of students' performance* for a *specific period*, usually after a lesson or a whole day activity. This kind of *continuous evaluation* should provide evidence for the effectiveness of the instructional activities selected by the educators. At the same time, educators have the possibility to make some *corrective measurements* on time. Immersive learning applications can have a feature, which provides instant formative assessment.

The activities of *project-based learning* can be evaluated based on individual and collective criteria. The project work is one of the most critical components and should be weighted relatively to the other learning activities. Educators should define at the beginning of the course, which components are going to be graded and how. Some evaluation activities can be attendance, the kind of participation, homework (individual work outside of the classroom), presentations, examinations or written assignments.

### **Summative Assessment - Assessment of Learning**

The summative assessment is usually conducted *at the end* of a module or term and represents the learners performance at the current moment. It is used in order to report to others about the *current learners' achievements* and incorporate grading activities, usually presented in a formal report. Based on this kind of assessment, students can be *compared* to others. This assessment can also be used as the basis for further recognition (i.e. issuing a certificate).

### **Self-Reflection - Assessment as Learning**

The third kind of assessment used is the *self and peer-reflection*. When using this method, learners should estimate their learning performance (or that of their peers) and can look at their achievements from an educator's perspective. This kind of assessment improves learners' *metacognitive skills* inasmuch as they understand why they are learning something, how this learning is related to previous or future knowledge or skills and how to better plan their learning activities in the future. The methods for reflection can be in the form of free text or designed like a questionnaire. The educators can support learners providing *questions for self-assessment* like what were the initial motivation and expectations, what are the results of the learning process as well as what were the difficulties and problems that occurred while learning. As performance criteria for *peer-reflection*, questions on independent learning, increased competence, responsibility for results and quality, team competence and responsibility for co-operation can be required.

### **Instructional Performance Evaluation**

There is always a need for iterative optimisation in order to bring greater satisfaction of the learners. Good *feedback management* and the implementation of new ideas can help to achieve better results over time. That is why educators should plan an evaluation of the *effectiveness* of the course and their *teaching performance*.

There are different ways to get feedback; it can be in oral or written form; it can be anonymous or not; feedback forms can be filled online or during the course. The time when to get feedback is also significant. Often, the users are more satisfied at the first half of the course than at the end of it.

This methodology prescribes *two methods* for course evaluation: an oral and a written feedback. The feedback can be communicated at any time during or after the instruction. The *direct oral feedback* can only take place in an informal atmosphere where the students feel free to share their opinion, knowing that there will be no disadvantages for them. During the project work in

the laboratories or during some pauses, supervisors can also ask for some instant feedback. If some issues bother the learners, the supervisor can ask them for suggestions for improvement. The *written form* of feedback should use anonymous questionnaires. Two *questionnaires* can be conducted: one at midterm and one at end of term. The midterm feedback can help supervisors to get aware of some issues and try to take care of them until the end of the semester.

Different categories of questions that can be asked:

- Effectiveness of teaching methods and learning activities
- Effectiveness of course structure and organisation
- Learners motivation and learning success (achievement of learning goals)
- Educators and supervisors performance
- Provided resources, rooms or laboratory conditions

Educators can require feedback on the effectiveness of the used teaching methods and learning activities as well as on the course structure and organisation. It is essential to know if the learners were motivated and engaged with the educational experience. At the same time, it can be asked how they estimate the motivation of their peers. At the end, questions about the learning success and the acquired skills can be requested. Further feedback criteria can be how the supervisors and tutors are perceived, were they also motivated and engaged and were they able to answer all their questions. It is critical to know if the provided facilities and infrastructure were sufficient, well available and if the working conditions were right, in order to improve the educational unit. The questions should be carefully planned, as well as the evaluation of the questionnaire. Likert scale with five answers between 1 and 5 is recommended. Space for comments, praise, criticism or suggestions for improvement should also be provided. In summary, for the evaluation of the entire learning process, it is vital to get feedback on what should be kept, what can be left out and what should be optimised.

## Summary

The educational layer deals as a foundation for this methodology and comprise all facets of the *instructional design process*. The steps of this process should guide stakeholders in designing a course that uses the most efficient and *state-of-the-art* didactic methods and learning tools.

The instructional design process starts with the analysis or re-analysis of the target group and the current state. The design step encompasses all related aspects and has the goal to create the first

draft of the overall didactical concept. This concept includes the learning goals, the teaching strategies, the learning activities with their evaluation as well as the structure and all needed educational resources. When the design is ready, and a positive decision for the implementation of the educational unit is taken, follows the development of all educational materials. In this way, the deployment of the course can start, and learners can enjoy the learning process. Every educational program finishes with an assessment of the learning progress and grading of the students. Furthermore, learners can provide feedback for evaluation and further optimisation of the educational program.

The educational layer can cover many *different kinds* of educational objectives. One goal can be the *teaching of authoring of immersive applications* in order to enable learners to acquire theoretical and practical knowledge in virtual and augmented reality. Another goal can be the *teaching of STEM skills* such as an engineering topic, programming or solving engineering problems based on the development of immersive applications. A virtual reality project can also be applied to teach *soft skills* like collaboration, communication, management, teamwork and others. Another teaching goal that the didactic methodology covers is the learning of a specific knowledge or physical skills through *immersion and interaction* in a virtual world.

## 4.2 Technology Layer

The excellent understanding of technology is the key to its successful adoption in education. Instructional designers and educators should not only understand what an immersive technology is, but also what are the particular characteristics that lead to the specific improvements in the learning outcomes.

This section provides all technical aspects of the methodology (see Fig. 4.11). Its first part presents a classification of the advantages and disadvantages of immersive technologies in education. Each benefit category is assigned to the technological features, which support it. Additionally, some examples serve for better understanding of how the benefits manifest themselves.

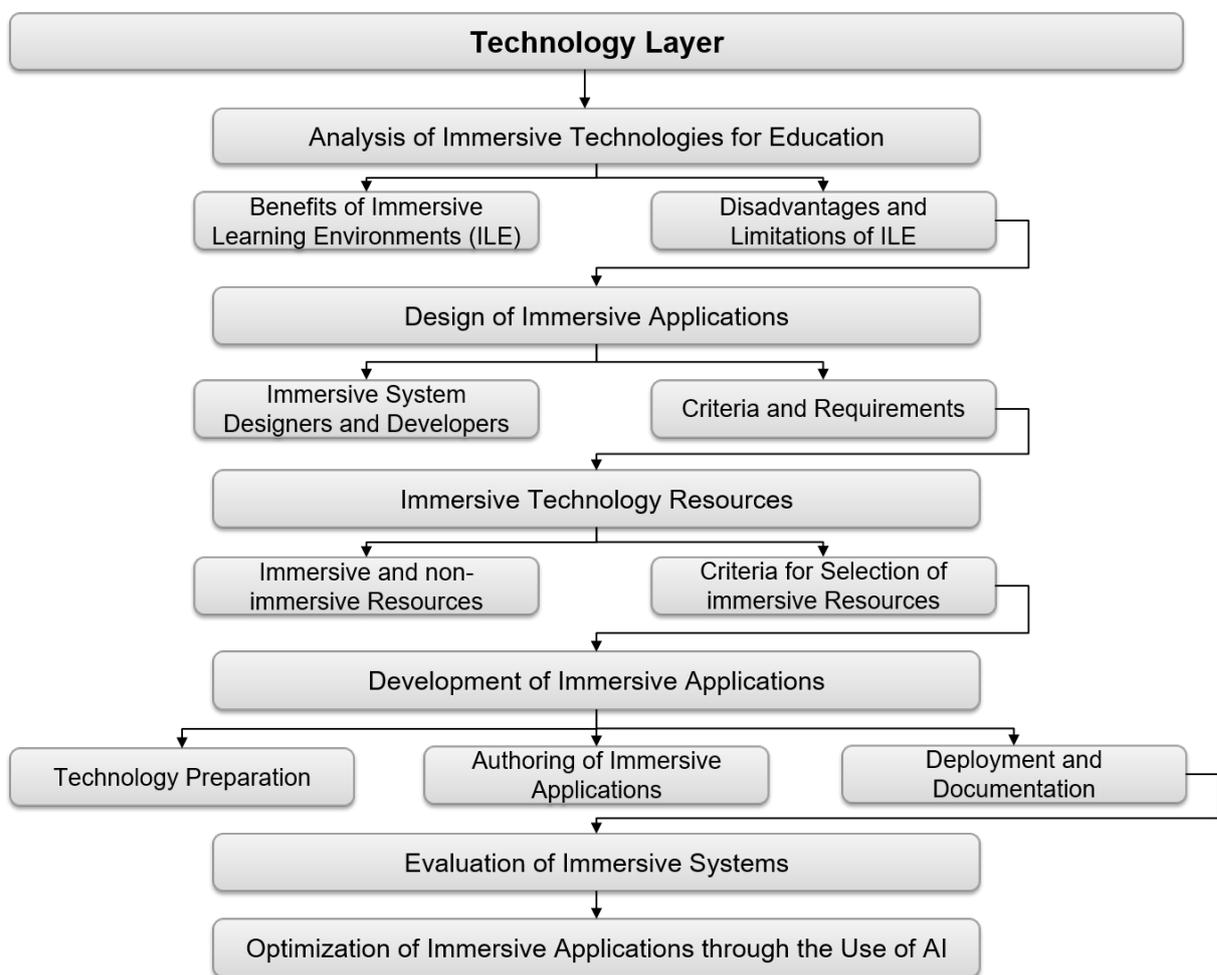


Fig. 4.11: Structure of the “Technology Layer” subsection

Further, in the section, a list with requirements and criteria for the design of immersive learning environments are presented in order to support the analysis and design phase. This methodology

distinguishes between two categories of technology resources used in the education and divide them in immersive and non-immersive technology.

Furthermore, the methodology describes significant technical aspects of the development process, which educators should consider when teaching authoring of virtual reality applications or plan the implementation of immersive learning environment. The highlight of the methodology is the novel method for authoring intelligent immersive systems that use approaches from the domain of knowledge engineering.

### **4.2.1 Analysis of Immersive Technologies for Education**

Adopting virtual reality for teaching and learning purposes implies *numerous benefits* and of course, some *downsides*. Each specific course or training has its own needs, requirements and problems to solve. This section will guide instructional designers and educators to answer the question, if virtual reality can help solve the current instructional problems and meet the analysed needs. For this purpose, an *extensive categorisation* of the benefits and downsides of immersive technologies was created. Each benefit category is assigned to the technological features, which support it. Additionally, some examples serve for better understanding of how the benefits manifest themselves.

For the implementation of the presented methodology, it is of great importance to have a deep understanding of the immersive technologies nature as well as their advantages and disadvantages for learning. In the chapters “Theoretical Background” and “State of the Art”, the characteristics as well as the hardware and software principles of those technologies, as well as some examples, are described in detail (see 2.2 on page 20 and 3.1 on page 35), which should guide the reader well despite future technology developments.

#### **Benefits of Immersive Learning Environments**

Due to the advantages it offers, immersive applications are already deployed in fields such as medicine, automotive, aerospace industries and entertainment. In the area of education, many studies have been conducted, and numerous applications were developed. Their goal was to prove the *effectiveness* of virtual reality in *enhancing the outcome* of education. Nevertheless, not all benefits of immersive learning environments over traditional educational environments have been explored thus far. Concerning the design of effective ILE, it is essential to know, which features of virtual reality (VR) support the cognitive process of learning. In the Tab. 4.13, all categories and subcategories of benefits, as well as the characteristics of the immersive learning environments that influence the benefits, are listed.

Main Benefit	Benefit Subcategory	Characteristics of the Immersive Learning System
Enhancing Learning Outcomes	Better remembering and understanding of concepts and processes	Visual-spatial representation, spatial abilities through abstract concepts, non-visible or hidden objects, inaccessible or non-existent environments, new perspectives, macro and microscopic views, multimodality: Visio-spatial, audio-spatial representation and haptic feedback, interactivity
	Enhancing motor-coordination and physical skills	Interactive environments and simulations, touch and force feedback
Increasing Motivation and concentration	Motivation and engagement	Novelty of the technology medium, active participation through interaction, managing of complexity, embedded gamification elements
	Focus and concentration	Immersion, exclusion of the real world
Fostering Soft Skills	Communication, discussion	Human-human physical or remote interaction, simulation of situations, virtual agents
	Collaboration, peer learning, improved group dynamics	
	Problem-solving, decision making, teamwork, management, leadership competencies	
	Fostering foreign language skills	Virtual characters/agents, multimodality, simulation of situations
Safety and Health Protection	Human safety: Fewer to no accidents and injuries	Virtual (not real) environment and risk
	Environmental safety: Less contamination and pollution	Virtual materials, consumables or chemicals
Saving Time and Costs	Time savings	Skipping waiting and time-consuming processes
	Costs savings	Virtual (not real) environment, cheaper to make changes or errors in the virtual environment, repeatability
Adaptating to Individual and Special Needs	Personalized learning	Supports different learning styles through multimodality, repetition, self-paced learning, intelligent tutoring
	Special educational needs	Immersion, interaction, multimodality
Facilitating Teaching	Automated Learners Evaluation	Systems for advanced user tracking, intelligent tutoring systems
	Easy changes of the training environment	Systems for customization of virtual world and tasks
	Saving time and efforts	Only software changes, fast reset of training, no repetition by the educator
	Usage of various pedagogical approaches	Virtual copy of real world teaching situations

Tab. 4.13: Categorisation of the benefits of Immersive Learning Systems (ILS) adapted by [Häf20]

## Enhancing Learning Outcomes

Many aspects of an immersive learning environment contribute to a *better understanding* of the learning material. The learning outcomes can be identified as the qualitative and quantitative improvements in the behaviour, skills and knowledge before and after a learning session. They are often compared with the traditional learning process and outcomes. However, there exist cases where using VR is the only way to provide a specific knowledge or skills.

Numerous studies on the learning performance of virtual or augmented reality environments were implemented and had different learning goals, budgets, fidelity and quality. Most of them witness *positive effects* on learning and discuss the issues and downsides of the used technology. One should have in mind that the learning outcomes in immersive environments depend strongly on the quality of the realised project. Concretely, it depends on the right incorporation of the instructional goals and learning activities in the immersive learning environment as well as the quality of the realisation of this environment, in particular the constructive selection of the hardware setup and the implementation of the software application. The provided level of immersion and interaction is of great importance for achieving some learning goals. The higher the immersion, the greater the *bandwidth of information* presented to the user, which can have an impact on the learning process.

In the following, we describe the benefits for the learning outcomes. We start with simple, immersive learning environments, which means basic virtual worlds with reduced immersion and interaction. We will continue to describe further benefits based on more advanced virtual reality setups using sophisticated interaction, simulations as those needed for a high fidelity flight simulator. The goal is to guide instructional designers to plan better the technical features of an ILE in order to achieve maximal learning outcomes and optimal budget.

### **Better Remembering and Understanding of Concepts and Processes through:**

#### ***Visual-spatial Representation***

As described in the theoretical part (see *Immersion 2.2.2* on page 23), immersion is a feature of the hardware system, that tries to stimulate the human senses like sight, hearing and touch. Humans usually perceive 70% of the information from their environment through the eyes; that is why the simulation of *stereoscopic view* and the *visualisation of concepts and processes* contributes mostly to the learning process. Additionally, the position tracking of the user allows him to move freely around an object and to view it from different sides. For instance, to get down on the knees and look at an object from below. This *intuitiveness* of the interaction is a characteristic of both the real and virtual world, but not possible on desktop computers or other non-immersive systems. Depending on requirements, facts can be presented very realistically as

well as abstractly or simplified. Furthermore, by *highlighting* important information or *slowing down* a process in an immersive environment, it ensures the understanding by everyone [Man01, GWW06].

### ***Spacial Abilities and Abstract Concepts***

Virtual reality supports not only the virtual representation of existing objects and environments, but also *abstract, fictive concepts* and such concepts that are *non-visible* and people cannot observe with the naked eye. Abstract and theoretical information is usually more difficult to imagine, such as the structure of a molecule as well as the process or a chemical reaction [Pan10].

The interactive, virtual-spacial learning enables users to take advantage of the graphical representation of the information. In many cases, new knowledge can be conveyed simply by a suitable representation of real or fictive, visible or non-visible objects [Lut05]. According to Dede et al., among other immersive technologies, virtual reality has a great potential as a tool for supporting the learning process, and for explaining tangible and abstract concepts [DSLA00]. Virtual reality can provide a *tangible representation* of abstract concepts, such as a mathematical surface that students can walk on, or a world where “efficiency” takes on physical properties [BF95].

The main objective of geometry education is to improve the *spacial abilities*, which includes components like spatial perception, spatial visualisation, mental rotations, spatial relations and spatial orientation [Mai96]. The immersive environments can facilitate this task with the aid of vision-spatial representation and interaction. One example is the three-dimensional geometric construction tool called “Construct3D” which uses the collaborative augmented reality system “Studierstube”. It works with a stereoscopic head-mounted display and a two-handed 3D interaction tool [KSW00]. The application target group was for mathematics and geometry classes at the latter grades of secondary school and university. It should encourage the experimentation with geometric constructions and facilitate the learning with the aid of stereoscopy. The results of the project show that using this kind of immersive learning environment is a more effective learning tool than the traditional CAD package [KSW00].

An excellent example for teaching abstract concepts is Virtual Water ILE for science, physics and chemistry developed for students in the final year of secondary education and first year of university [TFA02]. The accompanying study indicates that 3D virtual environments may help students with *high spatial aptitude* to acquire a better conceptual understanding of the subject matter. The main advantages, according to Trindade et al., are the ability to visualise situations which cannot be seen otherwise and to immerse the students within these situations [TFA02]. Students reported that the stereoscopic view gave them a more *tangible grasp* of solid state

structures such as that of ice. Another example for educational application for learning abstract concepts is the “Virtual Reality Physics Lab” that allows students to understand concepts such as force, acceleration, velocity, position and others in a playful manner [MLB<sup>+</sup>19]. In such applications, students can both observe physical phenomena at *macroscopic and microscopic levels* or can *control the time*.

### ***Non-visible or Hidden Objects***

Through virtual reality, there are possibilities to illustrate better the learning matter, through visualisation of *hidden and difficult to see* components and processes [Pan96, Man01]. Details that are not visible from a specific perspective to the naked eye can be pointed out by easily *disassembling* a device or *zooming in* on this special information [TFA02]. With augmented reality, representations of non-visible phenomena can be linked to real objects, and thus new insights can be achieved. For instance, parameters like electrical current flow or gas pressure can be faded in, in order to improve the understanding of the learning matters [Bro13]. An example for teaching non-visible concepts are present by Blum, who uses a very innovative and attractive approach for teaching anatomy using an augmented reality magic mirror [BKBN12]. The system uses a depth camera to track the pose of a user standing in front of a large display. A volume visualisation of a CT dataset is augmented onto the user, creating the illusion that the user can look into his body. Users can select different slices from the CT and a photographic data set for visualisation using gestures. Besides, the system can show 3D models of organs, text information and images about anatomy. The visibility of hands and body is modified based on the distance to a virtual interaction plane. Thus, the user can understand the *spatial relations* between his body and the virtual interaction plane.

### ***Different Perspectives, Macroscopic and Microscopic Views***

A benefit of virtual reality compared to traditional methods is that it enables observation of system features that would be either too small or too large to be seen on a standard scale system [Min15]. Once a virtual world is designed, it is easy to change the camera perspective (and thus, the users’ perspective) and set virtual learning waypoints depending on the learning goal. Students can perceive the world from the perspective of an animal, be a small bee or a big Godzilla. Immersive technology supports the learners in observing how a system is operated from *different perspectives* [Min15]. Learners can better understand some learning matters like physic laws, where taking the perspective of a falling object can be beneficial.

### ***Inaccessible or Non-existent Environments***

Virtual reality makes it possible to explore environments that are *not accessible* for everyone like process engineering plants, a wind power station or an oil rig. Virtual learning environments are beneficial everywhere, where students can not feasibly gain real-world first-hand experience, like walking on the Mars, travelling through the Solar System, or visit a space shuttle. Developers can easily represent *non-existent environments* like fictive futuristic worlds and unleashes the learners imagination. Virtual simulations of *past worlds* and civilisations can contribute a lot to the history education [Zha19].

### ***Multimodality***

Next to the realistic and three dimensional visualisation, the immersive technologies offer other possibilities to reach the *human senses* like spacial sound and haptic feedback. Sounds are essential for a realistic learning experience and should always be combined with the visual effects such as the sound of a chemical reaction or a specific machine. Whereas the smell and taste senses are simulated very rarely, the senses of touch and force are crucial for some training activities and motor physical learning (see paragraph “Touch and Force Feedback” below).

### ***Interactivity***

According to Confucius the *learning by doing* has a significant impact on comprehension as he states in his famous quote “I hear, and I forget. I see, and I remember. I do, and I understand.” Learners can get realistic experience with the learning matter by interacting in immersive virtual environments, which should have many learning outcomes. Interactivity encourages *active participation* and enables *exploratory learning*. Through the immersive representation of virtual worlds and the interaction with it, learners feel part of the learning world and the experiences made are consequently much *more intense* than with two-dimensional media. Furthermore, the films or other media are linear and can not provide the interaction level that immersive learning environment can. Different *interaction levels* can be provided based on the learning objectives. Exploratory worlds implement low-level interaction, where the users navigate through the scene and observe the virtual objects. Higher interaction levels include the manipulation of objects or processes as well as the feeling of touch while grasping a virtual object. Learning applications with advanced interaction can include complex simulations and haptic feedback, where they can teach not only action-reaction principles and the relationship between cause and effect, but also motor coordination and physical skills can be trained.

## **Enhancement of motor coordination and related physical skills through:**

### ***Touch and Force Feedback***

Haptic devices and setups can provide tactical and force feedback to the training. Haptic devices are actively used in medical training, where higher levels of *precision* and *procedural skills* are necessary [PPM<sup>+</sup>14]. Sophisticated simulators like flight, drive or skydive simulators try to simulate the real forces like acceleration, centrifugal, centripetal forces in order to get near to the reality and transfer the skills learned in the virtual environment into a real situation. Interaction with the virtual environment can also be built based on the real-world interaction which provides specific haptic elements. For instance, a virtual reality painting training with a spray-can incorporates a spray-can-like device, where users have the same interface to dose the paint.

### ***Dynamic Environments and Simulations***

Sometimes representation of static objects is not enough for achieving the desired learning outcomes. Animations or simulations can be implemented in an immersive environment to understand some *causal effects*. The learners can observe and grasp *dynamic behaviour* and interconnections between objects or processes, like in many of the learning applications with physics subject matter [JV13]. It is necessary to implement a driving or flying simulation in order to provide an environment for realistic training.

## **Increasing Motivation and Engagement**

There are several effects of immersive technologies on the motivation and engagement of students. For instance, the *thrill* of new technology can enhance the motivation of the learner [HHO14]. It arouses the learners *curiosity* who want to try it out, and the likelihood that they stay focused is higher. New gadgets, which are not part of everyday life, makes the new learning medium *exotic* and more *attractive*. However, the appeal of the new technology can sink over time, depending on its future dissemination. Psotka states that “the motivation and mindful engagement that comes from this [the usage of virtual learning] environment stems not only from the novelty but from the challenge, interactivity, realism, fantasy, cooperation, and immersion that are natural extensions to the benefits of games and simulations” [Pso95].

Good example for motivation based on new technology and playful concepts is the MINT-BOX Project described in the validation chapter, in section *Virtual Reality for Teaching STEM in Secondary Education* 5.3 on page 256. The students have to solve a programming task based on a STEM subject issue and then test the result in a virtual reality driving simulator. On the

one hand, students were motivated to do their tasks in order to use the driving simulator. On the other hand, since there was only one simulator for all students in the class, this created competition between the students (who will finish first).

According to the results of the Franco-German research project EVEIL-3D, which goal was learning of foreign language in a virtual reality setup, "the immersion intensifies the feeling of presence which in turn heightens motivation and has a positive impact on the learning process" [BRS13]. Thanks to the high level of immersion and interactivity of a virtual reality environment, it makes learning more active and engaging [HHO14]. The motivation of trainees increases through their *autonomous action* and *self-directed learning* [BRS13].

Engagement is an essential factor for every learning process. Educators can observe and measure it only during the VR session. Researchers can observe increased engagement during numerous experiments and often reported about its positive effect, partly independent from the application area. Numerous studies prove that virtual reality motivates students as it requires interaction and encourages *active participation* rather than passivity [Pan10].

Another factor playing a role for engagement is the *managing of complexity*. A virtual environment can represent complex data in a way that becomes more *interesting and simple* [Min15].

Additionally, the combination of the immersive technology with a *playful component* in the form of a serious game proves to be an incentive and a motivation factor for learning and can intensify the effect on engagement. Once the learners are motivated to test the technology, further embedded features like *gamification elements* can contribute to their engagement to longer learning phases and more joy in the learning process. Some gamification elements are the narration, the quest design or role models as well as other game-based principles like badges, points and progress bars. Educators can utilise those game-based principles to provide experiences of technology self-efficacy, and create motivational incentives for prolonged engagement. Virtual reality training can explore a variety of *playful interaction styles* that engage the users in the process of *playful discovery* and allow them to want to learn more. Playful features can support a functional purpose as well as making the system easy to use and more *intrinsically rewarding*. For instance, the EVEIL-3D project also used gamification elements. The feeling of presence and the motivation to solve the quest induced students to speak freely in a foreign language to the virtual character. They were students who had never spoken in class.

### **Increased Focus and Concentration**

Another factors that improves the understanding is the focussing and concentration on the learning matter. Immersion in the VR experience is determined as a key element in the cognitive

variables associated with the processes of learning. It seems to be facilitated by the *ability to control attention* and focus in the new VR to the *exclusion of the real world* [Pso95].

## **Fostering Communication and Collaboration Skills**

Immersive environments have the potential to improve communication, collaboration and soft skills. There are different ways to achieve this regarding the learning goals, technology setup and implemented features.

### ***Collaborative environments***

One use case is the usage of powerwall or CAVE setups, where a group of learners with or without the educator can observe, *interact and discuss* the projected virtual environment. Learner can collaborate physically in a team, in order to *solve a specific task* in the ILE like *discover mistakes*, solve a problem or *make decisions* together. Furthermore, collaboration between CAVE and VR headset can also be efficient [PC17].

Another scenario is the remote collaboration where the users communicate with peers from distant locations. Here VR or AR headset setup can also be applied analogue to multi-user computer games. The networked virtual environment emulates the kind of collaboration, that is usual for the real world and can benefit the collaborative and active learning [Che10]. The MIT Media Lab presents a recent example of a collaborative environment called Electrostatic Playground, where learners can explore and discover principles of electrostatics through experimentation [GCM<sup>+</sup>19].

Communicating in immersive learning environments enable collaborative, also *peer learning* and contribute to improved *group dynamics*. Concrete *soft skills* that are possible to learn and train are, for example, teamwork, problem-solving, decision making, management, leadership competencies and others.

### ***Foreign Language***

Immersive environments can also provide a good communication platform for learning a foreign language, especially between students from different countries and cultures. Additionally, they support capabilities like listening and speaking using *virtual characters* [BRS13].

In the context of communication, the use of VR can overcome *language barriers* [Pan95]. If trainees do not understand the information verbally, an immersive environment can visualise it. Additionally, the learning environment can utilise automatic real-time translation algorithms.

---

## Safety

### Human Health and Safety

In a virtual reality learning environment, learners can train *dangerous* tasks or scenarios in advance *without the pressure* or the danger of the real environment [Pan96]. As the learners gain a better understanding of the learning matters and are *warned* by the VR system against potential risks, accidents and injuries in the real world can be reduced [SGR<sup>+</sup>02], and *lives can be saved*. There are numerous examples for *safety training* using virtual or augmented reality, for instance surgeries, firefighting, mining evacuation, nuclear decommissioning, aircraft inspection and maintenance, anti-terrorism measures, crane driving and safety, pedestrian safety for children just to mention some [AA04].

### Environmental Protection

From an environmental perspective, such virtual safety trainings protect not only human health, but also the environment and the equipment, thus further saving costs and time and reduce the risks. For example, trainees can practise the handling of *toxic or contaminated* material in the VR environment without the danger of contamination [Iow19]. Thus accidental *damages* of the environment can be avoided. There is *lower material consumption* and wearing of equipment when using immersive training applications, which also leads to higher protection of the environment [Sta17]. Virtual reality hardware components have to be produced, transported, and their operation can be resource-intensive (i.e. power consumption). However, overall it should be more energy-efficient and resource-saving compared to a real training or printing paper materials (e.g. textbooks).

### Time and Costs Savings

Time, effort and costs are closely interconnected and reducing time means, in most cases, automatically reducing costs. That is why they share one category. Learning and teaching involve high investment of time and resources. Virtual training can avoid *preparatory* and *follow-up* activities and save time. It is for example, not obligatory anymore to put on protective clothing before painting or to clean up after every training lesson [Iow19]. Also *waiting periods* for operation not relevant to the learning process (i.e. booting of a computer) can be skipped in a virtual world. If the equipment for working or learning is *not yet available* due to long production or delivery periods, the training can be provided virtually. An excellent example here is a machine that is currently in a design, production or delivery phase. However, it is possible

to start training based on the virtual twin of this machine [GWW06]. As soon as the machine arrives and is installed at the production site, it can be put directly into operation.

Another saving potential lies in reduced time and costs for *transportation* of trainees, trainers or training subject thanks to collaborative virtual environments.

A virtual training has a high impact on savings in terms of operating resources and consumables like different materials, fuel, energy or wearing of machine elements [Sta17]. *Machine downtime* that is necessary for the delivery of instructions can also be saved. *Errors* made in real training are usually costly, and the correction time can be very long [Pan96].

Human resources and in particular, educators are also a high cost factor. Some immersive systems featured with *tutoring systems* can reduce the need of extra qualified training personnel [Pso95]. In the example of Lufthansa Training for flight personal, there is only one operator who should monitor and support nine flight attendants simultaneously during the VR training [Stu19].

Furthermore, a well-built immersive learning environment should provide a mechanism for a fast and easy adaptation of the training due to new insights [GWW06]. Once created, the virtual environments that can be of low cost, can be *distributed and duplicated* as much as needed [Min15].

## **Adapting to Individual and Special Needs**

### **Personalized Learning**

#### ***Different learning styles***

Learning is an *individual process*, and each person has a different learning style. Virtual reality helps to create an *authentic* learning environment, that is suitable to various *learning styles*. This is possible because ILEs provide multi-modal representations of learning materials, and the virtual world can be *customised* and *adapted* using intelligent algorithms. Minocha notes some benefits of ILEs for the integration of student's different learning styles and abilities like: The possibility for creative children to use their imagination; its effectiveness for children with visual learning style, who learn easier using images, colours, textures; better acceptance of shy and isolated children from their peers due to their skills in technology [Min15]. ILEs can support auditive learners through the surround sound. According to Bell "in virtual reality, auditory cues, (such as the sound of a door closing), provide significant contributions to the realism of the overall experience, and this component can easily be expanded to provide educational

sound cues, such as the sound of bonds breaking as molecules react, or the changing “pitch” of entropy” [BF95].

### ***Repetition***

Another benefit of ILEs for personalised learning is the possibility for repetition and learning on *own pace*. Over time the memory retention of learners declines, and if the learner does not repeat the learning matter, he will *forget* it. Virtual environments can be used again and again without additional costs until the learning effect is reached, such as specific comprehension level or a muscle memory [Pan10]. An additional effect is that mistakes made in a virtual environment are not so harmful and are usually not punished compared to those in a real environment. Learners can reduce their stress and repeat a learning step until they reach a level of accuracy. Another example where repetitions in the real world are not possible are the organs dissection in the human or animal body. By using immersive applications, medical students can examine the organs from any angle, make a virtual cut into the organs and repeat this process as long as necessary, compared to the real organ, which a student can dissect only once [Min15].

### ***Self-paced learning***

To adapt individual needs, ILEs make the self-paced learning possible. Some students deal more intensely with information and want to make their own individual experience [HRL10]. Single-step can be skipped or repeated according to the learners’ abilities [Pan95]. Virtual reality allows the learner to proceed through an experience during an extended period that is *not fixed* by a schedule or an instructor. Trainees can prepare themselves for challenging situations *without the pressure* of an emergency [LK16]. In an artificial environment, processes can be slowed down, and learning matters can be supplemented with additional information [Man01], which supports the individual learning and this on own pace.

### **Learners with Special Educational Needs**

Next to the need for *tailored* learning environments due to learning styles, immersive technologies provide unique help for learners with special needs. Those are individuals who need *assistance* and *specialised care* for disabilities like sensory impairment, autism, learning disabilities, attention deficit disorder, behavioural disorders and severe cognitive disabilities.

Another example is the learning of *life skills* by people with severe hearing impairment like safely crossing a street. A study showed that virtual reality training can be “as efficient as real street training in improving street safety in individuals with severely impaired vision” [BL17].

3D interactive environments help children with *visual disabilities* to solve problems in Chilean geography and culture [SS06]. The children can orient themselves, identify the positions of various characters and objects and avoid obstacles with the use of sound.

One example is the training of *social skills* for people with *autistic spectrum disorders*, where virtual reality provides a safe and controllable environment to practice skills repeatedly [YI18, PM02]. Lessons for such special needs can cover social or *safety skills*, that are necessary in everyday life like ordering food, going to a store or a restaurant.

An interesting implementation of augmented reality system helps to improve *cognitive capability* and *adaptive ability* in the daily lives of *developmentally disabled* people. In the presented example, these people can train to serve food and drinks in a restaurant [Kim13].

## Facilitating Teaching

### Usage of various pedagogical approaches

Immersive technologies in education makes it possible to use a variety of *pedagogical approaches*, such as the behaviourist, cognitivist and constructivist learning as well as situational learning, game-based learning, and inquiry-based learning [Sta17]. Educators can design their training and courses using immersive learning application that can cover all levels of the Bloom's taxonomy, as well as addressing each of the five dimensions of Felder and Silverman's learning styles [BF95].

### Automated Learner Evaluation

Immersive learning environments provide learners with an *objective* and *real-time* performance feedback [Min15]. Algorithms for tracking the user interaction over the hardware devices and in the virtual environment allow a computer-aided evaluation [Man01]. The educators usually specify the tasks for the evaluation in advance or the tasks are generated by a *tutoring system* depending on the actual learners' performance. Then, the execution of the tasks is tracked and analysed by the system based on the intended pedagogical approach. The most immersive learning applications use *rewards* for achievements and in general, ignore and do not punish errors. This approach makes the learning by mistakes a more pleasant task, compared to delivering the training in real environment, where errors can be devastating to the learner, harmful to the environment, capable of causing unintended damages, or costly [Pan10].

### **Easy changes of the training environment**

Depending on the particular implementation of the virtual reality system (e.g. using content *configurators* or generators) for learning and training purpose, teachers are able to create new learning content depending on changes like new insights, technical change or new equipment. They can provide a *quick adaptation* of the environment and react to frequent changes, not only of the learning matter, but also of the learners' needs. Furthermore, *cross media* approaches like the integration of other media in the virtual world like websites, images, videos, interactive presentations and virtual whiteboards are also possible.

### **Saving Time and Efforts**

Educators can save time for the introduction of learners to the immersive environments due to their intuitive usage and perception. Additional instructions can prevent *overfeeding* at the beginning of a training.

Another time and effort saving factor can be found in the preparation and follow-up activities. Usually, educators should manage many administrative work as *preparation activities*. An example here is a real excursion with a school class (compared to a virtual one), where educators struggle with many management tasks such as managing costs, parent's permission, organising transportation or accommodation or taking out insurances.

Another example, where educators can save preparation and follow-up activities, is using immersive applications such as the virtual paint training [Iow19]. In the real-life for the painting training, trainees have to cover the floor, put protective clothing and tidy up afterwards. In the virtual environment, it is enough to press the *reset button* to achieve these tasks. One main saving potential of follow-up activities represents the *facilitated* or *automated* learners' assessment and evaluation.

### **Concentration on Further Skills and Individual Needs**

The development of immersive learning applications features has its limitations, due to time, costs or technology limitations. That is why they should be combined with traditional learning activities. Educators can focus on *further teaching methods* and materials that augment the virtual ones in order to provide a better understanding of the learning matter. They can concentrate on teaching activities for mastering *higher-order skills* as well as some *individual needs*, that can not be obtained using the currently available virtual environments.

## Disadvantages and Challenges of Immersive Technology for Education

Nevertheless, immersive learning environments are not beneficial in every case. Often people fascinated by a technology tend to see only its positive sides, and this can lead to bad decisions. The provided list of possible downsides of the technology should guide the educators or stakeholders to make an *objective decision* if to use or not immersive technologies in their educational project. At the same time, the issues listed below may serve as a *warning notice* for the design and implementation processes. The goal should be to achieve more *sound implementation* of the immersive learning environment, since often the drawbacks come from the particular design decisions and implementation. The disadvantages and challenges are classified in *eight categories*: Presence and immersion, learning outcomes, time and costs, health, communication, technology, acceptance, as well as miscellaneous (see Tab. 4.14).

Category	Disadvantages and Limitations
Presence and Immersion	Technological (e.g. low immersion) or individual issues that disrupt the presence
Learning Outcomes	Distraction from the learning process; no evidence for improvement of learning outcome or process
Time and Costs	Too expensive to justify the usage and the benefits; Complex and time-consuming development process
Safety	Physically safety (motion sickness, hygienic issues) or emotionally damaging (fuzzy, light-headed, depersonalisation and derealisation)
Security	Risks of security breaches and misuse of personal information (profiles and avatars); No alignment with compliance regulations (e.g. because of embedded camera)
Communication	Disturbing the social presence because of wearables (e.g. VR headset); Attention tunnelling
Acceptance	Technology issues such as low immersion (lags); low fidelity, low robustness (e.g. crashes), poor usability, discomfort; Active rejection due to social pressure, fears and other user attributes or individual beliefs
Miscellaneous	Occurrence of cultural, ethics, liability issues; Training recognition issues

Tab. 4.14: Categorisation of the downsides and limitations of immersive technologies adapted by [Häf20]

### Presence

According to Psocka, due to the *individual experience* of immersive technologies and *temperamental differences* of the users, they react differently on particular technology limitations.

Additionally, the use of good visual imagination is necessary for better presence and immersion of the virtual environment [Pso95]. There can be different reasons technological, but also individual for *disrupting* the feeling of "being there" and *destroying the illusion* created by the immersive environment. Low level of presence can lead to weaker engagement, and with it disturbs the knowledge or skill acquisition process. Presence problems occur due to the fact that users can feel *disembodied* (they cannot see their own bodies) and *isolated* when wearing a VR headset.

### **Learning Outcomes**

The embedding of immersive technology in a course will not be beneficial if, the learning outcomes are not the same or better compared to those in reality (i.e. an actual visit to a museum or park). Using conventional methods strongly depends on the concrete learning matter, mainly when content can be explained well and easily with traditional training materials, media and methods. The same applies, if the training with the *real subject* and in a real environment is *easily accessible* and available for all learners. Additionally, all other beneficial criteria for better understanding are met simply with the real learning environment like pointing out of details, analysis of components separately, slowing down or stopping a process for explanation. Immersive technologies can lead to a *distraction* of the learning matter, where instead of focusing on the educational experience, students get excited about the gadgets [Min15].

### **Time and Costs**

Usually, one of the main goals using ILE is to save time and thus costs. If this advantage is not applicable, and there are not further advantages compared to traditional methods, the usage of immersive technologies should be reconsidered. Another negative factor can be that sometimes long time and *tremendous effort* to develop suitable virtual reality environment, or an extensive and time-consuming training of the educators and technical staff in order to apply the ILE is needed. The process of the preparation of the learning content can also be too time-consuming, for instance, to extract and analyse resources and back end data [Min15].

Implementing immersive technologies for learning can, in most cases, save many costs [Stu19] (see also project 5.4). Nevertheless, if there are a too *small number* of learners or too *low the frequency* of the training, the return on investment may not be possible. Considering that the immersion depends on the system quality, achieving an excellent immersion can imply relatively high hardware investment costs. With an increasing demand for quality, immersion and real-time capability, the price of the VR system can rise quickly. Especially the need of high fidelity learning environment like virtual reality flight simulators, can demand *very high costs*. At the same time, the development of the software for the immersive learning environment

can also take more time and high budget if the learning matter requires complex content and context in the form of rich virtual worlds as well as intelligent tutoring system for automated evaluation. If at first appearance, it is too expensive to justify the usage of ILE for the specific learning matter under the consideration of the expected learning outcomes, it is not advisable to develop such application.

### **Safety**

Using a virtual environment can be in some degree physically or emotionally *damaging*, like the occurrence of nausea, dizziness, headaches or some balance issues for some users [Run14]. There are many studies on the causes as well as proposed solutions for diminishing the *motion sickness* (or symptoms of sopite syndrome) problem [CMM15, LC19, WCM19]. Some VR solutions isolate the user from the natural environment entirely. Potential *obstacles* might be overlooked, resulting in injuries, so hitting an object, stumbling or falling are the most probable way someone can get harmed while using VR device. Cautious planning of the immersive hardware setup and the available physical space is from higher importance. There are also some *hygienic issues*, that should be considered when more than one user should use VR headsets, 3D glasses, controllers or earphones. Those gadgets are potential fomites that can transmit infections between users. That is why it is crucial to clean the headset, headphones, controllers with anti-bacterial solution after each session.

While the physical health issues are already good known, some of the *side effects* of immersive technologies for the *emotional health* are not extensively studied yet. Some users report that they feel temporarily fuzzy, light-headed, or in a dream-like state after being immersed in a virtual reality. Much worse should be the *dissociative effects* that can arise. In a study from 2006, Aardema reports that the “results indicate an increase in dissociative experience (depersonalisation and derealisation), including a lessened sense of presence in objective reality as the result of exposure to VR” [AOCT10].

Some are afraid that using a virtual environment can result in “literalisation”, which means that a simulation is so convincing that some users can confuse virtual model with reality [Pan10]. Another problem that can arise is an *addiction* to virtual reality, but this depends strongly on the virtual environment and the possible actions and interactions in it (i.e. gambling like situations). *Psychological health problems* that can arise in this context are anxiety, attention deficit disorder, depression, autism and similar. Some believe that virtual learning environments can give a *false sense of security*, which can lead to further problems. It should be considered that the psychological health issues are not studied yet and are more common for those users, who are predisposed to them.

## Security

Another downside of virtual and augmented reality can be the security in the cyber space. When using virtual (collaborative) environments over the web, the connection and the data should be *encrypted* to protect against access and misuse by third parties. For many companies, who want to provide distant training on novel machines or technology, it is important to protect their data from *corporate espionage*. An other issue can be a misuse of *personal data* like profiles and avatars [McG20]. Virtual reality can reveal new ways of misuses like the *unconscious manipulation* of the users (for advertising or other purposes). In the past there were many *privacy* concerns because of the camera on AR headsets used for tracking and positioning of the virtual object. Especially, when using AR in healthcare centres there are strict compliance regulations that protect patient privacy [OJ20].

## Communication

There are learning situations, where the interaction with real humans, between educators and learners or between learners in learning teams is necessary and from great importance for the learning impact. In that situation, it can be beneficial not to use immersive learning environments. The usage of VR headset cuts off the user from the real world, so he cannot communicate with others in the same physical space as usual. The communication and *social interaction* with those people can be *partially restricted* as the eyes, and facial expressions can not be seen. There are similar problems when collaborating in a virtual environment from different locations. Eye contact is not possible, only voice and some gestures can be transmitted. A simple avatar often substitutes human body. Here network issues can also hinder the communication and the learning experience. The cause of *attention tunnelling* is also possible by using immersive technologies due to their multimodal nature and can also hinder the communication. Attention tunnelling is defined by [WA09] as the allocation of attention to a particular channel of information, for a duration that is longer than optimal, given the expected cost of neglecting events on other channels". Some critics believe that too much dependency on technologies like VR, AR and computers can lead to *loss of personal contact* with the teacher. Only a face to face classroom can teach *social interaction skills* and it is not possible with current immersive technologies [Min15].

## Acceptance

There can be some technological limits, that hinder the virtual simulation of the real-life situation and cannot provide the desired immersive learning environment. One example is the *low immersion* caused by low resolution of low-cost VR headsets, which makes impossible reading a text. It is beneficial to visualise concepts than text or formulas. Another example is, where

haptic and precise motor skills are from crucial importance for the training, but still not possible to simulate, i.e. stitching with needle. Alternatively, some applications that make no real sense like learning to play a piano in a virtual reality world, where sound and haptic simulation of the musical instrument should be implemented. However, using augmented reality to learn playing a piano makes much more sense, so users can use the real instrument and augment it with information directly on the keyboard.

It can be the case that flexibility or usability of the immersive system are insufficient to achieve the particular learning outcome. When designing a virtual environment, one should be cautious about platform compatibility and stability, such as support of operating systems or deployment on different devices.

Often problems are rising due to missing knowledge and qualification by educators to operate and supervise the virtual reality hardware as well as for the users to navigate the virtual environment software. To compensate this issue extensive and specific training can be necessary [Min15]. Another limitation of an immersive learning system due to its design is that educators cannot create new learning content and that they are limited to a specific features or domain.

Acceptance problems can arise because of technical issues, where *no intuitive interaction* or ease of use can be perceived. Another main reason can be the *limited fidelity* of the virtual world or *lags* of immersive system. For instance, low fidelity of a haptic simulation can lead users to prefer other training methods [PPM<sup>+</sup>14].

In the context of education and learning, a significant concern is that potential interference parameters or environmental impacts might not have been sufficiently considered. Training participants can overestimate their abilities, which in turn leads to dangerous situations [Pan10].

Especially within the elder generation acceptance, problems concerning VR can be registered. They are generally *sceptical* about the use of new technologies and can have a negative attitude towards immersive virtual reality [Pan10]. This issue is valid as well as for the educators, that may not want to accept teaching with new technology, but also for elderly learners that should use it. Other people raise concerns that VR is only a temporary hype and any efforts in this direction are pointless. Other acceptance issues are that educators and students can *actively reject* the usage of the technology because of social pressure or anxiety. Further, there can occur *unrealistic expectations* or *limited awareness*.

### **Miscellaneous**

Minocha lists some *cultural challenges* that can arise when using immersive technology for education such as the occurrence of *liability issues* caused by, e.g. health problems, law enforcement issues or that it may lead to an inventory loss of objects in virtual world [Min15].

Additionally, one should check if some norms or laws speak against the implementation of virtual training. It can happen that the specific authorities do not acknowledge the certificate for virtual training, and no recognition is possible. An *ethic issue* concerning learning is, for instance, that behaviour ethics should be complicated to teach in virtual environment [Min15].

The upside of this categorisation is that the most of the weaknesses and challenges of immersive technologies can be avoided or diminished if the design is well thought out and the implementation is sound. Instructional designers can use the proposed classification of the VR limitations for the creation of further analysis tools for termination criteria (such as questionnaires or checklists). Those should help on the way of deciding if an immersive learning environment fits best the learning goals and how to design and implement it properly.

This section proposed a *categorisation* of the advantages and disadvantages of the immersive technologies in the area of education. It should support the instructional designer in his *decision-making process* during the methodology implementation.

## 4.2.2 Design of Immersive Applications

In this part of the thesis, the methodology provides guidelines for planning and design of an immersive learning application based on the definition of design criteria and requirements.

Before the presentation of the criteria for the technology design, two main questions have to be asked. The first question is who is going to develop the immersive system, and the second is what are the knowledge and skills necessary for the development of an immersive application.

### Immersive System Designers and Developers

In the process of designing an educational program that uses immersive technology, the question arises, who is going to develop the solution, if there is *no off-the-shelf solution* available. Here several answers are possible. The implementation of the immersive system can be outsourced to an external company with expertise in this area. Other options are implementation by the same team that designs and delivers the course, or by the learners themselves.

- *Outsourcing*. The benefit of purchasing the immersive learning environment from an external service provider is that there is a team with experience in the field of developing immersive environments. They can provide good consultation as well as support during the delivery of the training. The drawbacks are that each future change in the software, hardware environment, or the content should be conducted by the external service provider

and are often not flexible. Here the customer can demand special tools for content creation, i.e. tutoring system, where the new task can be easily added by the educators or evaluation procedures can be changed.

- *In-house*. Another possibility is the development of the application internally in the organisation. For this purpose, one needs some knowledge and expertise in this area. This issue can be solved by hiring an expert or an expert team or train existing personnel. It depends strongly on the organisation possibilities and strategic planning.
- *By Learners*. Often the development of an immersive application can be the training task in an educational unit. This way, the students learn how to create immersive applications and at the same time are learning the subject matter that they should incorporate in the virtual environment. Nevertheless, educators should provide an excellent development environment and know-how in order to supervise the students.

In all cases, it is essential to know what an immersive application is, what its components are and how the development process looks like. This knowledge should help instruction designers to better plan and embed the technology in the learning process as well as communicate better with an external immersive software provider or technical course supervisors.

### **Knowledge and Skills for Development of the Immersive System**

In this paragraph are listed the knowledge and skills that learners must have or will acquire during the development of an immersive application. The following description can be used for both use cases, what are the backgrounds needed for learning authoring of immersive applications and what the experienced VR developer already can do. During the authoring of an immersive environment, a lot of knowledge and skills can be gathered. On the one side, are those technical skills that are learned or trained during the development like application logic programming or asset creation. On the other side, developers get detailed knowledge on the domain of the represented virtual world (e.g. human anatomy).

The following list presents the knowledge and skills a team needs or can learn, when creating an immersive application:

- Programming Skills
- Interactive Computer Graphics
- 2D/3D Graphical Design
- (3D) Sound Design
- Further areas like
  - Simulations
  - Robotics
  - Computer Networks
  - Embedded Systems
  - Big Data and Artificial Intelligence
  - Project Management, Teamwork
  - Specific Domain Knowledge

The programming skills can differ in core-programming and application logic. The *core-programming* is usually necessary when the developers work on the core modules like the engine, on simulation modules where they add or improve core functionality. Usually, for this purpose, a high-level programming language like *C++* or *C#* are used. The virtual reality engines and frameworks often provide an *abstraction level* of the core implementation to ease the programming of the application logic, in particular with *scripting languages* like *Python* or *Lua*. Some tools also use *visual programming*, which provides sequence diagrams and dialogue boxes to configure the desired functionality.

The *graphical design skills* are connected to the creation of the assets. Those assets are usually 3D models that fill the virtual scene. For the creation of a 3D model, skills in *3D modelling* and texture creation (2D graphic design skills) are necessary. Furthermore, an asset can be an animation created for a specific 3D model like a walking animation for a virtual character. Developers should be cautious because not all virtual reality frameworks support the import of animations and other advanced functionalities.

Due to the multi-medial representation of a virtual world, the *sound* is also significant for the immersive experience. Depending on the available hardware for sound output, 3D sounds, as well as background music, can be embedded for a better experience.

Often VR environments use *haptic devices* for more realistic training applications. Here the usage of *physics simulations* and understanding of robotics is of great importance. Often in the area of scientific visualisation, there is a need for knowledge on *simulations* like fluid dynamics or knowledge on big data and data mining to prepare data for *visualisation*. Knowledge in *artificial intelligence* is helpful to automate processes, simulate virtual agents or even to improve the hardware performance like tracking. Some projects require the development of custom interaction devices that have to be designed and produced. Knowledge in the area of *embedded systems* can be beneficial. Working in a team and having a specific role in that team allows someone to further develop *soft skills* like, for example, project management, teamwork and communication.

Usually, the VR developers are not experts in the domain of the specific application they develop. They learn during the creation process a lot about the *application domain* in order to recreate a realistic virtual experience.

## **Criteria and Requirements for Immersive System Design**

The listed criteria should support instructional designers and IT specialists in the design process of an immersive system. Furthermore, the requirements of the immersive application help for the selection of the right hardware and software components. The provided categorisation with benefits and limitations from the previous section 4.2.1 facilitates the design process. The methodology provides ten design criteria as listed in Tab. 4.15

### **Type of Knowledge or Skill**

The learning and teaching objectives are derived from the performed analysis and instructional design consideration described in the educational layer. They specify the knowledge that should be learned or the skills that should be trained.

### **Level of Virtualisation**

The level of virtualisation decides which elements of the immersive system should be real and which virtual. Based on the definition of *Milgram* on the Mixed Reality (see section 2.2 and Fig.

Criteria	Description
Type of Knowledge or Skill	Which knowledge and skills should be acquired in the virtual environment?
Level of Virtualisation	Which kind of immersive technology VR, AR or MR should be used?
Level of Immersion	Which hardware devices and in which quality should be used?
Level of Interaction	Which interaction paradigms and features are necessary?
Level of Fidelity	How detailed and appealing should the virtual scene looks to achieve the learning goals?
Level of Intelligence	How realistic should the virtual world react to the user?
Level of Communication	How many users should take part in the virtual learning session?
Level of Gamification	Which gamification elements should be implemented in the virtual learning session?
Level of Interoperability	Which platforms and devices should be further used and how they will be integrated to achieve continuous learning process (cross-platform features)?
Level of Learning Evaluation	Which level of automation of the tracking and evaluation of learners' performance is necessary?

Tab. 4.15: Design criteria for immersive systems

2.6), one can choose which system fits best the requirements of the immersive learning application. This definition helps to decide if the result should be an augmented reality application, a highly immersive CAVE application or a desktop environment with VR headsets.

### Level of Immersion

The next step is to decide which level of immersion should be sufficient for achieving the learning goals. The immersion is a characteristic of the hardware and its quality, so the decision here has a direct impact on the price tag of the immersive system. The immersion depends mainly on the visual output, but also the *fidelity* of the sound and haptic devices. The *quality* of the whole system is also dependant on the interplay between the hardware and the software components. For a *higher immersion* of the virtual output devices, there are several requirements to be fulfilled like a wide field of view, stereoscopy and high display resolution.

*Tracking accuracy* should be very high and *latency low*, in order to mirror the real movements in the virtual world with a high fidelity. Furthermore, some skills can not be acquired without

haptic feedback when manipulating an object like feeling its weight. Special haptic devices can improve the immersion and with it the teaching quality.

### **Level of Interaction**

The level of interaction has two aspects. One aspect are the hardware interaction devices like controller, haptic arms, but also the interaction features provided by the software like selection, manipulation or navigation. Experiential worlds need much more sophisticated features than exploratory ones. Training environments often have an extensive hardware system with *tangible interfaces*. An example is a cockpit of a driving or flying simulator. The interaction devices should serve the requirements of the virtual world, in particular, the interaction necessary for achieving the learning objectives.

*Low level* of interaction can be, for example, the exploration of a virtual scene by walking, flying or teleporting (realised with a controller or with the tracking system). It is possible to look at objects, observe them from all perspectives, but not interact with them. An example can be a museum where the exhibits are placed under glass or vast scenes like an oil rig that can be examined virtually. Furthermore, in such low-interaction environments, additional explanations that are displayed in the form of texts, images and videos next to an artefact can be very beneficial for the learning process.

The *interactivity level* grows with the possibility of manipulating virtual objects. Examples are the navigation and options selection over menus, drag-and-drop of objects, pushing of virtual buttons, opening of doors and many other kinds of interaction with various elements of the virtual scene—the more complex the response to user interaction the more realistic and immersive the user experience.

A *high interaction level* offer, for example, complex hardware systems like those for a high fidelity driving simulator with a hexapod for simulating forces acting on the user while driving. Another example is having force or tactile feedback when grasping a virtual object and feeling its weight. The implementation of complex simulations and low latency interfaces between the hardware and the visualisation is needed to achieve such experiences.

### **Level of Fidelity**

The fidelity of immersive environments is defined as the *richness and realism* of the virtual environment. It should be considered how *detailed and appealing* should the virtual scene look like to achieve the learning goals. Usually, there are two kinds of virtual world assets in learning environments. Of primary importance are the assets, who are representing the virtual objects of the learning matter. On second place are those that represent the context or the environment.

Here an example based on a virtual chemistry lab, primary objects will be the laboratory equipment like beakers, flasks or pipets for performing the experiments and of secondary importance will be the laboratory environment like the room, a whiteboard, chairs or others.

The (photo)realistic representation of the assets is not crucial to the *believability* and the feeling of presence in the virtual environment. The representation should match the users expectations and serve the overall instructional design. It is much more essential to provide proper synchronisation between the visual and acoustic feedback. The same issue applies to the area of augmented reality. The virtual objects should be placed in a natural-looking composition to achieve believability.

### **Level of Intelligence**

The level of intelligence in an immersive learning environment is strongly interconnected with the immersion and interaction. However, it can also be defined by the provision of an intelligent *tutoring system*. The interaction aspect is based on the *realistic feedback* of the virtual environment like physical laws and high fidelity simulations. An intelligent tutoring system should provide an individual learning experience, should enable the generation of tasks based on the performance level of the learners as well as be able to evaluate the performance of the tasks and prepares reports for learners and educators.

The intelligent tutoring system can be developed as a back-end of an immersive learning application. Using semantic modelling of the virtual environment, makes possible the knowledge-driven access from the description of the virtual environment and simplifies the development of immersive applications. A methodology for an intelligent tutoring system integrated in an immersive learning application is described in section 4.2.6.

### **Level of Gamification**

The usage of gamification elements in virtual learning environments or immersive serious games can contribute to a higher level of *intrinsic motivation* and engagement. Learning requirements become exciting challenges. Some *gamification elements* are the narration, the quest design or role models as well as other game-based principles like badges, points and progress bars. Those game-based principles can be used to provide experiences of technology *self-efficacy*, and create motivational incentives for *prolonged engagement*. Playful features can support a functional purpose as well as making the system easy to use and more intrinsically rewarding. The integration of gamification mechanisms aims to engage the user in the process of *playful discovery* of content and narration. On Fig. 4.12 is presented as an example of a learning application user interface with gamification elements.

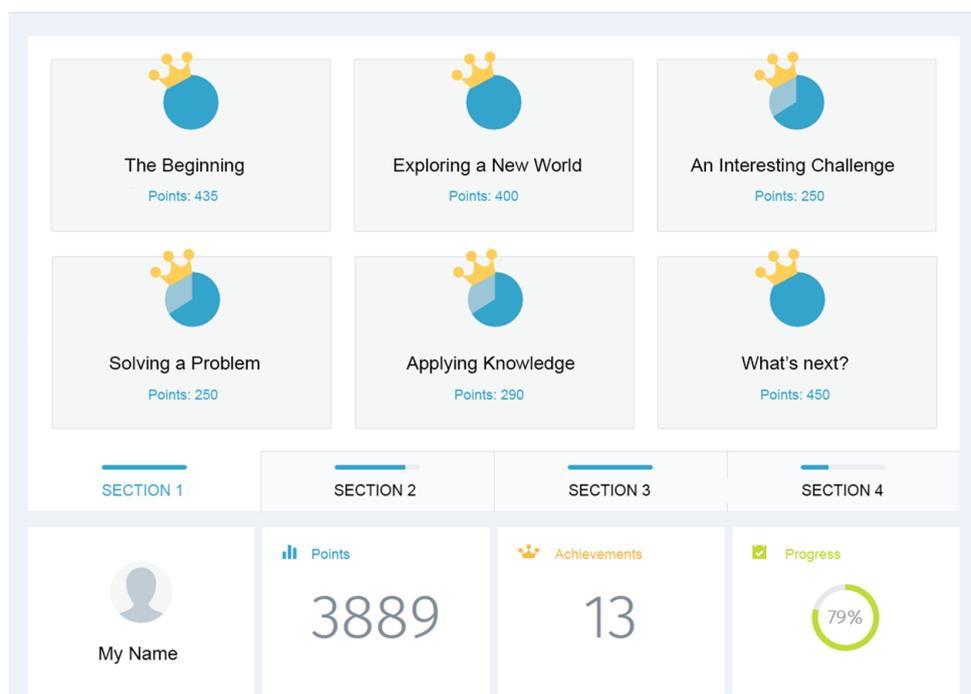


Fig. 4.12: Example of learning application user interface with gamification elements, designed by [Wer16]

Mastery is rewarded with points and badges. Points or high scores are automatically calculated from the player's performance in the learning environment. Content creators can assign strength or skill points for individual tasks (e.g. social and technical skills). Furthermore, achievements and their unlock-conditions can be defined for particular efforts. An example of learners statistics with game-based principles are presented on Fig. 4.13.

Based on the motivational theories, following *feedback types* can be used:

- Immanent feedback in terms of a powerful incentive system deeply integrated into the learning environment involving badges, points and progress bars;
- Social feedback in terms of group dynamics that emerge from the exciting contrast between cooperative (solving quests in teams) and competitive elements (rankings);
- Feedback from the virtual world, which is filled with quests and framed by a narration.

### Level of Communication

If required, features for support of *social learning* and collaboration should be provided. Communication with virtual agents as well as collaboration between educators and peers is possible to be implemented in an immersive learning environment.

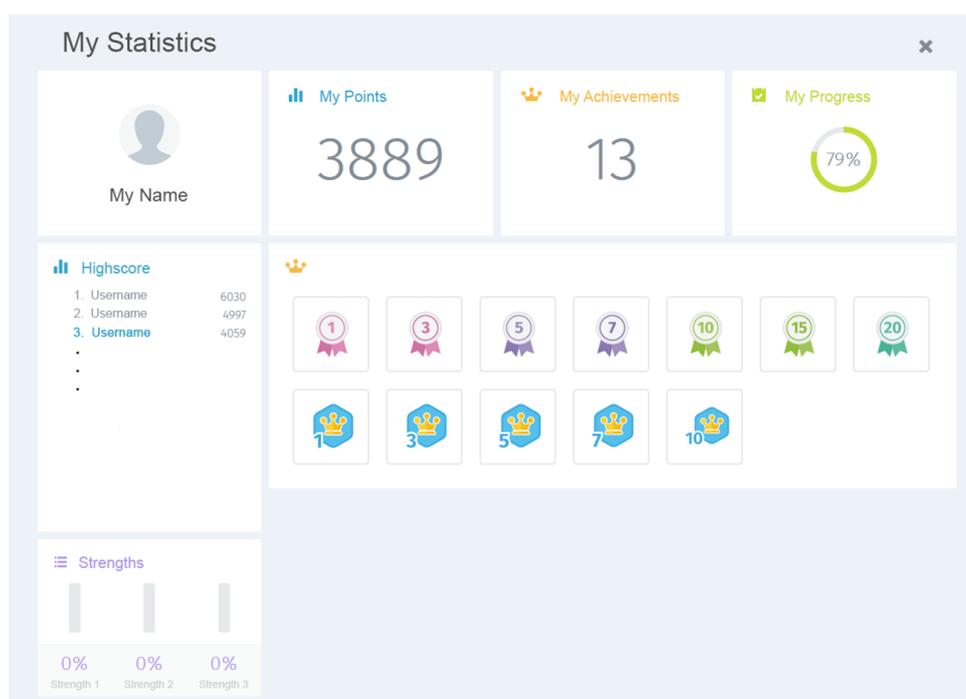


Fig. 4.13: Example of learners statistics based on gamification elements, designed by [Wer16]

### Level of Interoperability (Cross-Platform)

Another exciting feature is the so-called “No Media Break” or the continuous *learning over several platforms* resulting in a cross-platform learning experience, a concept borrowed from certain computer games. During learning with a virtual reality application, it is possible to visit web pages like, for instance, *Wikipedia*, *Facebook* or others. Learners can search for specific knowledge referenced in the application in order to finish the assessment or achievement. Furthermore, an *accompanying application* for mobile devices or desktop can extend the functionality of the immersive learning environment and provide additional assessment or special challenges for learners, which are adapted to the device’s potentials. The user can solve tasks in an accompanying application, which communicates with the server and sends back information on the user’s activities.

### Level of Learning Evaluation

Immersive learning environments can provide *real-time analysis* of learners’s performance data. The goal is to display learners’ particular strengths and weaknesses and to provide information on the *overall progress* in the curriculum. Data analysis provides feedback for content creators (the educators) on the quality of their courses and the performance of their students. Additionally, the skills and knowledge gaps among learners can be analysed, and *recommendations for improvements* of the particular educational systems can be collected.

## Requirements for Immersive Systems

Next to the design criteria, the most important requirements for the overall system are listed and explained below (see 4.16).

Requirements	Description
Real-Time Capability	Real-time interaction and rendering of the scene; No latency in the system
Robustness	Stability over long training sessions and durability of the system to a high number of users
Usability	Easy to operate and intuitive interaction
Safety and Security	Protection of user's health and misuses of user's data
Quality	The trade-off between cost, time and scope
Sustainability	Continuous and easy changes of the virtual environment; Continuous support of the software and hardware
Further non-functional requirements	System modifiability, scalability, maintainability, portability and others

Tab. 4.16: Requirements for immersive systems

### Real-Time Capability

One of the main requirements of the hardware is that it should support the visualisation of the virtual world and interaction with the world in *real-time*. It is always a *trade-off* between the *fidelity* of the virtual environment and the *hardware* capabilities, mainly when low-cost hardware devices or deployment for web should be supported. An essential component for good immersion and performance is the computer system and in some cases, the network architecture. The more powerful the computer graphics hardware is, the more complex is the virtual scene that can be rendered in real-time (frame rate should be at least 25 fps). At the same time, there should be *no latency* in the overall system and network.

### Robustness

In order to provide proper training, an immersive system should be robust. The system should stay *stable* over a long time with no crashes; those would disrupt the learning process. The hardware devices should be robust and *durable* to a high number of inexperienced users. Hardware devices will be used long, and the manufacturers and distributors should provide a warranty.

## Usability

As for each system, the immersive learning environment should be *easy to use*. That means that the start, stop and the operation is devised as simple as possible, so there is no need for additional explanations on usage or previous user experience. The system should offer *intuitive interfaces* and *interaction* to the learners. Gathering user feedback early on during the development will improve the quality and the usability of the system.

## Safety and Security

The system should provide a *safe environment* for human health. The typical causes of motion sickness should be addressed and contained. For augmented reality applications, the physical space should be secured. Cables and other physical obstacles should be visualised in the virtual world to avoid tripping. For instance, haptic devices that use strong forces should provide an emergency button in order to avoid injuries. Cleaning and disinfection of the hardware should also be considered during the design and maintenance of the system. Especially if the system is going to be used by many users. Another aspect when implementing virtual reality applications is the *cybersecurity*. The immersive applications which have a connection over the internet to other devices or users should provide data encryption. Furthermore, the users should be sensitised to do not give personal information.

## Quality

Cost, time and scope are factors that are interconnected and have a significant impact on the design and implementation quality. It is a *trade-off between costs, time and functionality* to achieve good performance and high quality of the system. Achieving a high-level of immersion and interaction requires higher performance, which implies higher costs for hardware equipment. At the same time, a high level of fidelity or intelligence of the virtual world needs more time for implementation which also leads to higher costs.

## Sustainability

The sustainability of an immersive system can be guaranteed in different ways. The software can provide features for *customisation* of the virtual world, the assignments for the learners and their evaluation. Algorithms for *generation* of open-worlds can help provide highly flexible and adaptive immersive software applications. For instance, instead of creating 3D models of each chemical element or compound, a molecule generator based on a chemical formula in the form of a string input can be programmed to generate automatically any kind of molecule.

## **Further non-functional requirements**

Some other non-functional requirements can be the system modifiability in the context of facilitating educators, system scalability, interoperability, maintainability, portability and others depending on the concrete needs and goals.

### **4.2.3 Immersive IT Resources**

Two main categories separate the technology resources. The first category are those resources, which have not a direct connection to the immersive technologies called “non-immersive” and the second category are the “immersive” IT resources, which consist of hardware and software needed to build and use immersive environments.

#### **Immersive and non-immersive Technology Resources**

##### **Non-Immersive Technology Resources**

The non-immersive IT resources contain the infrastructure in a lecture room, computer pools, as well as software tools needed for course administration, student management or for creation of the learning materials. The application of theoretical introduction in the form of a *lecture* requires a seminar room with multimedia system, that has a projector, sound output or microphones. For the *project-based learning* approach, where learners should meet and work together, educators should provide meeting rooms as well as work stations organised in computer pools and connected to the internet. If educators use online learning, they can need special equipment for streaming, capturing or editing of videos.

On the *software side*, many tools can be necessary. They are starting with an office package for creating presentations, documentation or collecting information. Furthermore, tools for course administration and learning management systems like *ILIAS*, *Moodle* or similar, are used for registration, communication, managing documentation, evaluation and others. Novel approach is the integration of social media and social networks for teaching. This practice allows immediate sharing of content and performance of the users and can foster communication between learners-learners, educators-educators, learners-educators and allow sharing knowledge and experience.

Some tools support the *development of the software* projects directly. In this case, they strongly focus on the implementation of virtual or augmented applications. We categorise those kinds of tools as non-immersive. Such applications are building the development environment and facilitate the work of the programmers. Examples are code management software so-called

IDEs ( i.e. *Visual Studio*, *Eclipse*, *Code::Blocks*), code repositories and version control systems ( i.e. *SVN* or *GIT*) or systems for issue tracking and feature requests.

### **Immersive Technology Resources**

The immersive IT resources are more sophisticated and include the immersive hardware, the software tools for building virtual worlds and those supporting the hardware devices. For further information, the reader can consult the sections *Immersive Technologies* 2.2 on page 20 and *Technological Advances of Immersive Technologies* 3.1 on page 35.

#### ***Immersive Hardware Resources***

The immersive virtual reality hardware components can be listed in following categories:

- Visual output
- Sound output
- Haptic input and output
- Tracking systems
- Hand controllers
- Sound input
- Computing infrastructure

#### ***Immersive Software Resources***

The immersive virtual reality software components and tools are categorised as followed:

- Tools for asset creation
- Authoring frameworks and engines
- Hardware drivers, middleware
- Data converters, plugins or tools for management of data interfaces
- Specialised libraries, back-end tools ( i.e. for simulations, pre-processing, data management or others)

## Criteria for Selection of Immersive Hardware and Software Components

In the coming paragraphs, we list few criteria for the selection of development tools for immersive applications.

Selection Criteria	Software components	Hardware components
Domain	Depend strongly on the application domain	Depend on the skills to be learned
Portability	Deployment on various operation systems and platforms	Wireless devices, portable, mobile immersive systems
Compatibility	Seamless and efficient workflows; interfaces without data loss	Available interfaces and drivers; compatible with the other devices
Developers/Users	Depend on the developer experience, skills and development environment;	Availability and usability of system components
Scalability	Support of many users and developers, making large and flexible code-base possible	High number of devices and users simultaneously
Availability	Available licences, support, infrastructure or developer skills	Parameters of the hardware on end user and developer side
Space	Digital space for data; Development environment and supporting tools	Physical space for free movement and installation of the immersive system
Costs	Trade of between price and features ;	Trade-off between the price and the level of immersion
Support	Hardware support; Support by the provider	Support of various VR engines and frameworks; Good support by the provider
Sustainability	Upgrades, large community, proper documentation	Easy to maintain, robust to high number of users, warranty

Tab. 4.17: Criteria for selection of immersive system components

### *Tools for Assets Creation*

The selection of the tools for assets creation can depend on the *application domain*. For instance, in machine engineering domain, typical tools are *CAD* software like *SolidWorks* or *CATIA*, and

in the architecture or building engineering tools like *AutoCAD* or *ArchiCAD*. More comprehensive and universal tools for modelling of 3D assets are tools such as *Blender* and *3ds Max*. Primary criteria for selecting a modelling tool are the *data interfaces* and the provided export format capabilities in order to provide efficient data workflows and *no data losses*. Of course, the tool should provide all necessary features and high usability.

### ***Authoring Frameworks and Engines***

There are two families of software systems for developing virtual reality applications: Gaming and virtual engineering engines. Both development environments have their advantages and disadvantages, have support for different data interfaces and immersive devices. *Gaming engines* provide powerful toolkits for the creation of virtual environments, have proper documentation and significant communities, which facilitates the low entry barriers. The *virtual engineering tools* provide better interfaces to engineering tools and have many specialised features according to the domain. A virtual reality software should provide *support* to the virtual reality devices like distributed visualisation, clustering, tracking systems as well as haptic or acoustic devices.

The *portability* of the immersive application, in the sense of its deployment on *multiple platforms*, should also be addressed. The VR engine should support the deployment on complex hardware systems like CAVEs and powerwalls, but also on VR headsets, mobile devices or even browser. The software should be *robust* and reliable and should enable the *real-time* and *latency-free interaction*. It should not be a bottleneck for the high performance of the whole system. An important feature of virtual reality software is the asset import capabilities as well as the possibilities to add application logic easily to the assets. The deployment of an immersive software on different operating systems is desirable, but not a must.

### ***Workflows***

The data interfaces and workflows between the tools have to be *seamless*. The export from one tool should not result in a data loss when importing in the other tool. Furthermore, when implementing the learning application, the users (learners and educators) workflow should be ensured to be *efficient*. An example for such workflow is the customisation of assignments by the educators, such as adding new 3D models in the scene or adjusting application logic and simulation parameters. Developers should consider where the data will come from, which formats are supported and where the data should be stored.

### ***Costs***

The software for development of immersive environments should not be expensive. In the last years in the area of virtual and augmented reality, many *matured tools* can be used for *free* or are *open-source*. One such example is *Blender*, which is a 3D computer graphics software toolset that is very powerful for the creation of 3d models. Next to the open-source virtual reality authoring frameworks like *PolyVR* and *COVISE*, there are some game engines, i.e. *Unity3D*, which provide a free version of their software. Many proprietary software tools can be *costly*. Developers justify their use with exclusive features and support needed for the specific learning application.

Concerning the costs for the immersive hardware, usually higher costs means higher level of immersion, interactivity and quality. Many VR devices are exotic and produced in *deficient number*, which makes them very *expensive*.

### ***Sustainability***

Adopting the right development platform can improve the sustainability. In particular, that is a virtual reality software that will be in use for an extended period, is *easy to maintain* and has a large *community*, proper *documentation*, and excellent *support*.

Since some development project can last longer, there should be considered the possibilities of *upgrades* or changes of system components. It is recommendable to start an immersive educational application project with the most advanced equipment. Despite, it is not always possible, because of the hardware available on the *end user's side* and its performance. In this sense, the development framework used, should further provide deployment on several *platforms* (such as immersive, desktop, web or mobile) and support of operating systems.

For the software platforms and tools like virtual or augmented reality authoring frameworks or 3d modelling tools used, next to the provided features, it is vital to have a large community and proper documentation. When selecting development tools or hardware components, the reliability of the producer and reseller should be checked, i.e. in terms of *warranty*.

### ***Availability***

#### **End User and Developer Hardware**

It is crucial to analyse what is the technical equipment that the learners already have or will have when the project is ready. Developers can not assume that all learners will have high-performance workstations and high-resolution VR/AR headsets at home. Of course, if the learning session should be done at home and not in specialised training facilities. Another

issue can be a long development phase, at which end the hardware system gets *outdated*, due to current rapid development in the area of the immersive technologies. In this case, developers should provide new interfaces to the devices of the *end-users*.

One criteria that can limit the design of the whole system can be the fact that some hardware or software components are already available, and this can save costs. Designers should check if the hardware components are not too old and if they can still utilise them when the project is released.

### **Physical Space**

Furthermore, there should be some physical space for some virtual or augmented reality hardware configurations and learning activities. Some *navigation* features can virtually reduce the need for physical space like teleportation metaphors or translating via a joystick.

### **Developers Skills**

There can also be some licences for software tools, that can force their usage even not suitable for the particular project. Another availability issue is related to the human resources and their *expertise*. Usually, developers tend to choose tools they are already used to and can work more productively. The existence or non-existence of developer skill can also be a determining factor for the selection of tools.

## **4.2.4 Development of Immersive Applications**

This section gives some insights of the *authoring process* of immersive applications. It should guide educators, while designing an immersive learning applications or supporting the project implementation. The authoring process is briefly outlined, and only some essential characteristics are described because of its complex nature and the necessary deep expertise in interactive computer graphics.

### **Technology Preparations**

#### **Teaching with immersive project development**

The main preparation activities for a course using authoring of immersive environments with a project-based approach, are connected to the *development environment*. The *licences* for the virtual reality authoring frameworks and supported tools should be bought and already installed on the learners work stations or made available for *installation* on learners hardware. The laboratory and computer pools should be *accessible* and the computers up to date. The immersive

hardware equipment, where the projects will be deployed, should be delivered, set up and made *available* for learners.

Additional preparation tasks are the introduction to the system components and the development environment. Supervisors can prepare labs, exercises, video tutorials, scripts, or any other documentation to introduce learners to the software tools. Furthermore, some configuration of tools for students and code management, communication, technical support like issue tracking system can be necessary.

### **Teaching with immersive learning applications**

Development environments for immersive applications is high dynamic field, and there is still no standardisation for tools, interfaces and programming languages. Furthermore, often the development of virtual and augmented reality require different development environments. That is why, as a next step, it is essential to carefully decide, which hardware and software tools are suitable for the specific project based on a *requirement analysis*.

An immersive system does not differ from any other system that foresees the usage of software application and its deployment on specified hardware. The traditional methods for *system engineering*, which include the system design and the definition of system requirements are also applicable in this case. In the paragraphs above described the distinctive features of immersive technologies for educational purposes as well as the criteria for their design, which should support stakeholders to define the functional and non-functional system requirements, before starting with the implementation.

The next step before the system implementation, is the definition of the *system architecture*. This step includes the *structure* and the *behaviour* of the overall system. An immersive application is highly complex, and its design includes all software and hardware components. Furthermore, all interfaces should be designed. There are *interfaces* between the components as well as between the system and the users. Modelling languages like *ADL* and *UML* are useful tools for the design and architecture diagrams for the immersive system.

### **Authoring of Immersive Applications**

The creation of an immersive (learning) environment is a complex task, where knowledge and skills from many areas are needed and can be compared to the creation of an interactive computer game, but deployed on immersive hardware. A virtual world is a computer-based simulation which contains all visible objects, sounds and interaction artefacts. The virtual world can be fictional or represent objects of the real world.

On the one hand, the hardware interface for the human-machine interaction should be intuitive and as near to the real world as possible. On the other hand, the implementation of the virtual world needs not only the programming of the application logic, but also the creation of realistic and appealing content. The content itself is multi-medial, and expertise in 3d graphic design, acoustics, simulations and many more can be necessary. However, the virtual content and application logic needed, depending on the goals and requirements of the specific application.

### Authoring process

The process of authoring immersive applications is *highly iterative*. On Fig. 4.14 can be seen one iteration step of the development process of immersive application. The first goal is to create a *logical framework* using small and straightforward virtual scene and some initial application logic. The developers of the application logic should not wait for designers to provide the high fidelity 3D models. Instead, some primitives with low polygons, which are rough representation of the future 3D models can be used. One benefit using primitives is that the programming and the design of the assets can be performed in parallel, and another advantage is that the overall performance can be better controlled.

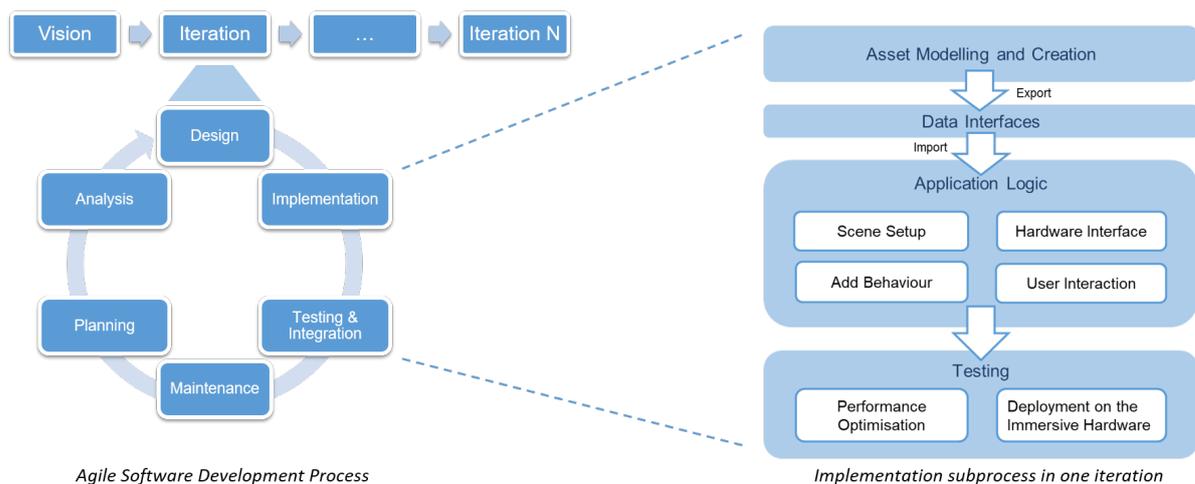


Fig. 4.14: An iteration step of the immersive application development process

In order to ensure the overall system functionality, one important iterative step is to *deploy* and test the application regularly on the immersive *hardware systems*, that are going to be used later by the *end-users*. The interfaces between all hardware devices and the software system should be continuously implemented. Early deployment ensures that the framework supports the hardware, which is vital for the project success.

The *iterative* and parallel development of the immersive application and the overall system provides an initial proof of concept. Software developers and designers can detect difficulties

early in the project and communicate those with the stakeholders. Together they can change some requirements and configurations or even cancel the project, if necessary.

The iterative development approach enables the control of the system *performance*, which is the most crucial feature of an interactive computer graphics applications. It is essential to consider the trade-off between the realism of the scene and the performance in any moment. For instance human perception can fill in details into a scene, even if they are not present, because of previous experience. A 3D object which is far away from the user should not be represented with great details. The user cannot see it well, but the abstraction level is enough to provide believability.

When authoring immersive learning applications, the educational content and tasks should also be iteratively integrated into the virtual environment from the very start.

### **Assets**

An immersive application is *multi-modal*, and the assets consist mainly on 3D models, images, sounds, simulations or any other relevant *data*. A three-dimensional virtual world can be created entirely manually or can be generated with algorithms. The same can be applied to the sounds, which can be captured from the real world or synthesised based on mathematical models.

### **Assets Modelling**

The assets for the virtual scene are usually modelled *by hand* with 3d modelling tools, where the effort scales with the complexity of the scene. When creating virtual worlds, it is usually the assets that are the most *time-consuming* part. The assets also determine how appealing the scene will be. Rich scenes with detailed and high-polygon objects, can be very expensive for the overall performance. The 3d geometry can also have materials and textures, which describe the appearance of 3d objects' surfaces. Textures can be created with special images (called bitmaps) or using mathematical functions (procedural textures). The different kinds of *texturing* methods today can reduce the complexity of 3D models drastically, and increase their visual quality. For the manual creation of assets, designers should know which objects are necessary, are visible as well as should have detailed information about the objects. *Storyboards* and task descriptions can help to decide which objects are needed and which are visible in the virtual world. Additionally, designers need *descriptive resources* like images, drawings (with object dimensions), 2d layouts, CAD data, texts or videos to recreate the virtual world in three dimensions. The benefit of the stepwise manual modelling compared to working with existing assets, is the *control* over the level of detail of the objects and with this the control over the real-time capability of the application.

Recording *audio* for virtual reality environments should be *binaural* in order to create *spatial sound* and the impression that the sounds are coming from near or far away from the user, or a specific direction. There exist methods for capturing panoramic three-dimensional sound, in order to later listen on output devices like surround sound system or headphones.

### **Assets Generation**

Another possibility next to the manual creation of the 3d scene is the usage of open-world and world asset generation. For this task, more experience in computer graphic and programming are expected. The benefits that can be achieved are the automation of the authoring process, a *sustainable* virtual world for training and the facilitation of the educators. Such bases can be used by educators to *configure* the virtual world based on provided parameters.

The same principles can be applied for the generation of sounds. The *sound synthesis* is a method that use electronic hardware and software to generate sounds and is mostly used for music applications. Some sounds are difficult to be recorded or used in a dynamic virtual reality simulation like the sound of an engine in its different states. That is why synthesising the motor sound based on several parameters like the throttle pressure, the current gear and the landscape gradient, is sophisticated but more flexible solution.

### **Editing of Existing Assets**

Today there are several possibilities to obtain 3d models or recorded sounds. They can be downloaded for free or bought from online *databases*. In the case of free files, one should be careful with the kind of the *licences* and to which rules are the licenses bound. During the requirement analysis, it should be already established, which are the assets already available and can be directly used. For instance, an immersive training on a particular machine or production process can profit from available 3D construction data of those machines. Independent of the source of the existing 3D models, their *quality* should be checked. There can be the case that some *rework* should be done in order to improve the appearance or performance.

After analysis of the provided data, it should be decided which of the three options will be most efficient, the rework of the existent assets, their modelling from scratch or their generation.

### **Preparation for Export**

After modelling or reworking of the 3d assets, they should be prepared for export. This step is very crucial because there can be different issues in the further development process. The following list provides some examples of issues that can occur after assets import and adding the application logic in the virtual reality framework:

- The process of exporting and importing 3d models can cause data loss due to conversion from one (usually native) format to another.
- The coordinate system in 3d modelling tools and those of VR authoring systems often differ in their Y and Z-axis.
- Together with the modelled geometry, further artefacts like lights or cameras can be exported. Those artefacts are usually not used by the VR authoring engine, but can cause some issues.
- The information about the textures, UV-mapping and materials should also be exported together with the geometry.
- The calculations of the normals should be checked before export, to be sure that their orientation is right and the 3d models are rendered error-free in the VR engine.
- The selection of precise and logical names for the objects, their parts, materials and textures is very essential for further processing. Special characters and spaces can lead to problems during the import process.
- After the import in a VR framework, an object looks too big or too small, because of different units set in both applications.
- The 3d models should be positioned at the origin of the coordinate system in the 3D modelling software, especially if the 3d model should appear on the floor in the virtual scene.
- Scaling factors should also be avoided in the modelling tool. Scaling issues can result in errors in visualisation, animations or simulations.
- The limitation of the depth buffer resolution results in strong flickering when the camera or object in the virtual world move. The flickering can be reduced by avoiding the modelling of surfaces lying directly on top of each other.
- 3d modelling tools enable the creation of key-frame animations, but some virtual reality frameworks can not import them. This interface should be analysed before efforts are provided in modelling the animations.

---

## Application Logic

### Resources

A virtual reality application usually recreates real environment and processes. For this task, next to the assets, some further information is necessary. The real training, its *procedures* can be described with text, diagrams or captured with videos. Some *parameters* for the simulations can be provided in the form of tables. There should be sufficient *data* in order to *reproduce* the real *environment* and the *behaviour* of the objects in it.

### Scene Setup

The asset workflow starts with the export from the modelling tool (as described above) and is finished with the import of the assets in the virtual reality framework. From there, the assets are first managed in a virtual scene and then further functions can be applied.

A *virtual scene* consist of assets like 3D models, materials, textures, sounds and other artefacts like lights, virtual cameras and virtual sound sources. The arrangement of those assets in the 3d space and the relations between them are usually realised with a scenegraph.

The *scenegraph* is a hierarchical graph structure that represents the topology of the scene. The nodes of this graph have parent-child relations, and each node can represent, for example, a geometry or light element. This structure is mainly used to realise the *rendering* of the virtual scene. In each frame, the scenegraph is traversed, and the transformation of the active camera viewpoint, the world transformations of each object, their visibility, the active light sources and further functionalities are computed.

### 2D Elements

Sometimes 2D elements like images or text can be beneficial for the application and rendered in a 3D world. Those elements use *sprites* and allow the mapping of an *image* on their surface or integration of textual information. Very convenient method for the realisation of 2d graphical *user interface* are websites, mapped on a sprite or a 3d geometry and rendered in a virtual scene.

## Programming

In order to add logic like interaction or animations to the virtual scene, some programming is necessary. Most virtual reality engines have abstracted editors using *script languages* like *Lua* or *Python* or visual programming tools. With scripts, all necessary actions in a virtual environment can be realised. Some of those are graph operations, content import, lightning management, creation of animations, parameterising simulations, or any other needed functionality.

There are different possibilities to trigger scripts or programming building blocks to control the application flow as follows:

- The initialisation scripts can be triggered, just right after the scene has loaded
- Scripts can be executed each frame
- Scripts can be triggered when receiving a signal from a device, in order to handle user input, a network message or a callback.
- Scripts can be triggered for a specific time (timed execution).

## User Interaction

Interaction is one of the significant features of immersive application. The user interaction is determined by the user behaviour and the interaction device. The virtual reality hardware components offer much more possibilities compared to the mouse and keyboard well as the accompanying WIMP paradigm (which stands for windows, icons, menus, pointer).

The interaction functionality in the specific immersive environment depend on the provided hardware system. The immersive system should have a *tracking system*, which next to the head tracking, will allow the user to interact intuitively in the space with his body or the controllers as a natural extension of the user's hand in the virtual world. The user can *interact* with the virtual objects, in order to select, grab and move them virtually. Furthermore, different *navigation* modes can be implemented depending on the needs like walking, flying, teleporting in the virtual world. A realistic *manipulation* of objects such as giving or receiving force to and from objects can be achieved through the visualisation of their physical reaction (i.e. deformations) and the implementation of force feedback. Further features that can be implemented in the context of interaction are the *communication* with virtual agents or with other users in the same virtual environment.

## Add Behaviour

In order to set objects in motion and to create a *dynamic relationship* between objects in a virtual world, there is the possibility to use *animations* or *simulations*.

### *Animations*

Animations are programs that allow the control of objects *behaviour*, like the opening of a door or walking of the virtual character. Some engines have visual tools for creating animations, but they can also be programmed over scripts. An animation describes the start and the end transformation of an object. The motion is usually interpolated over the time. Animations can be triggered by events as well as a series of animation can be organised in a state machine.

### *Simulations*

The animations are often fixed processes, which are the same each time-triggered, but simulations can be used to define behaviour based on *continuously changing* parameters. The most used simulation in VR applications is the physical simulation, which should provide convincing *physical behaviour* of objects like collisions, vehicle dynamics, gravity, and other forces. Furthermore, in the virtual engineering applications, there are used *CAX simulations* like n-body, finite elements methods or fluid dynamics. Usually, VR frameworks have already embedded physical engines, and at the same time provide the possibility to use external simulation engines or existent libraries.

An exciting kind of simulation is the particle system. With the help of many tiny objects emitting from a source, different kind of natural phenomena like waterfalls, fire or chemical reactions like explosion, smoke and many others can be visually stimulated.

## Performance Optimisation

There are many tricks to optimise the performance of an interactive virtual reality application. Some are mentioned below.

### *Level of Details*

The usage of features like the level of details (LOD) or tessellation shaders should *reduce the polygon numbers* and with this to provide better performance of the immersive system. The LOD feature means that the designer provides for specific 3D objects different *abstraction levels*, and depending on the *distance* between the user and the virtual object, the corresponding version of the object is displayed.

The performance of an interactive application can be improved using *geometric shaders*, because they are calculated directly on the *graphic card* in run-time. With *tessellation shaders*, it is also possible to program the level of details. Simpler meshes can be subdivided into finer meshes based on mathematical function, which can be related to the distance from the viewing camera.

### ***Emphasis on the Essentials***

Another possibility to reduce the number of 3d objects in order to achieve better performance is to design only those virtual objects, which are *near the user* and can be seen from different perspectives. Such objects are most directly connected to the learning matter, and the user interacts with those objects intensively. There are applications where the context in the sense of scene background is essential to be there, but mostly it should not be designed in details. Developers should test if there is a noticeable difference for the user and if some details are missing in the virtual environment and decide if the effects are worth the performance costs.

### ***Skybox***

One technique for creating an impression for a rich scene with low-performance costs is, to create a *2d background surrounding* the user, using a skybox. The image of distant and unreachable objects like sky, mountains, city skylines can be projected to a cube, so-called *cube mapping*. The user perceives that the objects are far away. There are also some advanced techniques like 3D or *dynamic skybox*, where effects like moving of the clouds can be simulated, or part of the distant objects are three dimensional, for the case that users can navigate near enough to see them.

## **Deployment on the Immersive Hardware and Documentation**

Usually, during the development of an immersive application, the features of the devices are *abstracted*, in order to provide implementation without the final input and output hardware. The full functionality of the interaction can be achieved only with the deployment of the application on the dedicated immersive hardware setup. For this purpose, the virtual reality authoring system should support those devices, which means signals send from the devices should be received by the application logic and further processed in order to interact with the virtual world.

VR authoring frameworks provides *support* to separate VR *devices* like tracking systems, controllers, visual and sound output devices or compete systems like VR headsets. VR headsets are usually delivered as complete solutions, with tracking cameras for head, hands, and even eyes, with controllers, head-mounted visual output and headphones for sound output. VR setups like

CAVEs, powerwalls setups or other custom made VR systems use separate components, which should be handled by the virtual reality software.

Many VR engines abstract the hardware features and provide *general input interfaces* to provide broader support for devices. For example, a controller can have input data for buttons and axes, information if device represents a physically-tracked hand and have some tracking target on it, if the user holds the device in the left or right hand. For the *tracking system*, the common input data are geometric information for each device, that is usually a *pose in a space*, but can also be one or two dimensional. Hand or body tracking means that a *kinematics model* of the tracking object is needed. Furthermore, one should differentiate between the tracking in case of VR headset and a CAVE. The display in the first case is attached to the user's head. In the case of stereo display or projection, it is static in front of the user.

Additionally, there are different tracking technologies. There are optical tracking systems where the signal emitters are placed at fixed places in the physical space, and the user wears or has attached passive or active trackers (also called markers). The other way around is when wearing the emitters, and the sensors are attached to the physical environment. Moreover, some devices can also perform eye tracking, which should also be supported by the software. There are more complex or custom interaction devices like haptic feedback hardware or data gloves, which have complex interfaces with many input and output parameters.

### **Documentation**

Parallel to the development and no later than the project is finished, it should be provided documentation for all stakeholders. Learners, educators or system administrators ought to get different instructions. Learners are interested how to use the immersive training system, the educators are interested in the usage, configuration and customisation, and the system administrators should get the information for the installation, the supported hardware and others.

### **Maintenance of Immersive Systems**

Maintenance of virtual reality equipment can be considered like any other complex system and depends on the hardware and software installed. The software maintenance includes the *technical support* and the *updates* on regular basis. Furthermore, it encompass the report of issues and the resolving of bugs, but can also provide the implementation of additional features and learning content.

The VR and AR headsets may have wireless *components* that work with batteries that should be *recharged* after a while, in the best case directly after a longer training session. The same

applies to shutter glasses and interaction devices used in a CAVE or powerwall environment. Other follow-up activities include *cleaning* glasses, controllers or other interaction devices that have been in close contact with the skin of the users. In particular, if the hardware is used by many people, it should be *disinfected* after each training participant.

The complexity of a high-end visualisation results from the number of projections and the number of computers that support them. In addition, they are connected in a local network, which can also be a reason for future *system failures*. Due to its complexity, the maintenance of CAVE system is usually carried out periodically by the hardware providers. During a maintenance session there are many checkpoints. An important task is the *recalibration* of the projectors in terms of *colorimetry* and *contrast* as well as the position in relation to the screens. Depending on the type of projector, it may be necessary to change the projection lamps according to their working hours. The tracking system should also be recalibrated during the maintenance check. In addition to the hardware components, it may be necessary to upgrade a driver or special software like this for media control.

#### **4.2.5 Evaluation of Immersive Systems**

During an *agile* implementation of a software, there are always *tests* that check if the developed functionalities work according to the requirements. The evaluation of immersive learning system should be done not only regarding the technology itself, but also its performance to acquire knowledge and transfer this knowledge in real-life situations should be evaluated with the target group.

There are *two main methods* in terms of evaluating the potential impact of interventions or services, in particular teaching is concerned as a service (see also *Evaluation and Optimisation* 4.1.5 on page 101). While *formative evaluations* collect data stepwise starting as early as possible, *summative evaluation* strategies rely on pre-post research designs in order to measure differences between two or more testing times. Both methods generally incorporate *qualitative measures* like interviews, introspections, screen captures and *quantitative measures* like surveys, checklists and semantic differentials. During the development of an immersive application, it is essential to use formative evaluation, since this approach aims at optimising the product until launch. When implementing immersive learning environments, it is recommended to combine elements from both formative and summative evaluation strategies using quantitative and qualitative measures.

*Physiological measurements* can be used for evaluation of virtual environments applying *non-invasive methods* of data collection such as eye tracking, electrodermal activities or heart rate [LDC<sup>+</sup>10, KHO15]. Physiological signals provide valid and often unique data which are of

particular interest for the user experience, especially for the learning process. Furthermore, including physiological measurements will provide deep insights into effects like immersion and motivational impact. This combination is unique in terms of *quality and fidelity*.

Sensors can allow to collect physiological signals, which provide invaluable information for the assessment and evaluation of immersive learning environments. Physiological measures can quantitatively and objectively measure *users' subjective experiences* during the interaction with the virtual world [KHO15]. In contrast to *self-report questionnaires* or low ratings, which are used during or after the activity, physiological measures can be used to acquire user data at the exact moment users are engaged, immersed or in the flow, without disrupting the user experience. This approach is highly recommended for measuring interference-prone subjective experiences, such as flow or immersion.

For the immersive application usually, a smaller sample size (approx. 30 users) should be involved since the fidelity, and therefore the *complexity* of physiological measurements is much higher. The physiological measurements can be accompanied by interviews and thinking aloud protocols. In order to measure these variables, methods with different levels of fidelity should be applied. Such methods are the tracking variables for mapping different motivational states (between traditional and immersive training), embedded surveys for measuring usability, the fun of play and knowledge, physiological signals such as heart rate, electrodermal activity for measuring presence using NIRS and other non-invasive methods as well as interviews, checklists and thinking aloud protocols for *measuring usability and immersion*.

The results can be displayed as *inferential statistics* and calculated using quantitative methods like multivariate analysis of variance - MANOVA. In this way, it can be checked if there are *significant statistical effects* on motivation, interest and knowledge in comparison to traditional education methods.

The evaluation should demonstrate knowledge and skill development, user experience and most importantly, attitudes, motivations and engagement with the learning process.

## Summary

As seen above, authoring of virtual reality applications and the programming of the application logic is usually very complex process done manually by experts. This process is very time consuming, error-prone and is limited to the resources and efforts available. The application content should be linked explicitly in the application logic by the developer. They usually do not have any semantic description or classification. In the next section is described a method for

authoring intelligent immersive environments, that should reduce the effort and automate this process by using approaches from knowledge engineering.

#### 4.2.6 Optimisation of Authoring Process through the Use of Artificial Intelligence

The presented methodology for authoring of intelligent immersive learning environments proposes the use of a *knowledge-based* artificial intelligence and recent technology advances in the area of Semantic Web. A *semantic layer* is embedded in the immersive application and serves as a foundation for a tutoring system. The *smart tutoring system* can then evaluate the user performance based on the assigned tasks and their correct execution. The main objective of this method is to create a reliable, intelligent system, which deduces correlations and makes assumptions and evaluates the user behaviour.

The benefits of using knowledge-based AI with ontologies and reasoning engine, are that once implemented, there is no need for reprogramming of the intelligent system. The notation used for semantic web is understandable for both human and computer, which makes the adding of new knowledge and rules easy for users with no programming skills. Such a smart system preferable, because it reduces efforts and time for changes of the immersive application. Using knowledge-based system has following benefits according to [Hä19]:

- Easy reuse of application logic, interaction paradigms and specification for a domain;
- Facilitate the description of complex behaviour;
- Achieve automation of the authoring process;
- Instantiate and automatically parameterise simulations;
- And even go beyond the current (human) possibilities of scripting application logic

The method consists of the following procedure to implement the semantic layer:

1. Design general ontologies for the domains of the virtual world and subject matter and define the necessary queries for the training sessions of the tutoring system.
2. Check for inconsistencies and redundancy in ontology design with a reasoner (reasoning in the design phase).
3. Design the rules and inter-connections between its objects from different domains.
4. Check for under-constrained class descriptors and false results of the queries after reasoning due to bad design (reasoning in the design phase).
5. Link the ontology concepts with the graphical representations of the virtual world assets.
6. Populate the generic ontologies with instances of the virtual world, during applications initialisation and run-time.
7. Provide real-time performance reasoner to answer the queries about the domain, i.e. for evaluation of driving behaviour

### Implementation of the Knowledge Base

The knowledge-base contains different *small ontologies* that describe all *domains*, necessary for the application. The ontologies itself contain the taxonomies of the concepts and the definition of the relationship between concepts. Furthermore, in the ontology are defined the rules. Some of the domains of the virtual reality driving simulator for teaching driving include the description of the *virtual world* with its road network, the traffic regulations, the weather conditions, the vehicle and its dynamics, the driving student behaviour and his skills.

The first step is defining the domains and building up generic knowledge-base by reusing and extending existing ones. Defining ontologies is a very free process; there are always different possibilities to arrange new concepts and properties or write new rules. This process can be troublesome, especially if the knowledge should be extended in the future or other developers want to reuse it. The *guidelines* used for creating the ontologies are borrowed from [Hä19] and should facilitate later the merging and mapping of different ontologies. Some concrete guidelines are explained below:

- The language used to model an ontology should be English, and the characters used the ASCII character set.
- Short and intuitive concept names should be selected.
- The most common term that best defines the concept should be modelled.
- Unnecessary redundancy in the naming (combined words) like for example a property “hasState” should be avoided, all properties have to respect the “has” relation towards their concept, thus “State” is fully sufficient.
- Numbers or special characters in the concept name should be avoided.
- After adding a new concept, it should be verified that the “is a” relation is respected towards the parent concept. The same applies to properties, where a property has to respect the “has” relationship towards its concept.
- Balance between the width and the depth of the taxonomies should be kept.
- Easy extendable and reusable structures should be used.
- It should be kept simple.

The reason for using the *English language* is to avoid incompatibilities and thus maximise the reuse. It makes merging ontologies much more reliable. The choice for the English language is due to the limit to *ASCII characters*. Moreover, the use of English in sciences and engineering is widespread, and the language is succinct. For example, when deciding on specialising a concept or adding new member variables, always the later should be prioritised. A derived concept should be added if it is a common term in natural language. It should be avoided to add a massive amount of concepts that differentiate themselves only by one aspect. A simple example would be a “Colour” as property, adding a colour property to the concept “Object” avoids to define multiple derived concepts like “RedObject”, “BlueObject”, “GreenObject”, this dramatically reduces the depth and complexity of the taxonomy as well as making it flexible and reusable.

The further process of modelling the knowledge base after the design of the ontologies is to check for *inconsistencies* and redundancy in the ontology design as well as for under-constrained class descriptors and false results of the queries after reasoning due to bad design. This process is also known as reasoning in the design phase.

## Population of the Knowledge Base

Ontology population is the task of updating an ontology with new facts from an input knowledge resource [LNM19]. In the case of immersive virtual environments, the semantic layer is enriched with all entities from the static virtual world up to the dynamic user behaviour data. One part of the population is done during initialisation of the application, mostly if data is not changed during run time (i.e. user data, profile) as well as initial setup parameters. Changes in the virtual environment mostly triggered by the user interaction with the immersive system or by the tutoring system (i.e. creating new task) are populated during run time (see *Implementation of the Semantic Layer* 5.1.4 on page 203 as an example).

## Reasoning

The *active part* of the semantic layer is the reasoning module. A semantic reasoner also called reasoning engine is a software that can *infer logical consequences* from a set of asserted facts. The reasoner is the active element and also one of the most complex parts of the semantic layer. The reasoner can answer questions by incorporating stored knowledge about the immersive learning environment and the user and can make assumptions or deduce correlations. On Fig. 4.15 is described the reasoning process of the in PolyVR embedded reasoning system.

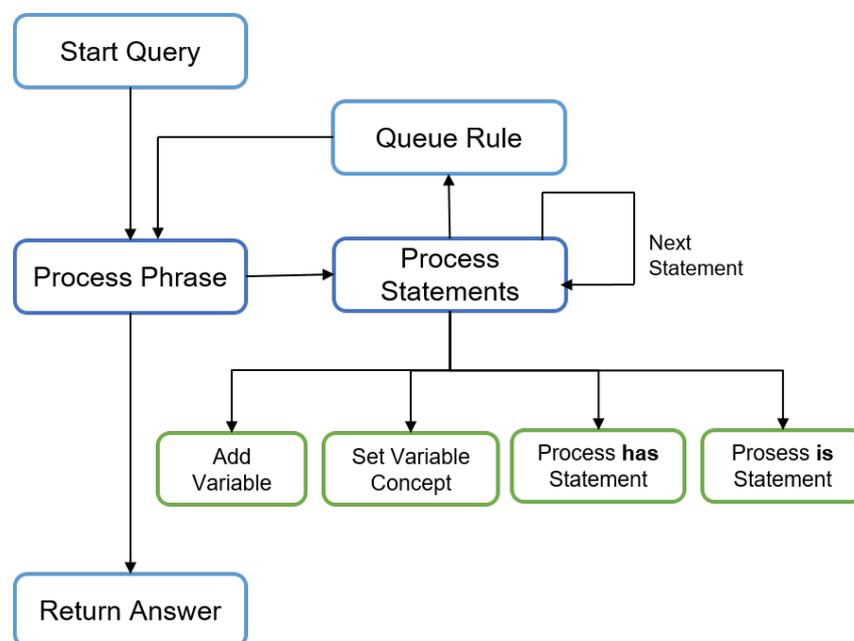


Fig. 4.15: Reasoning workflow of *PolyVR* adopted by [Häf17]

As described, the reasoning is a data mining algorithm, a system to allow to query information in a data set, while having the ability to infer and make assumptions. In this chapter we show

how to use it for intelligent interactive virtual environments, where the data to analyse is essentially the semantic information, the knowledge, of the virtual scene, and the queries are usually triggered through interaction of the user with the scene.

The tutoring system asks the reasoner with queries if the currently executed task is performed according to plan or there is a specific diversion. The reasoner can answer based on the knowledge populated in the ontologies in real-time, as described above. The generic workflow between the semantic layer and the immersive system is depicted on Fig. 4.16.

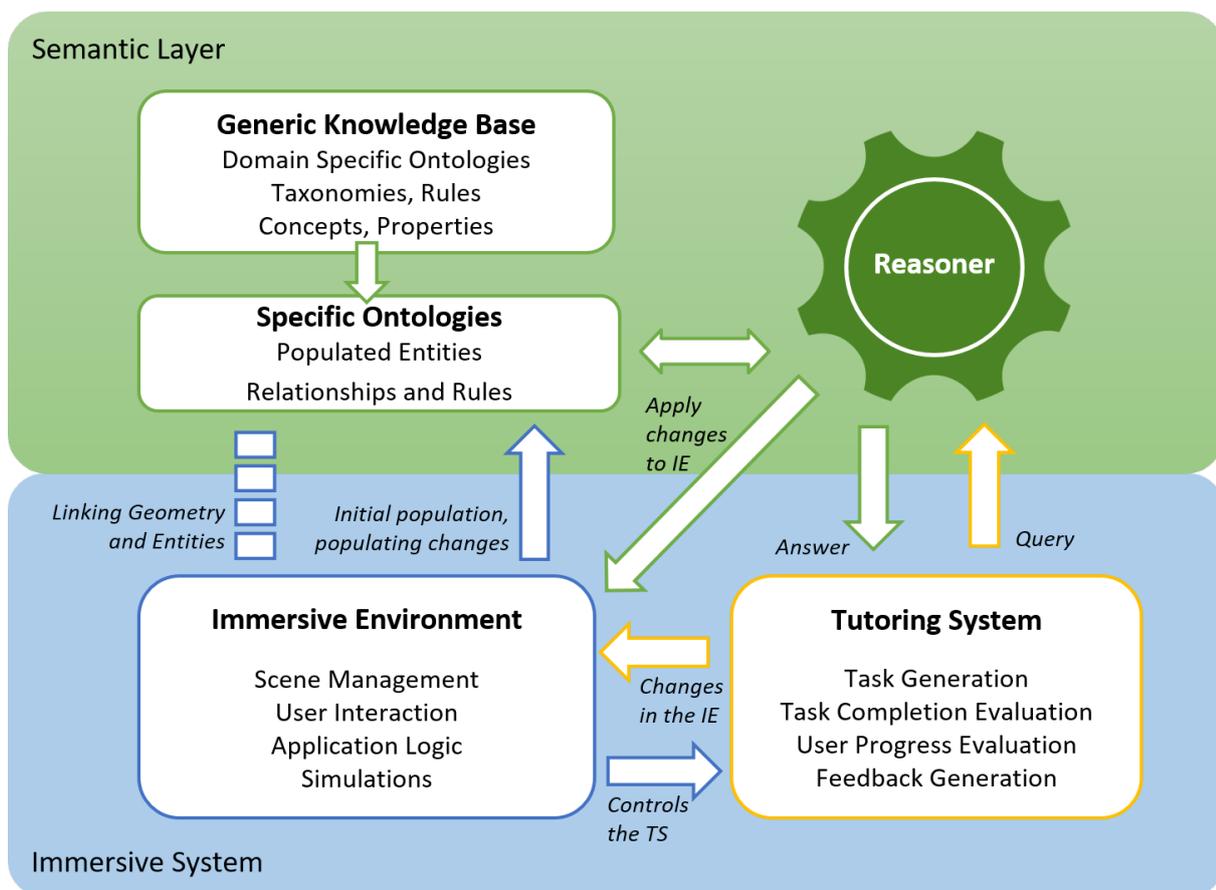


Fig. 4.16: The semantic layer and its interaction with the other components

The implemented reasoner enables the real-time evaluation of predefined rules concerning such as driving errors, task progression and user skill increase based on the populated data. The reasoner can change the virtual world directly, or this can also happen over the application logic. The application logic processes the signals from the hardware and thus from the user interaction and populates the data in the semantic layer in order the reasoner can analyse the current behaviour.

Whatever hardware setup is used for the learning application, it should be described in the generic ontologies and linked with the interaction and application logic to its visual representation and hardware signals.

An immersive learning application is highly dynamic. It has one update loop that is executed the user over the hardware interfaces can trigger each frame and events. Based on the change in the system and parameters with the coming events, the tutoring system should analyse the correctness of the user behaviour.

The method proposed in this work addresses the virtualisation of complex scenes using an ontology-based approach and the use of the semantic knowledge for advanced applications. It was validated based on an immersive driving simulator with an intelligent tutoring system, which is described in details in section *Immersive Driving Simulator with Intelligent Tutoring System* 5.1 on page 181.

## Summary

While the educational layer acts as a foundation, the technology layer is the *core of the methodology*. The *first part* of the technology layer contains an extensive *analysis of the benefits* and downsides of immersive technologies in education. The main objective is to guide key stakeholder groups to answer the question if immersive virtual or augmented reality can help solve the current instructional problems and meet the learners' needs for the specific educational program. Furthermore, it supports them to decide how to incorporate immersive learning applications in their courses. Based on extensive and well-established *categories*, one can create multifaceted questionnaires. The latter should be answered by different stakeholders and provide a comprehensive analysis of the current educational needs. In the next step, instruction designers can map the results to the main characteristics of the immersive technology, which should realise the identified potential.

Immersive learning environments are not beneficial in any case and may have some disadvantages. The *categorisation of the challenges and downsides* should provide educators with a tool (e.g. checklist) to verify for possible risks. The provided limitations categories of the limitations include issues connected to presence and immersion, learning outcomes, time and costs, health, communication, technology, acceptance as well as culture and ethics.

Furthermore, the author provides an extensive list with criteria for immersive system design. The ten *criteria for the design* of immersive learning applications proposed, include the type of knowledge and skills, the levels of immersion, interaction, fidelity, intelligence, gamification, communication, and virtualisation, interoperability and learning evaluation as well as further *requirements* such as real-time capability, sustainability, robustness, usability, safety and security, cost and time. They should guide educators to define the requirements and the subsequent steps when designing and implementing an immersive learning environment.

The technology layer also gives an overview of the *immersive resources* and defines *criteria for their selection*. Next to the knowledge and skills necessary for the development of immersive systems, this section provides an insight in the *authoring process*. The development of immersive environments has many challenges and pitfalls, for which inexperienced users have to be careful.

The section ends with a methodology for implementation of *intelligent immersive learning environments*. We apply technologies from the artificial intelligence and in particular the knowledge engineering domain to develop a system, that automates the world creation and the assessment of learners behaviour.

## 4.3 Management Layer

There can be different reasons to develop an educational program or module that uses immersive technologies, depending on the kind of organisation - school, university or company. However, next to the educational and technological tasks, there are some management aspects and tasks such as business analysis and strategic planning.

The education is related to some business aspects like the fact that more skilful people earn more money or the issue that a course or training are services that have costs, have a price and compete on the market. Educational institutions have many costs for designing, developing and delivering courses including educators, facilities, technology and many more. That is why a holistic view on educational programs combining the didactic, technological and economic characteristics is crucial for the overall success.

In the management layer section are described methods and tools to provide the life cycle management of an educational program or a module. The section includes the business analysis and strategic planning, the economic and benefit analysis and evaluation (see Fig. 4.17). Furthermore, it offers an extensive decision-making support process, which gives a solid foundation for a judgement if to apply immersive technologies in a particular teaching program or not.



Fig. 4.17: Structure of the “Management Layer” section

### 4.3.1 Decision Support Method

One important question before starting an immersive education project is whether it can pay off the efforts and costs. In many organisations, there is a need for *in-depth analysis* of the benefits

and the *economic effectiveness* before a decision for implementation can be taken. Management often do extensive research on the *return on investment* of a new technology, without having experience and deep understanding of it. It is challenging to make a calculation on profitability for non-monetary outcomes, mainly based on the human capital like learning. Often companies or institutions pass chances because of analysing and overthinking about the needed investments instead of starting directly with a small pilot project.

In this section, an extensive method is proposed that should help stakeholders to decide whether to implement a course or training based on new technologies like virtual or augmented reality or even intelligent systems. The method was first presented by Häfner et al. [HDSO18] and an adapted version is described in this methodology, in order to present a holistic approach for integrating immersive technologies in education.

The decision support process presented below consists of several steps that are arranged along the life cycle of an educational program and includes tasks from all three layer. (see Fig. 4.18).

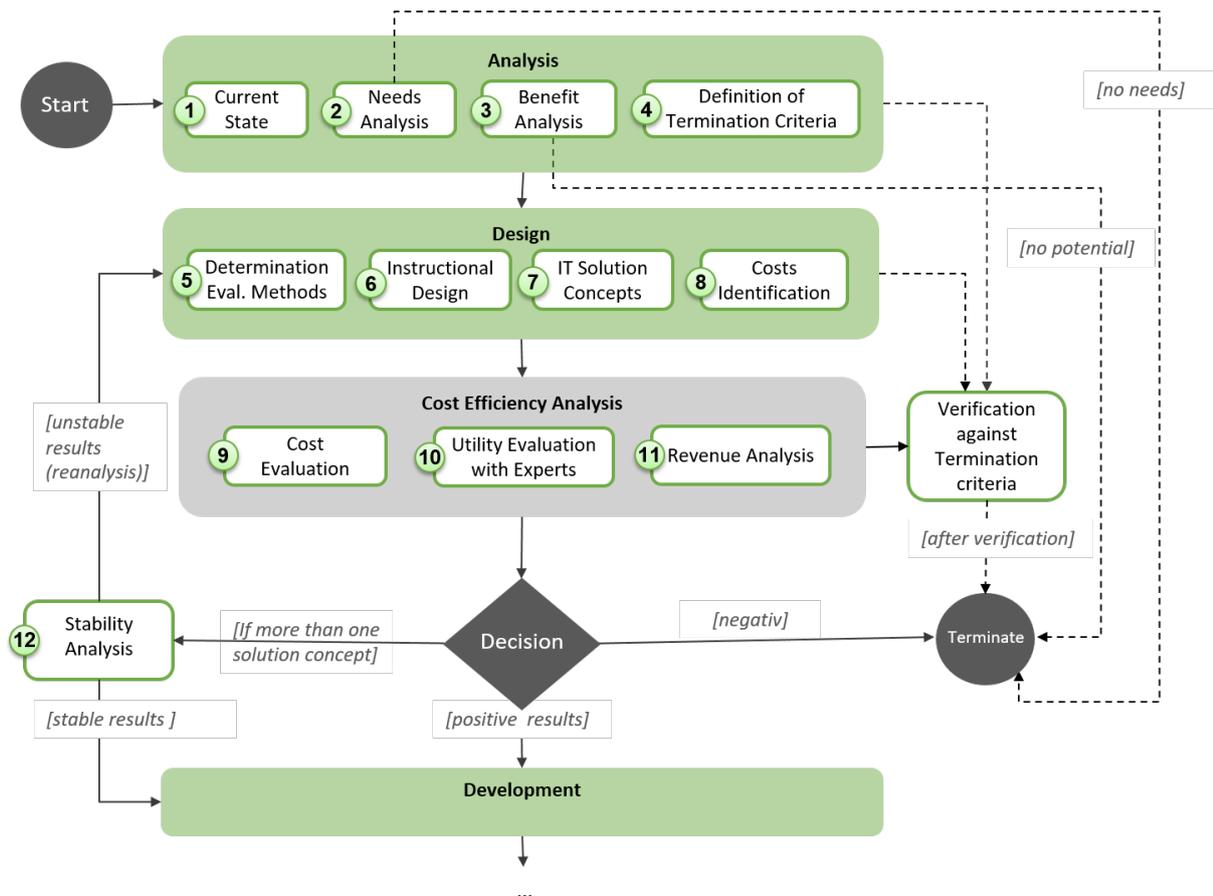


Fig. 4.18: Decision support method for embedding immersive technology in educational program, adapted from [HDSO18]

### **Step 1. Current State**

The process starts with the record of the current situation for all stakeholders. The current situation can differ depending on if there is already an existing educational program, that should align to new requirements, or it is going to be implemented new one. Next to the state of the educational program, this of the market situation should also be analysed. The current state of the overall situation for an organisation should be considered as described in *Recording the Current Situation* 4.3.2 on page 169.

### **Step 2. Needs Analysis**

The next step is the needs analysis, that is usually conducted for the leading target group (the learners) before the first draft of the instructional design is made. The analysis of the target group and their needs is described in the Educational Layer (see *Analysis* 4.1.1 on page 70).

### **Step 3. Benefit Analysis**

After the analysis of the current situation, the presented problems and the needs of the target groups, it is required to check if using immersive technology solution will be beneficial to solve those issues and to satisfy those needs. For this purpose, the methodology prescribes the carrying out of a benefit analysis based on the benefits categories elaborated in the Technology Layer (see section *Benefits of Immersive Learning Environments* 4.2.1 on page 106 and Tab. 4.13 on page 107). The methodology proposes as a tool a *questionnaire* as this presented in the Appendix A.2.1 on page 326. Furthermore, to identify the potential benefits of the use of immersive technologies for educational programs, next to a questionnaire, some interviews with all groups of interest can be conducted.

*All key stakeholder groups* have to answer questions to obtain a tendency statement on whether immersive technologies can be beneficial in their particular case. The concept of the model implies that the three primary interest groups: Learners, educators and managers, should answer the questions.

Course participants often perceive a training differently than an educator or the management does. While the management is responsible for the investment decision on establishing a training based on immersive technology, it is not always aware of the exact contents and procedure of the training session. However, it usually has excellent knowledge of the incurring expenditures. The educator knows best which knowledge and skills are most relevant and what can be potential difficulties and issues. He is responsible for finding a suitable teaching strategy, learning activities and for delivering relevant learning matters to the course participants [HDSO18].

The areas of high potential can be quickly identified when using questionnaires. The respondents can also be asked to rate the *importance* of the different use categories for the decision making such as participant motivation and engagement, a better understanding of the learning matter, cost-saving or others [HDSO18].

The questions in the questionnaire for benefit analysis can be ordered according to the previously defined categories (see 4.2.1) and formulated as statements concerning the different use aspects. Here an example for the formulation of a question in the category of better learning outcomes:

“Immersive technologies will be beneficial to use for improving the learning outcomes, if

- the understanding of the learning content can be improved by presenting it from additional perspectives, that are not possible to demonstrate with traditional methods.
- the understanding of the learning content can be improved by presenting previously invisible (not exposed) components or processes.
- better visualisation of the dynamic behaviour of the learning environment can improve understanding of the learning content. For instance, usage of simulations to understand action-reaction principles. What is the consequence of a specific action?
- the “trial and error” of different scenarios is important for understanding and so far time and resource-consuming
- for the learning of knowledge or motor skills, it is necessary to repeat the time consuming or resource-intensive tasks more often.”

Depending on the use case, there can be a need for higher granularity of the questions on the benefits and important categories. The proposed questionnaire was developed and validated in the frame of the project *Sewing Machine Training with Haptic Simulation 5.4* on page 280 [HDSO18] and can be seen in the Appendix A.2.1.

#### **Step 4. Definition and Verification against Termination Criteria**

Based on the limitations and downsides of the new technology and other organisational factors, termination criteria for the educational project have to be defined. A list of the possible termination factors should be created as soon as possible and be checked iteratively.

Depending on the specific educational program and the educational organisations there can be different criteria for termination depending on *external or internal factors*. Possible aspects for termination can be high acquisition costs, time limitations as well as safety, social or legal

aspects. One crucial issue that should be considered is if the knowledge and skills acquired in the virtual world can be transferred in the real world, and if recognition from other parties can be guaranteed.

The provided *classification* of the limitations and downsides of immersive technology for education can guide decision-makers in this step (see *Disadvantages and Challenges of Immersive Technology for Education* 4.2.1 on page 120). The questionnaire derived from the benefit analysis can be supplemented with some questions on the perceived limitations. A checklist to evaluate during this step can be created, as well. During the cost efficiency analysis, further evaluation of the benefits and downsides will be specified more concretely for each technology solution with experts.

### Step 5. Determination of Evaluation Methods

Based on the results of the SWOT analysis and the defined objectives, the evaluation methods for the educational project and the accompanying *key figures* can be determined. It is recommended to define criteria for monitoring of the success according to the objectives' achievement, the monitoring of the impact and the economic efficiency [BMF11] (see *Business Analysis* 2.4 on page 30).

The main questions are:

- Which are the expected results?
- How the results can be measured?

The evaluation can be based on *qualitative and quantitative criteria*. For instance, if the goal is to save time for the training, the reduction with one or two days can be set as a concrete qualitative measure. A qualitative result can be the increase of the learners satisfaction. It is crucial to convert the expected results in *measurable key indicators*. They should be used later to *monitor the execution* of the educational program and provide the bases for further evaluation. The quantitative results can be easily measured, and one should think about how to make the qualitative results measurable. For instance, advancing our example on course satisfaction, giving the students a scale to evaluate the course before and after, can help in better tracking an increase or decrease of satisfaction [HDSO18].

### Step 6. Instructional Design

The process of instructional design encompasses all consideration around the learning goals, activities and their evaluation and results in a tangible concept for an educational program. This step is presented in details in the Educational Layer (see *Instructional Design* 4.1.2, page 73).

### Step 7. Design of Immersive Solution Concepts

Parallel to the instructional design, the suitable technology solutions are designed. The proposed method recommends to create more than one solution concepts in different price segments and distinctive advantages that can be later evaluated against each other in the cost efficiency analysis step.

The differences in the concrete immersive solutions can come from many factors like:

- Which knowledge or skills types should be acquired?
- Which fidelity level of the virtual world will be sufficient?
- Which interaction level (input and output devices) is necessary?
- Which immersion level is necessary (which implies the quality of devices and interaction)?
- Is communication with other learners over the ILE necessary (which implies an implementation of a multi-user online world)?
- Which are the time constraints and the number of participants?
- How the learning outcome will be evaluated (inside or outside of the virtual world)?
- Who is going to develop the virtual learning environment (internal or external for the organisation)?

If there is no experience of immersive technologies in the organisation, it is recommended to adapt the identified needs and potentials with the *help of experts* in the area of immersive technologies. In some cases, this can be *external contractors*, who will later provide offers for the different solutions and advise the organisation about the *alternative solutions*. Consultants and educators can provide together the first designs of the alternative technology solutions and provide all relevant costs. It should be clear that not any solution can help to reach all identified benefits equally, and it is recommended to define *several solutions* in different *price segments*. This will provide a good foundation for the decision making, and further economic consideration and cost-benefit analysis. After the alternative designs of the immersive learning environments are defined, the possible potentials should be considered again with the experts and the benefit analysis should be updated, in order to achieve a more realistic prognosis for the final potentials [HDSO18].

### **Step 8. Costs Identification**

After the instructional design and the alternative immersive solution concepts are defined, there is a need of detailed identification of the costs for the whole educational project (as described in *Financial Resources and Costs Identification* 4.3.3 on page 170).

### **Step 9. Cost Evaluation**

The step 9, 10 and 11 are connected to the audit of the *economic efficiency*, which examines whether the most favourable relationship between the objective pursued and the resources employed has been sought and achieved. The first of those step includes the *pure cost evaluation* step based on monetary criteria that includes both one-time and ongoing costs categorisation (for more details see *Cost Evaluation* 4.3.3 on page 171).

### **Step 10. Utility Evaluation with Experts**

Another way to evaluate the benefit, where the assignment of a monetary value to the measure of effect is not possible, is a cost-utility analysis. A benefits analysis is carried out again, but this time with experts, which should provide more precise prognosis on the realised potential for each designed solution concept (see also *Cost Evaluation* 4.3.3 on page 171).

### **Step 11. Revenue Analysis**

During this step it is time to consider the available budget and, if applicable, the income that the educational program will bring. Profit organisations should take care of the *business model*, and non-profit organisations may need to apply for *funding* (see also *Cost Evaluation* 4.3.3 on page 171).

### **Step 12. Stability Analysis**

The analysis is completed when with the stability of the result are checked. Since many parameters are included in these calculations, it should be examined to what extent result changes if the input parameters are slightly varied. For instance, the percentage weightings of the criteria can be varied. If this does not change the final result, one can speak of a stable result [Sch14].

## **Decision**

Two main results support the *decision on alternatives*. One of the result is *qualitative* and based on the benefit analysis. The second is *quantitative* and based on the monetary calculations. One immersive solution may be ranked in first place for both analyses. In this case, the stakeholders should decide which is more important.

Based on those results, the management and educators can decide if they are going to maintain the available training such as it is (if already existent) or advancing the educational program with an immersive learning system.

## **Development**

At this stage, it is recommendable to implement a *pilot project*, if it is an option, before starting with the implementation of a big and expensive project. A pilot project will help to collect experience with the technology, test and validate the learning outcomes and see if the estimated benefits are correct. The project can be managed with a small budget, less efforts and small user numbers. The *collected experience* with the technology will support the further decision making. This approach is also known as validated learning approach described by Ries [Rie11]. At the same time, this will help to save resources and efforts if the application of this technology was proven to be not suitable for the target group needs.

This method should provide stakeholders with a solid base for the decision, whether to create a new educational unit based on immersive technologies or not.

### **4.3.2 Business Analysis and Strategic Planning**

The strategic planning in an organisation foresees activities like defining strategies in the form of *strategic goals*, allocating resources and determining actions to achieve those goals and finally the evaluation of their impact. It is vital to have a plan, but it is necessary to remain open for new opportunities and changes during the development. A proper analysis at the beginning of such a project can help to save efforts, time and costs and at the same time will increase the chances of providing an appropriate learning environment and desired learning outcomes. The analysis phase should try to collect enough facts and data as a solid foundation for the decision making processes: whether the planned project should be realised and how. It should be prevented that a decision is made in advance based on emotions or so-called gut feeling, because one only looks ex-post for reasons for decisions already taken.

In this section, we will describe the initial tasks of the methodology for analysis and planning, like the methods for recording the current situation, the definition of the strategic goals and the determination of evaluation methods.

## Recording the Current Situation

During the analysis phase, next to the target group analysis and their needs (see section *Target Group Analysis* 4.1.1 on page 71), the current state of the overall situation for an organisation should be considered. It can be the case that there is no existent training and a new one is necessary. Alternatively, there is already an educational program that should be *optimised* based on feedback and *recommendation* by the participants, or there are some *efficiency problems*.

An excellent foundation to start changing is to capture the current state. This methodology recommends the description of the current educational program and educational issues, together with the organisational and technological boundary conditions, like available resources and others. Some external factors for the organisation, such as competitors, policies, or others, are also important. There is a tool called *SWOT* that helps companies during the strategic planning to analyse the actual situation (see *Business Analysis* 2.4 on page 30). This tool supports the identification of the *general needs* and *optimisation potentials*. The *SWOT analysis* is based on the description of the strengths and weaknesses as well as the opportunities and threats [HW97]. It provides *state-in-time snapshots* and should be performed regularly in order to check the strategic position of an organisation and its field of operation. The strengths should give information about the advantages that a company, the specific project or product have over the others. The opposite will be the weaknesses that represent the disadvantages compared to others. Both strengths and weaknesses are internal factors that can derive from human, financial or physical resources such as activities or experiences. There are many circumstances that educational organisations or companies cannot influence. Those external factors are summarised under the categories of opportunities and threats. The opportunities represent the environmental conditions that bring advantages over others, and threats can be harmful for the business or project. Some external factors can be connected to politics, world or local economics, demographics, natural catastrophes and many more.

## Objectives, Requirements and Resource Planning

Depending on the organisation, there can be different strategic objectives. The latter should be periodically defined, and their achievement evaluated. A *strategic objective* can be the launching of a new training as well as the optimisation of an existing one. The initial analysis will

support the process of defining objectives on the management level and also contribute to defining the concrete instructional goals (educational layer). This topic is addressed in the section *Instructional Design* 4.1.2 on page 73.

Allocation of resources is also part of strategic planning. In the methodology, the tasks connected to the planning and allocation of resources are spread over the layers in the design phase (see *Educational Resources* 4.1.2 on page 87, *Immersive IT Resources* 4.2.3 on page 136, *Decision Support Method* 4.3.1 on page 161).

Technical projects need a *requirements* definition in order to ensure a successful implementation of the system. With the help of these requirements, it should be defined what a system must do to satisfy the stakeholders needs (see *Business Analysis* 2.4 on page 30). Further, the requirements drive the project activity and serve as navigation through the project [DHJ17]. When an educational organisation that has no technology experience orders an ILE system from an external company, the project requirements provide the basis for the planning of the system and its trouble-free acceptance on completion. Furthermore, the requirements definition allows a *risk and change management*.

As a requirements analysis method, *interviews* of all key stakeholders and experts and *questionnaires* are recommendable. In this thesis, the procedure from our preliminary work is adopted [DHO16]. The focus was transferred from the integration of virtual reality in the industry to the application of immersive technologies in education. For this purpose, the questionnaires were adapted, the cost-benefit categories were supplemented, and analyses were simplified and made more concrete. The specific thing about the questionnaire is that the participants are introduced to the topic during its completion, since the use of immersive technologies is not yet widespread. Employees from different departments should answer the questions in order to provide general information about the willingness to invest and the relevance of the project for the company. At the same time, the requirements are queried via possible applications. The requirements are later specified, together with experts, based on the questionnaire results.

### **4.3.3 Economical Analysis**

#### **Financial Resources and Costs Identification**

Educators with less experience in economics or project planning can struggle with the preparation of the needed budget for the new course, especially if it requires *novel or sophisticated technology*. Some backgrounds on costs structure as well as some tools, are presented in section *Business Analysis* 2.4 on page 30. Technology factors like high fidelity and interaction level of the virtual world can imply higher costs for the immersive system. In Tab. 4.18 are

proposed additional questions to determine the available and necessary resources, which should help consider the ILE budget.

✓	Should new hardware or software tools be purchased?
✓	Do immersive applications for the achievement of the learning goals already exist off-the-shelf or should they be customised or implemented from scratch?
✓	Should new staff be hired or the existent one trained?
✓	If there is a limited budget available, how will it be distributed on hardware, software, educators, materials and other activities in order to achieve the learning goals?
✓	Are there incomes from courses such as registration fees that can be used for budgeting learning resources and generate profit?

Tab. 4.18: Identification of the necessary resources

In general, there are *one-time costs* that are made at the beginning of an investment project (see Tab. 2.4 on page 31) and *running costs* that are repeatedly occurring over the usage of a system. Among the running costs, there can be direct or indirect operating costs as well as overhead costs (see Tab. 2.5 on page 31). Some costs should be estimated, for instance, increased hardware costs due to unplanned outages. Those unknown costs can be handled by involving risk levels.

The costs that need to be considered and provided for are as follows:

- Investment costs for both hardware, software and services (project costs, installation, customisation, teaching),
- ongoing cost for maintenance of immersive solution per year (support, updates, repair, warranty costs),
- average operating costs per year (like personnel, machine downtime, consumables).

## Cost Evaluation

The audit of economic efficiency examines whether the most *beneficial relationship* between the objective pursued and the resources employed has been sought and achieved. The commonly used methods for economic efficiency analysis or also called profitability analysis are categorised in Tab. 2.6 on page 32. The educational applications usually have a lot of non-monetary objectives, and in this case, a utility analysis is recommended within the framework of the cost-benefit analysis.

If the *benefit analysis* shows that the added value is high enough, it is worth conducting a detailed cost evaluation. The various *alternative solutions* are then analysed using a utility evaluation in qualitative areas with the help of experts as well as a static investment calculation, which next to pure cost evaluation of alternatives, includes profitability comparison, calculation and amortisation.

### Pure Costs Evaluation of Alternatives

The cost evaluation based on monetary criteria includes both one-time and ongoing costs categorisation. The calculated results can be plotted in a diagram with axes for costs and time, since ongoing costs are calculated for one year. Additionally, the amortisation and the net present value can also be added in the calculation and supplement the first pure cost evaluation of the different systems. The results can be compared quickly based on one number of the *same order of magnitude*. In order to compare the relative costs and the benefits of the different solutions, a cost-utility analysis should be made.

### Utility Evaluation with Experts

The second way to evaluate the utility is a non-monetary benefit analysis. It is based on the initial benefit analysis, where the identified benefits were estimated by the stakeholders, who should have no or less experience. This time the realisable benefits should be *estimated by experts* for each alternative solution. The assessed benefit factors can be arranged on a scale from 0 to 100, where 0 means not beneficial and 100 fully the application of the benefit [DHO16]. For this purpose, a *spider chart* is appropriate for the visualisation of the results (see Fig. 4.19). It is recommended to use only five to ten benefits, arranged by the priority set by the stakeholders.

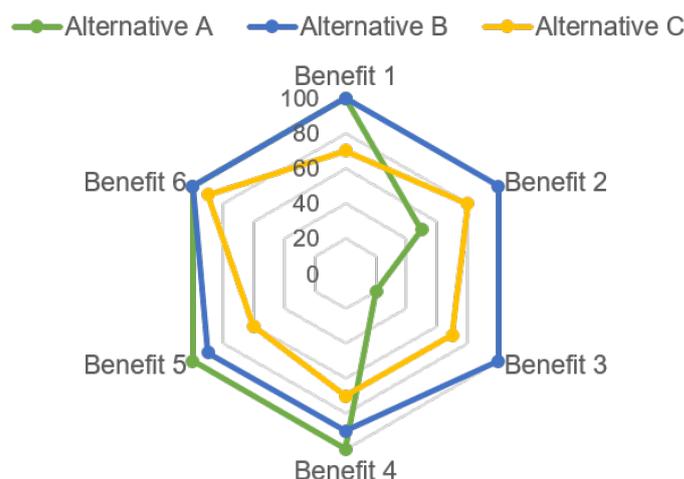


Fig. 4.19: An example of spider diagram of different solutions and their benefits

Further analyses such as *cost-effectiveness* or cost-benefit analysis may be carried out (see further details in [DHO16]).

### **Revenue Analysis**

The revenues of the delivered educational program can also be considered in the cost evaluations. Despite if profit or non-profit organisation, the investment costs at the beginning and the ongoing costs demands the availability of a *budget*.

### ***Profit Organisations***

Usually the profit organisation plan to *generate revenue* and profit from the educational program. In this case, an additional step in the cost evaluation should be the development of a *business model*. The most fields of a business model are already covered in the analysis and the design phase, but revenue streams should be additionally identified. One of the most used tools is the business model canvas, which provides a good overview for all stakeholders [JP16].

### ***Non-Profit Organisations***

The economic situation of the non-profit organisation that should provide the immersive technology education should also be considered in terms if funding is necessary and what funding opportunities are available. Covering the methodology steps and layers of the design process gives the first outlines and provides a solid foundation that can be used for *funding application*. Organisations can apply for public funds, donations, support from government agencies, income from organization's activities, fundraising activities, and membership dues.

## **4.3.4 Management of the Project Development and Deployment**

After the analysis and design phase, the tasks of the management layer are mostly related to the management of the project development. Parallel to the development of the training materials, many administrative tasks and preparation activities like management of the *human and financial resources* should be done. Furthermore, tasks connected to risk, quality and change management should be considered.

## Preparation Activities

In the area of *human resources*, the persons responsible for the management should carry out the planned measures. Such measures can be the recruitment of experts who will support educators in the implementation of the immersive learning environment or during the training with immersive technologies. Another task can be the training of the educators or other team members to enable them to author or teach with immersive technology, depending on the project needs. Hiring experts is, in general, a time-consuming process as there may be a lack of experts, especially in the area of virtual and augmented reality.

Further planned activities can be the *purchase* of the development of an immersive learning system from an external contractor and the management during the development. Another case will be to buy off-the-shelf immersive hardware and software, that is going to be embedded in the traditional educational program. Some organisations have a very complex buying process, which makes each purchase a time-consuming task, and this should be taken into consideration.

## Marketing

The marketing of the educational program can start as soon as the minimum viable product is developed, and there is a proof that the designed training can be provided. Marketing activities can be necessary in order to find course participants. It will be ineffective to spend much time in creating a great course, buying costly immersive media and at the end, there are no or fewer registrations. The target group and the *communication channels* are already identified during the analysis. Furthermore, the essential information, the potential participants need to know, is already elaborated during the design. The best marketing instrument is the word-of-mouth *recommendation*, but at the very beginning of a new course, this is not possible. Once the first course is held and the participants are satisfied, they can later recommend the course to their colleagues or friends. Next to the distribution channels, the presentation form and content are of great importance. All *relevant information* should be provided, as described in the instructional design.

- *Organisational Information.* The target group should get information about when the registration starts and where and how to register, where the first course will take place and who is responsible for the course with contact information and where they can get further information.
- *Learning Outcomes.* The decision on taking part in the course lies strongly on the learning outcomes. The most learners are interested in the skills as well as in the recognition they are going to gain. For example, all theoretical knowledge and skills the students can achieve during the educational program should be listed.

- *Course Content and Structure.* How the different units of a course are structured accompanied by all important dates, time and places. For instance, answers to the questions when the course starts, how long is each unit, when exams should be given and similar.
- *Learners Assessment.* The learners should get brief information on how the evaluation is going to be realised, which skills will be graded and how they are going to be assessed (i.e. oral, written exams).
- *Media.* A short description of the equipment and media used for teaching can provide good advertising for the educational program. It may be of advantage since immersive technology is still novel and attractive.
- *Additional Information.* Any other information that can be beneficial for the potential participants should be provided and made easily accessible. An example can be the background needed to take part in the course or the price and the payment methods, if applicable, and many more.

## Deployment

With the begin of the educational program implementation, it should be ensured that all preparations are done, and everything is ready for its deployment. The learners have all the necessary information to make their decision and to enrol in the course. The main tasks of the *project management* in this phase are the *executing* and *controlling* of the plan to achieve the set goals. One should be aware that not everything can go according to the plan. That is why the management of issues during the project implementation is from crucial importance. Main areas for management are *risk, quality, resource and change management*. Educators should take care that the hardware and software resources are used with caution and that the course takes place in a friendly atmosphere. If necessary, some *conflict management* should be performed to enhance learning and group outcomes.

### 4.3.5 Overall Project Evaluation

The evaluation of the overall project is a combination of the evaluation of the educational, technical and management aspects in the different project processes. The main objective of the evaluation is to find *evidence* if the learning experience with the novel immersive technology was *effective and efficient*.

In the proposed method for decision support, a step for determination of the evaluation, quantitative and qualitative criteria was added at a very early stage (see *Decision Support Method*

4.3.1 on page 161). Those criteria were defined based on the analysis, goals and expectations for the results.

During the technology implementation process, some *formative evaluation* is necessary, since this approach aims at optimising the product until launch. A formative evaluation should also be done continuously from an educational perspective, during the delivery of the educational program and can provide summative evaluation for the technology as described in *Evaluation of Immersive Systems* 4.2.5 on page 152. The collected data and results should then provide the *summative evaluation* for the whole project.

The *feedback* required by the main target groups like managers, educators and learners should be analysed and checked against the *key performance indicators* defined at the beginning of the project. If data from previous courses are available, a comparison between traditional and immersive educational methods can also be made. Furthermore, the criticism and the suggestions for optimisation should be seriously considered, and *corrective actions* should be taken in order to improve the teaching performance.

The *business aspects* should also be analysed. For instance, an *economic target-actual analysis* can be performed. This analysis is essential for controlling in a company, which makes a comparison between the plan values and the actual values spent on a project [Sch17b]. This information is vital for the optimisation of the strategic planning and budgets for further projects.

On the one side, if the application of the developed immersive application revealed the *full potential* of the analysis, the decision-makers can decide to use it in the future. Furthermore, they can expand the software features and try to reach more users. The extension to further learning content or domains is also possible. On the other side, if the evaluation showed that *not the full potential* is achieved, there can be used those features that bring the most benefits. In the worst scenario, the project can be cancelled due to *poor performance*.

## Summary

The management layer serves as a frame of the educational and technological layers. It encompasses two main parts in the area of project management.

The first part discusses in-depth the tasks in the analysis and design phases to build upon a decision-making support process. This process starts with the analysis of the current state and needs, albeit from the (educational) organisation's perspective. It uses the technical analysis on the benefits and downsides to create tools such as questionnaires or checklists and to capture the technology potential according to all stakeholder groups. The decision support method prescribes the identification of the costs for the instructional design and the IT solution concepts.

The central step is the performance of a cost-benefit analysis and a utility evaluation with experts to validate the instructional design and select the optimal solution for the immersive system.

The second part of the management layer stresses on the importance of the project management activities but does not describe them in details. It deals with the classical tasks of the project management such as human resources, marketing, monitoring and quality, risk, change, conflict management, as well as the overall project evaluation and optimisation.

## Summary of the Methodology

The proposed methodology builds upon *three layers* (see Fig. 4.20). The educational layer serves as a foundation, the technical layer as a core and the management layer as a frame. All layers are strongly connected and interrelated. Thus they should be considered together. In the *educational layer* are presented state-of-the-art didactic methods and learning tools, which cover different kinds of educational objectives. It is structured along the life cycle of an educational program, which consists of five phases - the analysis, design, development, deployment and evaluation of an educational program (see *Educational Layer* 4.1).

One of the central thesis objectives is to guide the key stakeholder groups to decide if immersive technologies can help them solve the current instructional problems and meet the learners' needs. In order to achieve this goal, the *technology layer* presents an in-depth analysis of the benefits and downsides of immersive technologies in education (see *Benefits of Immersive Learning Environments* 4.2.1). Moreover, this technological benefit analysis is combined in the *management layer* with a cost-effectiveness analysis and provides a solid base for the *decision-making process* (see *Decision Support Method* 4.3.1).

The categorisation of the challenges and downsides of the immersive technologies in educational context should support the design of the immersive system and the *risk management* (see *Disadvantages and Challenges of Immersive Technology for Education* 4.2.1). The criteria for the design and authoring of immersive learning applications and the list with the immersive resources provides a solid base for the determination of *system requirements* (see *Immersive IT Resources* 4.2.3 and *Design of Immersive Applications* 4.2.2).

The *technology layer* describes the authoring process with its particularities and difficulties, which can serve for the better preparation of the teaching activities and the implementation of an immersive learning environment (see *Development of Immersive Applications* 4.2.4).

The main goal of the presented methodology is to go a step further in the development of immersive environments adding *smart elements*, especially those for implementing a tutoring

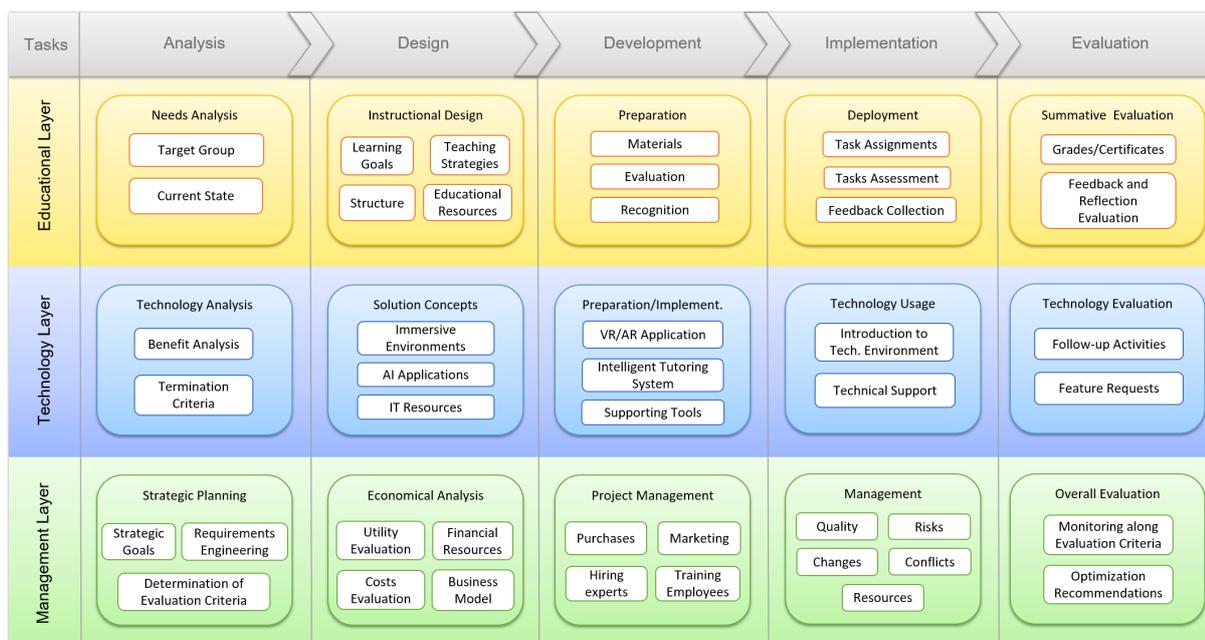


Fig. 4.20: The tasks covered by the methodology

system for achieving intelligent immersive learning environments. The proposed method should reduce the efforts for developers and instructors. It uses *knowledge-based technologies* from the area of logic-based artificial intelligence to create a *sustainable* and intelligent tutoring system. The semantic layer of the tutoring system includes all necessary information for the domain and the concrete entities of the application in order to deduce correlations, to make assumptions and to evaluate the user behaviour and performance (see *Optimisation of Authoring Process through the Use of Artificial Intelligence* 4.2.6).

The *management layer* section combines the life cycle management of an educational program and those of the development of an immersive system and propose methods and tools related to the business analysis and strategic planning, the economic and benefit analysis and evaluation (see *Management Layer* 4.3).

The methodology provides a *holistic approach*, discussing all aspects of the process of creating different educational formats that embed immersive technologies. It has an *adaptive design* and provides a *reliable framework* for educational programs where the learning matter and objectives can be easily changed based on the skills needed, which ensures the *overall success* of its application.

## 5 Validation

This chapter presents several examples of educational projects that use immersive technologies and has the goal to show how the methodology could be concretely implemented. Each validation use case has a strong focus on a specific layer or part of the process, which could be seen on the table “Overview of the methodology validation” (see Fig. 5.1). It shows which aspects are covered and to which extent. Each project tries to answer a specific research question and to achieve the defined goals. Furthermore, the validation use cases cover a long educational period, giving examples for secondary, higher, vocational education and on-the-job training.

Project	Layers	Analysis	Design	Development	Deployment	Evaluation
DriveSim	D	●	●	●	○	○
	T	●	●	●	○	○
	M	◐	◐	◐	○	○
VRPC	D	●	●	●	●	●
	T	●	●	●	●	●
	M	◐	◐	●	●	●
MINT-Box	D	●	●	●	●	●
	T	●	●	●	●	●
	M	◐	◐	◐	◐	◐
Haptic Sewing	D	●	●	◐	○	○
	T	●	●	◐	○	○
	M	●	●	○	○	○

Legend

	Didactic		Technology		Management
●	in-depth	◐	non-exhaustive	○	N/A

Fig. 5.1: Overview of the methodology validation

The project “*DriveSim*” concentrates on the design and development of an immersive training environment, that uses *intelligence* in order to facilitate educators, learners and the corresponding educational institutions. This use case does not cover the business layer in details. It shows how to *increase the efficiency* of the authoring process of immersive learning applications using

algorithms for *open-world generation* and an *intelligent tutoring system*. This goal was achieved by extending current authoring tools with features for automation of the authoring process. The *DriveSim* application provides a *proof-of-concept* for the intelligent tutoring system. In this way, the efforts for creating ILEs could be minimised and time and costs to be saved.

The *virtual reality practical course (VRPC)* is an educational unit for *higher education* that uses *constructive* immersive learning environment and a *project-based learning* approach to teach virtual reality technology, STEM subjects knowledge and soft skills. This use case covers almost all layers and processes of the methodology and provides its continuous validation. The project answers the research questions on how to systematically apply immersive technology in an educational context, which are the main aspects that should be considered during a course design and how to follow the course life cycle steps optimally for better learning outcome. The evolved methodology from *VRPC* could be applied for a *wide range* of target groups, especially *multidisciplinary, multicultural* and *multi-age* learners.

The *MINT-Box* project provides an excellent example for the combination of teaching STEM subjects and utilisation of immersive technology in *secondary education*. It proves some benefits of immersive technologies for education and provides a non-conventional didactic methodology for the usage of virtual reality in the classrooms. This use case covers all aspects of the proposed methodology, but in different level of details. It answers mostly the question of how immersive technology could be applied for learning and gives concrete examples of teaching STEM subjects in secondary schools, grades 9 through 12. The project also shows which learning theories and methods could be applied and which learning outcomes could be improved, applying immersive technologies *in schools*.

The project “*Virtual Simulation of Sewing Machine*” presents the validation of the *management layer* in the early stages of the training life cycle. It uses the elaborated in this methodology processes and tools like the classification of the benefits and downsides as well as the proposed *decision-making process*, including cost evaluation, utility analysis and others. The validation of the business aspects was conducted by virtual reality experts and members of the company management, that had no initial experience with immersive technologies and VR training. The technical part of the project is implemented on *proof of concept level* and includes the usage of advanced VR technology like *haptic devices*.

## 5.1 Immersive Driving Simulator with Intelligent Tutoring System

Driving is a widespread activity that permeates the whole society. Learning how to drive safely is vital for all traffic participants. Mainly, young or new drivers who lack experience cause the most crashes and are responsible for the high rate of accidents. The *DriveSim* project was a joint research and development project between a *Chinese start-up* company and the research institute for *Information Management in Engineering of KIT*. The work on the project was conducted between 2016 and 2019 by Victor Häfner, Michael Schröder, Felix Michels and Polina Häfner [Ins17]. The main benefit and focus of this validation use case lies in the design and implementation phase of an immersive intelligent driving simulator. It should present how complex can be the implementation of an immersive learning application and how good design can facilitate later the tasks of a driving instructor. The initial analysis is presented compactly, and user evaluation is not provided.

### 5.1.1 Analysis

The analysis for the *DriveSim* project was conducted based on *interviews* with stakeholders from the driving schools, regulator organisations and policymakers. Additionally, project partners conducted interviews and questionnaires with students at universities as well as driving course students in different phases of their driving education. Experts such as professors and researchers from universities and professionals from different companies in the area of automotive, electronics, IT technology and particularly immersive technologies supported the decision-making process. Next to the improvement of the learning outcome, the project *DriveSim* aims to create a novel product, that is why next to the didactic and technological aspects, we considered actively the economic aspects. For this task, we used current *statistics* in the area of driving education in China. We analysed the possible benefits and issues of immersive driving simulators based on the technical analysis of this methodology (see 4.3.1) and some further evidences from the *literature*.

#### **Analysis of Current State and Needs**

##### ***Current State of a Driving Course and Examinations***

There is plenty of theory to be learned and skills to be trained to obtain a driving licence and learn how to *drive safely*. The role of the driving instructor is to teach students the traffic rules and how to handle a vehicle safely. After an introduction to the theory like traffic rules, safety driving procedures and emergencies, the driving instructor teaches the students in *practical driving*, i.e. how to use a steering wheel, how to reverse and park as well as how to drive

according to the rules under urban and highway traffic conditions. Essential characteristics that a driving instructor should have are patience, excellent communication and teaching skills. Usually, the duration of a driving licence course is 3 to 5 months, but can vary in different countries. A driving course usually consists of theory part and practical driving (for detailed information see Appendix A.3.1).

### ***Current State of a Driving Schools and Driving Students***

For the business case, we evaluated the current state of the teaching activities and *quality* in driving schools along with the *economic situation*. In 2015 in China, the total number of drivers was 22 per cent of the total population. According to an internal report in 2015, there are approximately 13 800 driving schools, 686 300 driving instructors, 534 000 driving school vehicles and 3.4 million driving graduates in China. Fuyang, one of the ten urban districts of the prefecture-level city of Hangzhou in China, has up to 500 driving exams per day. Where the population of Fuyang district is around 750 000 and the Hangzhou prefecture has currently over 10 million people. According to the conducted research, the driving instruction market volume exceeded 100 billion CNY in 2015. Another indicator of the *rising demand* is the sales of passenger and commercial vehicles in China, which grew exponentially from 2009 to 2016 (see Fig. 5.2).

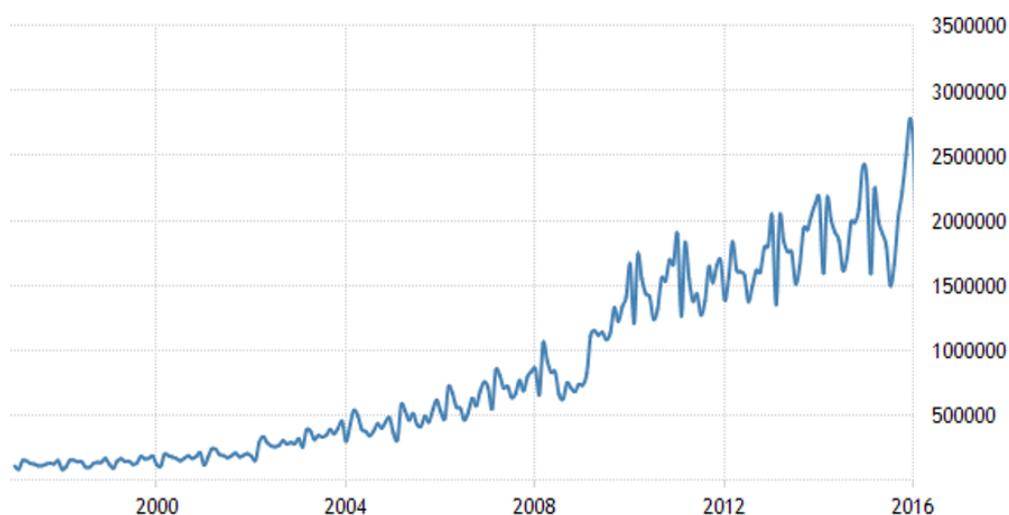


Fig. 5.2: China total vehicle sales for the period 1997 - 2016 [TE20]

Based on the *interviews* with driving schools and driving students following issues of the *current situation* in China's driving schools were detected. The enormous demand leads to *overburdened driving schools*, with not enough driving instructors and driving cars. Due to the nature of the driving instructor business, it *cannot scale* in time because the lessons are always one to one.

Driving students complain that it takes a *long time* to get a driving licence, and the quality of the training is declining. Especially in fast-growing regions, there is a rising demand for driving licences and a significant *lack of driving instructors*. Students cannot drive all necessary hours of practical lessons, which leads to often failure on the practical exam. Often students are forced to share driving lessons with other students in a car. In such cases, effectively everyone has only one-fourth of the time spent on driving.

In China, the students practise the most of the time on the *training ground*, which is a closed and *controlled environment*. The time spend under real traffic conditions is much less, which leads to difficulties and dangerous driving situation later. At the same time, the training grounds are overcrowded with training vehicles.

The driver training is limited mostly to vehicle control skills and knowledge of traffic regulations. There is no practical training on higher-level driving skills like risky situations.

The above-mentioned issues lead to the need to provide infrastructure for more students simultaneously. One possible solution is the building of new training grounds, buying of new driving school cars, as well as teaching and licensing of more driving instructors. Such measures should help to raise the quality and the safety of instruction, but it is a costly and time-consuming solution as well as depend strongly on the legal authorities.

### **Solution Concept based on Immersive Technologies**

The results of the provided analysis showed that there is a need to improve the learning and training of driving. One possible solution is to *extend* the available infrastructure of driving schools with *virtual reality driving simulators*. Those simulators should be *easily accessible* to everyone. Immersive driving simulators should bring the driving experience near to the real one and should enable a *safe environment* for training of the practical as well as theoretical skills. Additionally, the possibility of learning higher-level skills like an emergency could be enabled. An intelligent tutoring agent can provide an *individualised driving lesson* close to a human driving instructor and allow the driving instructor business to scale. The goal of the intelligent tutoring system is to *support driving instructors* in the teaching process using a virtual environment which is very near to real driving experience. It should provide an evaluation of the learner performance to the driving instructor. The *tutoring systems* should be seen as an assistant and has not the aim to replace the driving instructors. It should facilitate their job and save time for acquiring a driving licence. While driving in a safe virtual environment, the theory about the traffic rules can also be learned during the driving and can be done supplementary to a theory class. The practical driving should be supported from the beginning by the virtual reality environment and the tutoring system.

The SWOT analysis illustrated on Fig. 5.3 summarises all positive and negative *factors* related to the project. The company that offers the simulators has promising *strengths* based on the novel and engaging, immersive technologies and the near contact to universities. Furthermore, there exists a big market and a high demand. The most significant strength is that the company has the support of the local officials. As always there could be *threats* because of competitors or changing external conditions, but the more significant *weakness* of the project is the fact that it is hard to recruit excellent immersive technology experts to develop and support the prototypes to a mature product. Future threats for the business can be the developments in autonomous driving vehicles or other transportation alternatives such as e-scooter that should make the driving licence obsolete.

	Helpful	Harmful
Internal	<b>Strengths</b> <ul style="list-style-type: none"> <li>Using immersive technologies as novel, engaging technology and using real car as interface</li> <li>Location near to universities</li> <li>Several investors and consultants</li> <li>Partners from driving schools, companies and universities</li> </ul>	<b>Weaknesses</b> <ul style="list-style-type: none"> <li>Finding of local good IT and virtual reality experts is hard</li> <li>Small start-up team</li> <li>Small budget</li> </ul>
External	<b>Opportunities</b> <ul style="list-style-type: none"> <li>Big market</li> <li>High demand</li> <li>Government support</li> </ul>	<b>Threats</b> <ul style="list-style-type: none"> <li>New regulations by the government</li> <li>Competitors can be faster</li> <li>Autonomous driving vehicles make the driving licence obsolete</li> <li>Less acceptance by driving students and instructors</li> </ul>

Fig. 5.3: SWOT analysis for the *DriveSim* project

## Benefit Analysis

The realisation of a benefit analysis and listing some termination criteria had the aim to weigh up the advantages and disadvantages of immersive technology in the specific educational case. Below are two lists, that describe the benefits that derive from the usage of virtual reality driving simulator and intelligent tutoring system as a complementary training in driving schools. The first list presents the benefits from driving students' perspective (see Tab. 5.1) and the second from the perspective of the driving instructors and other stakeholders (see Tab. 5.2).

✓	Learning basic vehicle handling without endangering themselves or other road users
✓	Fun factor and enhancement of the motivation and engagement
✓	Repeating scenarios and situations and making errors without real harm
✓	Training risk-related skills, such as speed estimation, distance keeping, negotiating (get over/past) intersections or time-to-collision
✓	The process of acquiring a driving licence can be shortened. Students can learn faster practising parallel virtually and in the real world
✓	Settling nervous students;
✓	Providing simulation of driving situations that are not possible to have in reality and are very rare and dangerous (i.e. acting in accidents)
✓	No available infrastructure in the proximity to the practical training location (i.e. railway crossing) to cover all training aspects
✓	Access to various scenarios (accident scenarios and dangerous situations, darkness and snow outside of winter, difficult weather conditions and extreme road traffic density);
✓	Adapting to and feeling safe with car control support systems such as ACC and ABS;
✓	Experiencing different types of cars ( differences such as size, motor power, front vs rear wheel, motor type diesel vs petrol) and types of car controls i.e. automatic vs manual transmission;
✓	Learning to scan the road and anticipate (forecast) situations while driving with other road users, that should yield safe driving;
✓	Experiencing the influence of distraction elements (mobile phone, driver support systems, ambulance horns) and the loss of control if fatigue or when driving under medication or alcohol, so they do not underestimate it in real situations;
✓	easy and objective feedback on performance for students and instructors (i.e. watching recordings of their driving from different perspectives); Comparison between normative driving behaviour (autopilot) with students' driving behaviour;

Tab. 5.1: Main benefits for the driving students

### Evaluation Criteria

Performance indicators were defined, which should help us to measure the project' success. In the short term, the evaluation of the project results can be based on the time for acquiring a driving licence and in particular, if the students who practice in an immersive driving simulator finish the course faster and perform better. The immersive system should objectively measure the learning performance of driving students, and the driving instructors can provide some subjective, qualitative evaluation. Next to the acceptance, another indicators are the engagement

✓	Driving schools and driving instructors can handle more students and simultaneously achieve a better quality of the training;
✓	Driving instructors can be supported in their daily teaching routine, providing them with information such as learning progress or time spent for exercising. Instructors can concentrate on the tasks and high-order skills, that particular sensors and computer cannot provide;
✓	It can be very profitable for companies providing the hardware, software or the service around the virtual driving simulator, when using suitable business models;
✓	There are ecological and economic benefits like reduction of pollution due to savings of energy, fuel consumption as well as tyre and brake wearing and other operating resources and equipment;

Tab. 5.2: Benefits for driving instructors and other key stakeholders

and motivation of the students and if it increases by using an immersive simulator. Are students calmer in the real world after having practised in the simulator, is also a crucial question. Another performance indicator is the number of succeed or failed students during the exam. Next to the exam success, the system can assess the rate of significant errors and caused dangerous situations.

### Termination Criteria

In the following list contains some possible risks concerning the technology that can arise (see Tab. 5.3). It serves as termination criteria for the implementation of immersive driving simulator project. It extends the weaknesses and threats from the SWOT analysis and should provide guidance, when to stop the development of the project.

The termination criteria are mostly connected to technology, but some economic factors are also be considered. There is a trade-off between the level of immersion and the costs for hardware and the software. This trade-off will play an enormous role in the success of the business model. Since it is not possible to validate all termination criteria at the beginning, they will be evaluated after each project milestone.

### Decision

The analysis showed that the driving students and instructors have a high interest in an immersive driving simulator, and there is an expectation for a good acceptance. Furthermore, there was enough evidence in the literature that there can be a transfer of the skills from a simulator to the real car. The training in the immersive simulator should be combined with actual car driving to avoid trainees automatise skills in an artificial environment [DPF<sup>+</sup>01].

✓	No acceptance by driving students after different project states;
✓	Less acceptance by driving instructors due to fear of unemployment, of being replaced by simulators and intelligent systems;
✓	The local authorities do not recognise the driving hours in the immersive simulator;
✓	The immersive system can not provide the transfer of the knowledge and skills in the real situation;
✓	The provided solution can cause motion sickness to a high per cent of the users;
✓	The initial costs for the software or hardware solutions are too high;
✓	The solution is not be flexible, robust and sustainable enough or cannot provide the expected features or benefits;
✓	There are no qualified human resources for further development, support and maintenance of the system;
✓	The support and maintenance of such a complex system is too extensive and cost-efficient.
✓	There exist specific local legal issues, such as region-specific regulations, which hinders the distribution of the immersive system;
✓	The creation of beneficial business model and the return of investment is not possible;

Tab. 5.3: Termination criteria for the *DriveSim* project

In this phase, we neglected the problem with motion sickness for two reasons. On the one hand, because there is enormous research on the topic that should provide guidelines for implementation to avoiding simulation sickness [WCM19, LC19]. On the other hand, we assumed that there will always be some small percentage of people who are sensitive to simulators and could not use this service.

### 5.1.2 Design of the Immersive Learning Environment

The goal of the design process is to define the learning goals in detail based on the needs collected in the analyse phase and to map those goals to the learning activities. Furthermore, it is necessary to identify the requirements for the technology that should support the learning activities.

#### Learning Objectives and System Requirements

The primary learning objectives for the virtual reality driving simulator (see Fig. 5.5) is that novice drivers can learn fundamental driving skills like vehicle control, manoeuvring skills and

interaction with other traffic participants. It should provide driving lessons in intercity, motorways and night driving. The virtual training should cover the most practical skills and those like safe driving and avoiding dangerous situations. Safe driving should be trained with tasks related to speed estimation, distance keeping, negotiating intersections or time-to-collision. It is not the primary goal to learn driving theory and traffic regulation in the simulator, but to practice it. Usually, it takes time for novice drivers to combine the vehicle control with the traffic rules. They start to notice the markings and signs later, so this process can be accelerated using virtual environments. Further goals are the training on-demand and the providing of repeatable situations. The virtual environment should take away the fear and uncertainty of novice drivers.

The created virtual reality learning system should provide an environment as close as possible to a real car driving experience. The system should not overload the information processing capacity of the trainees and should be adaptive based on the user experience. From the perspective of the driving instructor, the immersive system should facilitate the assessment process. So he can concentrate on teaching higher-level skills and others that are not possible to be toughed through the immersive simulation.

## **Resources**

### **Human Resources**

Human resources needed are primarily for the development, maintenance and marketing of the driving simulator. For the design and development phase the start-up company decided to involve external resources, concrete our research and development team “Smart Immersive Environments” at IMI. Additionally, the start-up team consisted of executive officer, technical officer, people in charge of the software and hardware infrastructure as well as marketing. Driving instructors and experts from project related areas served as supervisors. After the development of the immersive simulator further human resources are going to be hired in order to further develop and maintain the product.

### **Financial Resources**

The start-up company planned the financial resources for this project based on an extensive business model. The initial costs, like those for the development of the prototype, were financed by investors. All information about the financial aspects of this project is strictly confidential and can not be provided in this work. Costs and effort for creating a virtual reality application for driving training can be compared to those of the computer games and depend strongly on the

level of immersion and fidelity of the virtual world. For instance, the marketing and development budgets of the open-world game DRIV3R were both around \$17 million [Sup14], and the famous GTA V game development costs were \$137 million [Sin13]. Unfortunately, budget for educational applications are much lower.

### **Time as a Resource**

The immersive virtual reality driving simulators will be installed in buildings that should be open for the public such as shopping centres, universities or unique places for the target group like driving schools. The driving student can decide voluntarily, how many hours he wants to practice and can book an hour in the immersive driving simulator over his smartphone. The driving instructor can make a recommendation. It is planned by the local authorities to make a prescription for the usage of simulators complementary to the driving training, which will be a minimum of 4 hours in a simulator.

### **Facilities**

There are many physical resources needed to achieve a virtual training. First the physical place such as driving school facility and halls should be equipped with the immersive driving simulator system. One of the project requirements intend the usage of a real car, so the cars should be provided and installed in the building.

### **IT Resources**

An immersive system is highly complex, especially those for driving simulators. On Fig. 5.4 are depicted most of the working areas and packages related to a virtual reality driving simulator. The hardware IT resources are in the top of the figure, and consists of the real vehicle, the virtual reality system and can have further hardware such as motion platform and sound system.

The main software modules are the graphic engine for the visualisation of the virtual environment, the sound engine for sound simulation and the physics engine for the simulation of the driving dynamics. One crucial module are the interfaces between the software modules and the hardware. Furthermore, the software can have additional modules such as weather, traffic simulation and other application-specific modules.

We implemented the virtual world with the virtual reality authoring system PolyVR (see chapter 3), which provided all necessary functionality for the project. Features could be further developed or missing features implemented from scratch due to the open-source licence of PolyVR.

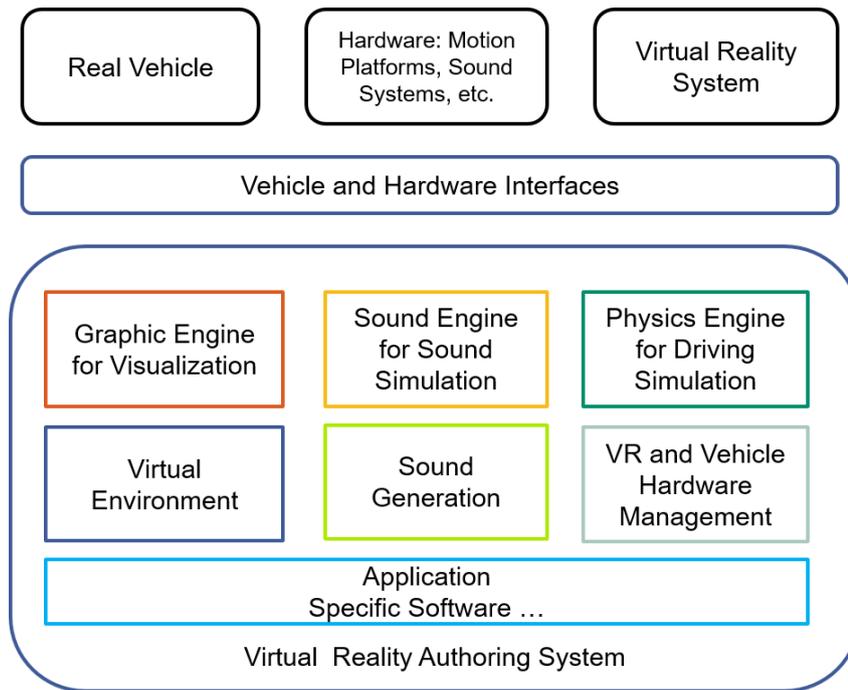


Fig. 5.4: Working areas of a virtual reality driving simulator

## Requirements for the Immersive Driving Simulator

The objective of the project DriveSim was to develop prototype of an immersive system for driving simulation. The full list of the project requirements is presented in the *Appendix A.3.2* on page 336.

The system must meet the following criteria:

- Easy access for driving instructors and students
- Immersive and realistic driving simulation
- Real vehicle as driving simulator
- Tutoring system providing customised learning and evaluation of driving behaviour

## Architectural Design

The simplified design of the software architecture is depicted on Fig. 5.5. The main interaction loop is between the user and the simulator. The interaction is based on all car controls like the three pedals, steering, wheel and gear lever, but also on all buttons and lever in the car cockpit. The signals from the car are then sent to the back-end (software modules). It then analyses

the user input and calculates in real-time the visual, acoustic and physical output on the system to the user.

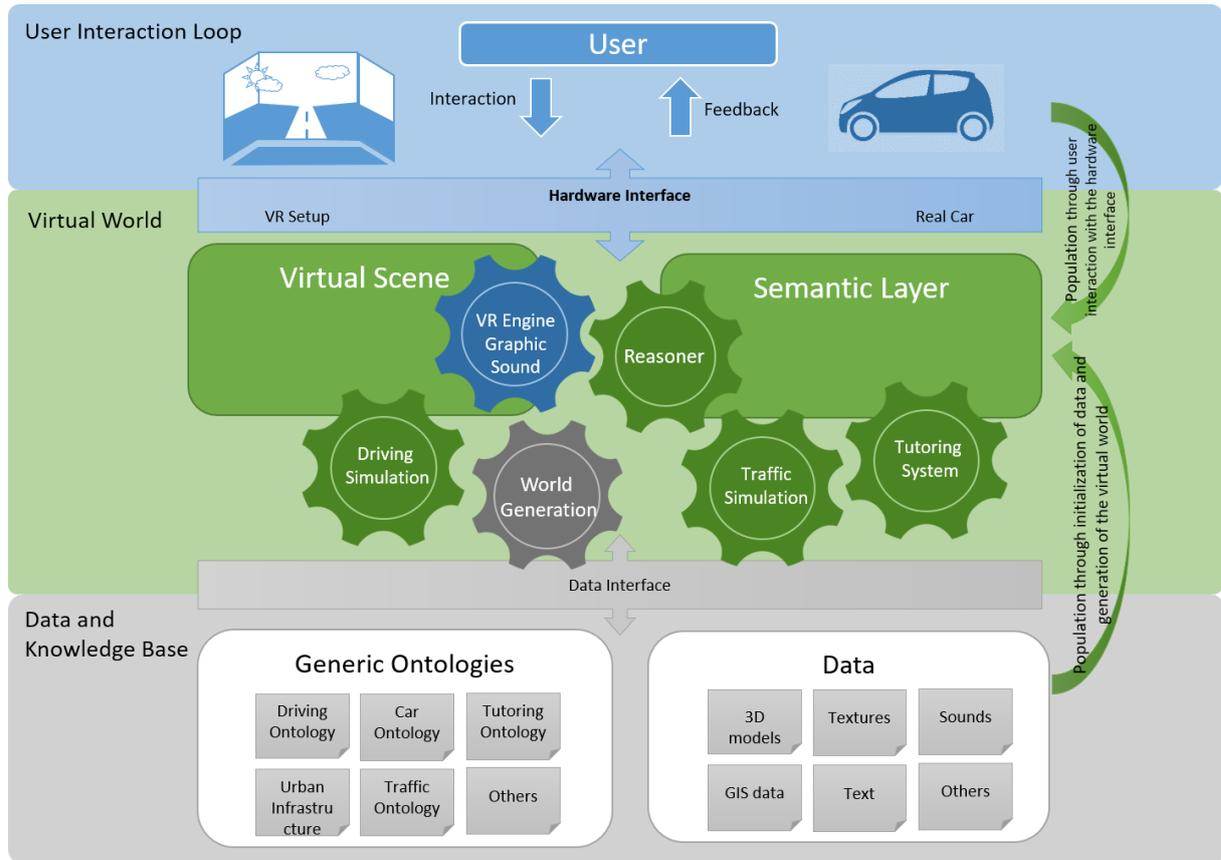


Fig. 5.5: Concept diagram of the intelligent immersive driving simulation

The *back-end* consists of the software modules and their interconnections. A special feature of this driving simulator is that the back-end is based on an intelligent component called the *semantic layer* (see *Implementation of the Semantic Layer* 5.1.4 on page 203). The semantic layer consist of the knowledge base and the reasoner.

The components of the virtual world are the virtual reality engine with its graphic and sound modules, the world generation module, the driving and traffic simulations as well as the tutoring system.

There is also a data layer and a data interface. On the one hand, there are semantic data needed for all domains of the driving simulation, such as the urban infrastructure, traffic rules. On the other hand, the data and assets for the immersive application, such as 3d models, textures, sounds or GIS data.

### 5.1.3 Authoring of the Immersive Driving Simulator

#### Immersive Hardware

During the project were realised and tested two immersive hardware configurations. One of the prototypes has one front projection and three TVs for rear-view (see Fig. 5.6 and Fig. 5.9). The front projection utilised the Optoma's EH320USTi projector with 1080p ultra-short-throw



Fig. 5.6: *DriveSim* hardware setup with front projection and rear-view displays [Kal18]

and with 1920 x 1080 resolution [Opt18]. The throw ratio of 0.25:1 allows a projection of a 100-inch image from 55cm away. The close installation of the projector to the screen avoids shadows from the car being cast across the screen. Optoma projector uses an active stereo and can display 3D content from almost any 3D source. It supports 144Hz rapid refresh rate and provides ultra-smooth flicker-free images [Opt18]. For the stereo view, an active 3d glasses were provided. The solution for the rear projection consisted of three 60 inch diagonal TVs. Each TV covers the view of respectively the left, middle and right rear mirror (see Fig. 5.6). The immersive setup used a powerful graphic workstation with a GTX1060 graphic card inside.

The second prototype used a CAVE for the immersive hardware configuration. The CAVE was built with four projections on each side surround the driving simulator (see Fig. 5.7).

A CAVE can usually have top and floor projections, but in the particular case of a driving simulator, they are not visible and thus not necessary. The cars and the projections around them are placed in small cells. That is why we decided to use the same short-throw projectors from Optoma, and we built projection walls around the car covered with projection paint instead of

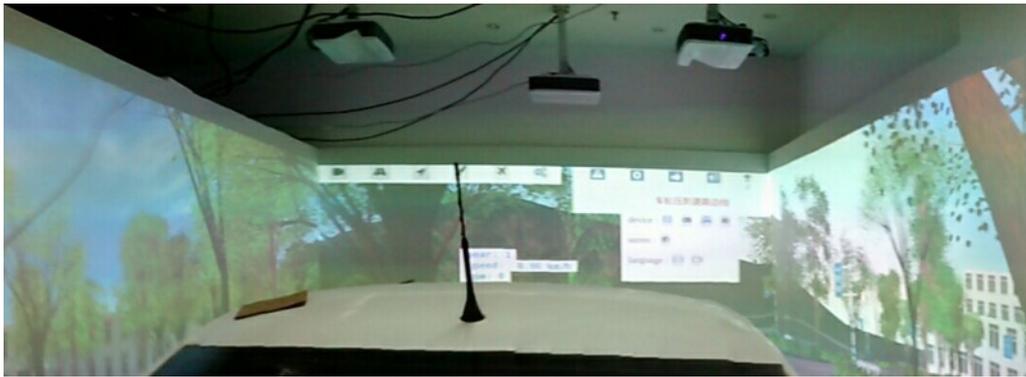


Fig. 5.7: *DriveSim* CAVE environment

projection screens. The Optoma projectors provide control over a web interface, which makes it easy to manage the immersive hardware setup from a distance.

One computer with two graphic cards supports the CAVE configuration. One GTX1060 graphic card calculates the 3d output of the four projectors and second graphic card is used for the output of the maintenance computer.

One of the key features of virtual reality is the head tracking. The head tracking system primary goal is to achieve a high level of immersion and presence in virtual environments, adjusting the virtual scene with the user head position in real-time. This feature gives the user the feeling that he is really inside the virtual environment. If there is not a head tracking system, it cannot be defined as a “virtual reality simulator”. The tracking system should be with high precision for real-time performance. Usually, a set of minimum two IR cameras depending on projection screens and tracking area are used together with passive or active markers. The used tracking system was the SMARTTRACK produced by the German company Advanced Realtime Tracking GmbH (see Fig. 5.8). The benefit of the device is that the two cameras are integrated into one body and is not so sensible to movements and do not need calibration once set. Another advantage of the particular head tracking system for the driving simulator use case is the tracking in a short distance from the camera. Because the space in the car indoor is very small. The user is tracked over an individual passive target fixed to the stereo glasses. The tracking system can also track additional targets if necessary, for instance, the hands of the driver.

A particular requirement of the project was the flexibility to use different technology and configuration for visual output systems. For example, the system should support a simple monitor up to CAVE setup.

To achieve this goal, we implemented a virtual reality configurator for the visual output in PolyVR. This application helps to easily calculate the desired size and position of the displays and views, independent of the used technology, which can be a projector or monitor display.



Fig. 5.8: View from the vehicle inside to the outside virtual world [Kal18]



Fig. 5.9: Student driver with shutter glasses [Kal18]

On this way, developers can validate the view from the driver perspective (on the computer screen or in an immersive environment). Occlusions and unprojected spaces can be easily detected and corrected in order to achieve a seamless view. The application can also mark the blind spots (see Fig. 5.10), and they can be taken into consideration by the planning of the simulators' environment. The size and position of the displays is relative to the 3D model of

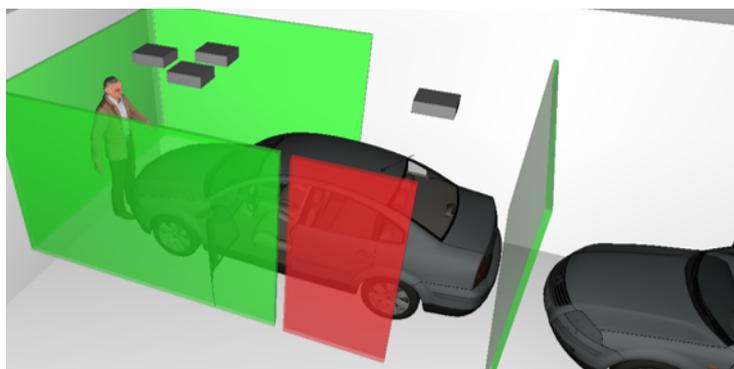


Fig. 5.10: Virtual validation of the areas visible from the vehicle

the car. Furthermore, the distances between the car and the displays are essential for the car maintenance. The attachment of the holders of projectors or monitors can also be calculated and foreseen using this application.

## Real Car Interface

The unique feature of the driving simulator is the utilisation of a real vehicle. In this way, the simulator interface is very intuitive. The car models used for the prototypes were: Smart Fortwo from Daimler and Jetta from Volkswagen.

Modern vehicles are equipped with a CAN bus, which is an internal network for the connection of all sensors and actuators. By using this interface, a regular vehicle can be modified for being used as a driving simulator without impairing its outer appearance [Ins17]. Each car type has its

unique CAN bus protocol which is also depending on production year and built-in components. These protocols are confidential and not available for others. The CAN bus for transmitting data decoding the messages of the control units with reversed engineering methods. We developed a special hardware device so-called “Car Interface Box” to interface the signals and to encrypt the data coming from the the real vehicle (see Fig. 5.11 and Fig. 5.12).

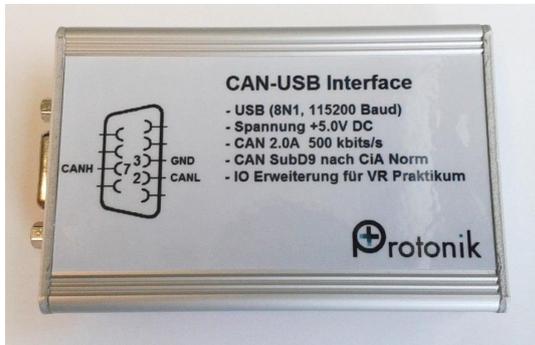


Fig. 5.11: CAN-USB interface box



Fig. 5.12: CAN-USB interface platine

The main tasks consisted in the development of the car interface, in order for the simulator vehicle behave as the real one. First, the electrical components in the vehicle, that can send data about the position of car elements like pedals, shift gear, steering wheel were identified. Then the data were obtained via reverse engineering. With the self-developed Car Interface Box, the data could be transmitted. For instance, the signal from the throttle could be transmitted to the virtual car simulation. The data was processed in the Car Interface Box and converted for further use in a speed signal. The Car Interface Box sends the signal from the throttle to the physic simulation in order to accelerate the virtual vehicle. The speed signal is then played back into the vehicle and displayed at the speedometer of the real car (see Fig. 5.13). This bidirectional connection between the car and the software allows the learner a genuinely realistic driving experience [Ins18].

The most important features were the control by steering wheel, pedals, gearshift, the feedback on the cockpit elements as well as the force feedback via the steering wheel. Next to the main components of the original car interface necessary for the driving training the car interface provided also data and control for the hand brake, the switches such as turn signal, lights, wipers, as well as additional elements like safety belt, key ignition, cruise control. Unfortunately, not all car devices are connected to the CAN bus, so additional sensors were developed and embedded in the car in order to provide all necessary data to the simulation and complete the car driver interface.



Fig. 5.13: Vehicle cockpit receives data from the simulation over the interface

### 3D World Generator

The most relevant modules for the visualisation of the virtual world are the 3D engine, the 3D world generator and the semantic layer. The implementation of the virtual environment uses high complex algorithms in order to create an open world, which should be rendered in real-time.

The 3D engine PolyVR takes care of the virtual environments and virtual reality hardware components. It is based around classical scene graph, clustering and multithreading tools related to 3D graphics. It controls the rendering pipeline, the lightning system and structures the scene objects. The VR engine takes care of the real-time display of significant amounts of complex 3D content on any immersive hardware setup.

The automated generation of rich open-world environments uses a generic planar graph structure for the implementation of the road network (see Fig. 5.14). This graph is then imported from available map databases like OpenStreetMap [HW08]. The 3D world generator implements all the algorithms necessary to import the Geographic Information System (GIS) data and at the same time populates the data in the semantic model. The semantic layer handles ontologies and does the reasoning which is necessary for the tutoring system (see *Implementation of the Semantic Layer* 5.1.4 on page 203).

Next to the road networks, the 3D world generator creates other road infrastructure and world elements like buildings, vegetation, traffic and much more. GIS data interfaces allow to import road networks, building blueprints and ground elevation data. Other specific world elements were set in the virtual scene as hand modelled 3d assets. Some examples are cones, cars and some specific buildings.

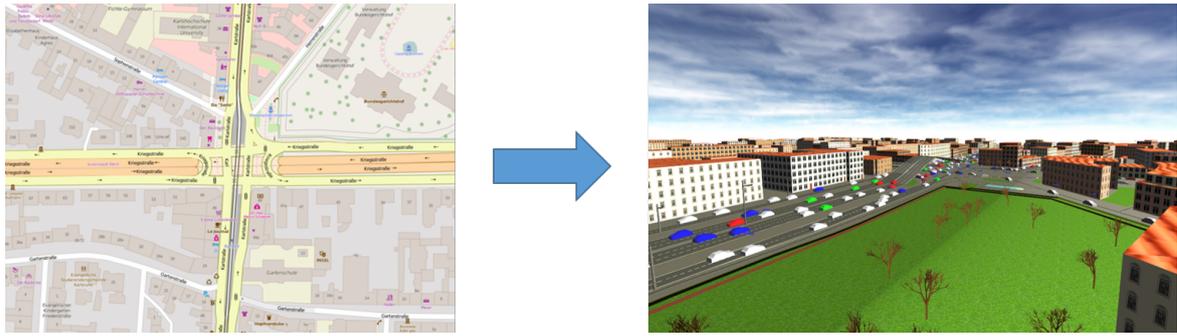


Fig. 5.14: OpenStreetMap 2D editor vs generated 3D world

An important task was how the world generation should be parameterised; in order, users or service providers can adjust the world to their needs. One of the main challenges was to find qualitative GIS data for the road network and all infrastructure elements, as well as the heights map data, that match all project requirements and provide a sound basis for the generation algorithms.

Further data handling algorithms for space partitioning were necessary, like dividing in smaller chunks, loading and updating the world. Some of the scripts for the data handling were realised in a central place, in particular, the simulator management server, so all simulators in the future has the same GIS data, and the users have the same experience on each simulator they use.

The usage of open source and crowdsourcing tools ( such as OpenStreetMaps) provides the project with very detailed information about the road network in the whole world as well as sophisticated tools for editing and optimisation (JOSM, OSM Online editor). Those editors allowed adding and editing all kinds of the project relevant data like road network, signs, buildings and many more. At the same time, this speeds up the development of the project with years, comparing to new development of configuration tools and creating a private GIS database from scratch. Combining this with the world generation algorithms gives the project an enormous innovation perspective and distinguish it from all other software for driving simulation.

## Terrain

The terrain of the world was generated using heights maps. An interpolation of the road network on the landscape was necessary, so the road is following the ground base and angles. The open-world system is built generically based on planet module. This module splits the planet surface into many sectors. Each sector has its terrain instance with its height data and map data. The height data for the terrain module is applied with a displacement map and uses a tessellation shader to achieve real-time performance (see Fig. 5.15). Atmospheric effects were added to make the terrain look more realistic (see Fig. 5.16).

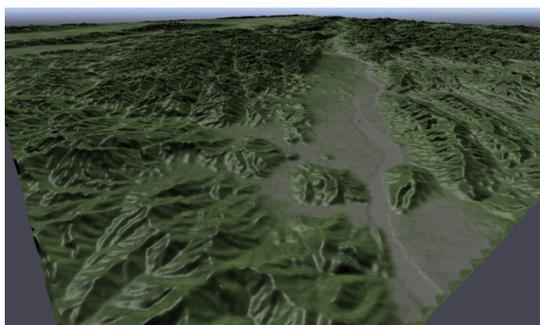


Fig. 5.15: Visualisation of height data for a particular chunk



Fig. 5.16: Generated topography with atmospheric effects

## Road Network

One of the main challenges of the implementation of the 3d world generator is the road network. It represents the foundation for the driving simulator and all other modules like traffic simulation or tutoring system. After the data handling algorithms for loading a small part of the visible world, the algorithms for the generation of 3D roads and intersections from 2D information source (like lines) were implemented (see Fig. 5.14 on page 197). One after another, all relevant elements like road nodes, lanes, markings, green belts and intersections could be visualised.

The real world out there is full of different repeating infrastructure elements. The most critical elements for the driving experience like road signs, street lights, fences embankments, and curbs for the sidewalk borders and park areas were implemented.

## Road Elements

### *Traffic Lights*

An essential aspect of the traffic simulation is to manage the active elements like the signalling systems. Traffic lights have to be visualised and controlled by the system. The definition of the traffic lights comes from the OSM data, where a traffic light is added onto a road node. For a four-way intersection, there are four road nodes close the intersection node with traffic lights definitions. Those nodes are not grouped into a single traffic system, and this has to be detected using a quite complex heuristic approach.

## Buildings

The generation of the buildings is based on the information on the building outlines its tessellation. It only gives the form of a building. In the OSM database are some additional metadata like the number of stories, which gives some vague information about the building height. For the buildings we are using special texture with a significant number of building elements such as

doors, windows, walls, roofs. The texturing for the buildings is randomised and fully automated. In this way, different kinds of buildings can be displayed (see Fig. 5.17). Additionally, the software allows the import and placing of some specific customised 3d models of buildings.



Fig. 5.17: Generated buildings

### Nature Elements

The nature elements cover a big part of the virtual world inside and outside a city. Algorithms for generation of trees, bushes and grass were implemented in order to be aesthetic and to have a realistic appearance (see Fig. 5.18) and in a manner that supports real-time performance.



Fig. 5.18: Level of Details for the generation of trees

The optimisation of the vegetation elements, especially trees and bushes, had to be prioritised because such elements are everywhere and quickly impact the performance. Sprite geometry, a special fragment shader and megatexturing are helping to keep excellent performance for this task. The LOD system was too detailed, thus inducing too much redundancy and thus memory problems. It is still used for the high detail tree geometries and higher scales for the LOD geometries. Sprite geometries are the cheapest and most suitable for tree LODs. They are aggregated in a single geometry to minimise the scene graph complexity and performance hit. The goal is to have around  $10e5$  or less vertices per map chunk of 5 or 100  $\text{km}^2$ .

A special fragment shader hides all but one sprite, depending on the view angle; this seems to be very efficient. The megatexture contains the textures of all tree types from two sides and the top.

This approach is very efficient, as the LOD geometry needs a single material to render all kind of trees. The megatexture also handles the generation of the corresponding UV coordinates. The texture renderer is used right after the tree generation to create a megatexture. No manual texture design is required because the texture creation is fully automated.

## Rendering

### Dynamical Sky Module

For the realistic experience of the driver in the immersive driving simulator, a dynamic model of the sky was implemented. The sky colours are physically correct following a specially developed mathematical model. The building of different clouds, as well as their movement with the wind, was also developed. Additionally, the simulation has a day and night cycle, so the sun is moving during the driving session.

### Weather Module

We implemented a rain simulation and rain visualisation in order to simulate different weather conditions and apply difficulty levels for the training (see Fig. 5.19). To achieve rain perception for the driver, first, the falling drops of the rain and its intensity and second, the drop effects on the car front windscreen were simulated. Additionally, the sky and clouds colour and luminosity, was parameterised according to the rain intensity. A wiper simulation was implemented to clean the raindrops on the windshield when moving. Occlusion effects were necessary, when rain is falling in the world, and it does not rain through roofs, and other objects.

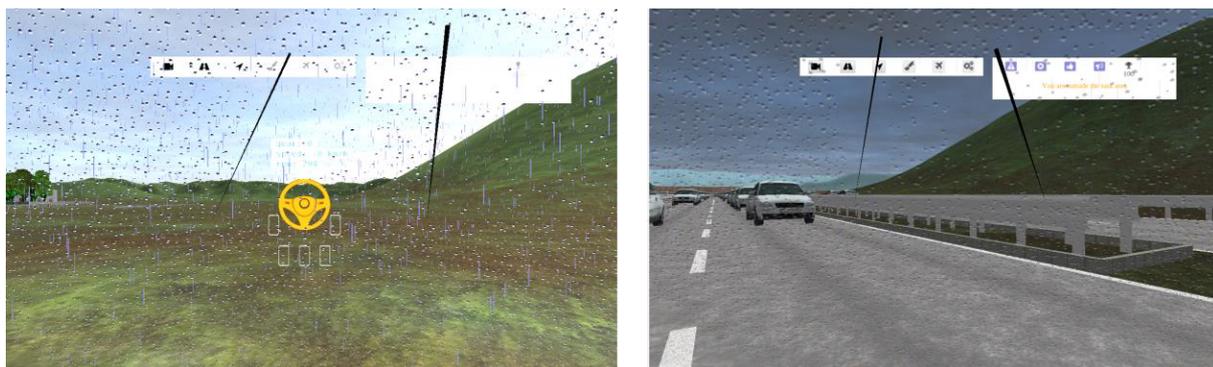


Fig. 5.19: Rain simulation

## Lights and Shadows, Day and Night Cycle

Lighting is a central component of the rendering as well as the simulation. Much work has been put in setting up the lighting system, including photometric light sources, point light shadows and directional shadows. To achieve this, we created a deferred shading pipeline. The benefits of the photometric lights is that a much higher degree of realism is possible. The realism is primarily essential for the car headlights (see Fig. 5.20) and streetlights (see Fig. 5.21). It is possible to load photometric data into the system and use it to illuminate the scene using a realistic light distribution. The deferred shading pipeline also enables much more lights simultaneously as well as a much more advanced shadowing system. The shadows from the directional light source, the sun, were also more challenging to implement.



Fig. 5.20: Headlights lightening

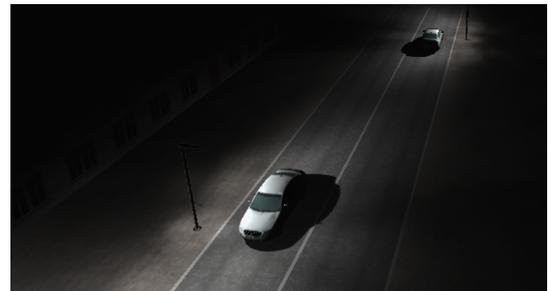


Fig. 5.21: Street lighting

## Driving Simulation

The driving behaviour of the car was implemented with the in *PolyVR* integrated physic engine Bullet. It already provided some driving dynamics for vehicles, which were further developed and parameterised. The simulation model consists of the three modules, the wheel and suspensions system, the engine and the gearing. The wheels are defined by their width and radius and are attached to the chassis through a spring system with a linear constraint. The simulation of the engine and gears was described with a set of parameters. Some sophisticated and vital for the driver training features like stalling and the engine brake were also simulated.

## Traffic Simulation

The implementation of the traffic simulation was a very challenging task. The cars around the user should react dynamically and realistically on the traffic rules and other traffic participants (see Fig. 5.22). Vehicles are propagated continuously. They accelerate and brake according to real physical vehicle movement. They can see traffic signals and react, like stopping at red lights, braking in front of them and accelerating again when the light turns green [Mic19].

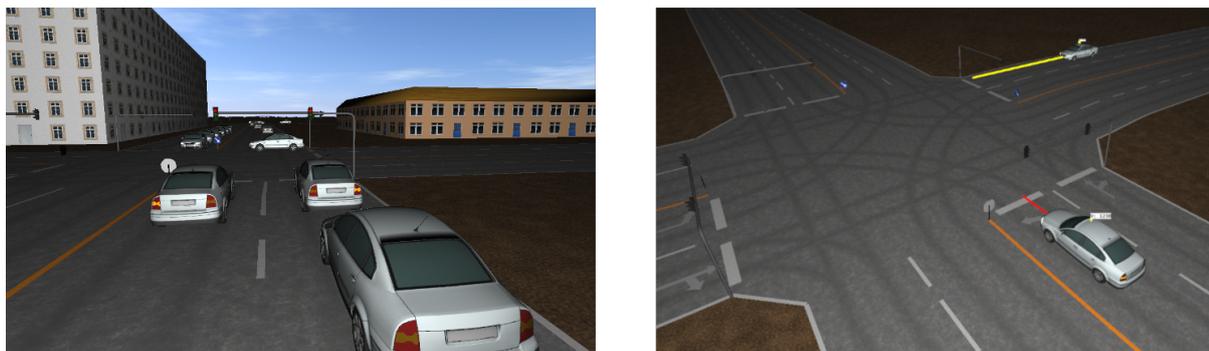


Fig. 5.22: Traffic simulation [Mic19]

Vision of single simulator vehicles has been implemented to recognise other vehicles in near-field and far-field, especially at intersections. Functionality has been established for traffic rules like right of way, e.g. waiting at intersections if traffic or a driving-simulator user is coming from the right. Left turning drivers will wait at intersections if traffic or a driving-simulator user is coming from the front. Braking lights and indicator lights are synchronised with vehicle behaviour and show intention ahead of the intersection so that the user can anticipate future decisions. Traffic signs and user collisions with traffic simulation vehicles are recognised and handled. The traffic simulation itself has been decoupled from the PolyVR simulation thread and set up on its thread to drastically enhance performance.

### Sound Synthesis and Vibration Feedback

Next to the visual output and the virtual world, the acoustic feedback is the next essential element to achieve a high level of immersion. The simulation of sound in a car is a challenging task because many sound sources should be considered. In the car, the driver hears the engine (except of electric motor vehicles), the sound of the wind, tyres or some other external noises. For driver training, the most vital sound is this of the car engine and its change with the revolutions per minute (rpm). It is not possible to provide engine sound based on sound snippets, because each car engine has its sound and it varies strongly by the current driving conditions (such as gear or throttle). The implementation of the sound consists of two main steps. The first step was the analysis of the sound for the particular car models and engines (in our case *VW Jetta* and *Smart Fortwo*) and the second was a speed-dependent real-time synthesis of the sound.

The sound analysis was conducted by recording sound samples from a real car. The samples were recorded in various driving conditions such as (car engine idling without load as well as at different speeds and gears). Microphones were used to capture the sound inside the car. The recorded sounds were synchronised with data acquired from the car board computer such as the current engine RPM, and car speed. The frequency analysis of the sound recordings was

performed with *MATLAB* scripts. The *PolyVR* sound synthesis module was used to recreate the engine sound in the virtual environment. The vibration feedback signal is also a sound wave with very low frequencies. It was synthesised similarly to the car engine sounds.

#### 5.1.4 Implementation of the Semantic Layer

Knowledge-based technologies from the area of logic-based artificial intelligence were used to create a sustainable and intelligent system. In particular, we realised technologies from the Semantic Web like *ontologies*. In this work, the module responsible for the intelligence is called *semantic layer*. It includes all necessary information for the driving domain and the concrete entities of the application in order to deduce correlations and to make assumptions and in the particular use case to evaluate the driving behaviour.

The following steps were necessary to implement the semantic layer:

- Create a knowledge base in the form of general ontologies and rules,
- population of the ontologies during application initialisation and run time, and
- using real-time capable reasoner, i.e. for task generation or evaluation of driving behaviour.

#### Design of the Generic Knowledge Base

The knowledge base contains different small ontologies that describe all *domains*, necessary for the application. The ontologies itself contain the *taxonomies of the concepts* and the definition of the relationship between concepts and rules. Some of the domains of the virtual reality driving simulator for teaching driving include the description of the virtual world with its road network, the traffic regulations, the weather conditions, the vehicle and its dynamics, the driving student behaviour and his skills.

The ontologies were modelled with the software tool *Protégé*. They reference built-in ontologies in *PolyVR* with for example maths and object taxonomies. *Protégé* is a free, open-source ontology editor and framework for building intelligent systems [Mus15]. It provides a graphical user interface to model the ontologies, which makes this task easier. Additionally, the tool provides deductive classifiers that can validate the created ontologies for consistency. New information can be inferred with the provided reasoners. Recently a web version was offered, which makes the work on ontologies even more convenient and collaborative.

*PolyVR* provides an interface to import *OWL/RDF*, that are exported with ontology modelling tools like *Protégé*. Alternatively, the ontology and the rules can be modelled in *PolyVR* over the provided graphical interface or directly in *Python* script or *C++* code.

The further process of modelling the knowledge base was to check for inconsistencies and redundancy in the ontology design as well as under-constrained class descriptors and false results of the queries after reasoning due to bad design. This process is also known as reasoning in design phase.

The ontologies needed for the development of the immersive driving simulator were in *several domains*, such as those of the urban infrastructure, the driving dynamics, the traffic, the vehicle and the tutoring ontology. The modelling of an ontology includes the taxonomy, its classes and their relationship as well as a set of rules in order to provide the explicit knowledge.

As described in the sections above the virtual reality world is realised with algorithms for *generation* of an open world. The data base for crating the driving infrastructure includes many data sources coming from *GIS systems* like height maps to visualise the landscape, the road network data, which provides the lines for each street and intersections, the building information in form of layouts and positions, the nature areas, where single trees to big wood areas are defined and all other road infrastructure like bridges, markings etc. All this information is modelled in an ontology that is called *urban infrastructure*. The concepts modelled should provide all necessary foundation for the needs of the driving training and the tutoring system. The ontologies are then populated with the world generation module, where only the instances of the visible world are created and stored in the semantic layer.

The *vehicle ontology* describes all relevant parts of a car as well as its behaviour. The instances of the car ontology include the virtual representation of the car interior and exterior. The dynamic vehicle characteristics like speed, acceleration are also initialised with ontology entities. The ontology rules describe the behaviour of a vehicle. The car parameters are than send to the physics engine to simulate the driving dynamics of the vehicle depending on the current virtual environment.

The *traffic ontology* describes all regulations for the traffic infrastructure elements i.e. like speed, traffic lights or intersection regulation and all road participants i.e. other vehicles, bicycles, pedestrians etc. The traffic regulations are implemented with ontology rules and the tutoring system can later check based on this rules, if the driving student follow the regulations. The simulation of other road participants is also modelled in the ontology and populated in real time.

Fig. 5.23: Urban infrastructure ontology displayed in *Web Protégé*

## Population of the Knowledge Base

Ontology population is the task of *updating an ontology* with new facts from an input knowledge resource [LNM19]. The semantic layer is enriched with all entities from the *static road network* up to the *dynamic driver behaviour* data. One part of the population is done during initialisation of the application, mostly if data is not changed during run time (i.e. user data, profile) as well as initial setup parameters (car state, simulations). *Changes* in the virtual environment mostly triggered by the user interaction with the immersive system or by the tutoring system (i.e. creating new task) are populated during *run time*.

In particular, the *static world data* such as roads, markings, signs, traffic lights and many others are initialised at the start of the application and saved as instances of the urban infrastructure ontology. A virtual world for driving simulation is highly dynamic, and the scene is changing *each frame*. With the change in the graphical representation, also the semantic layer is *continuously updated* with changing weather conditions and the day night cycle. Other significant world changes are the state of the traffic lights and those of the traffic simulation. The positions of the other cars are essential for the right interpretation of the road situation and applicable traffic rules. Since there can be many cars instantiated in the whole virtual world, and to avoid performance issues, only the cars that are near the user are populated in the ontology.

The *tutoring system* also sends regular updates to the semantic layer. The current set task is populated on run-time together with all related information such as the planned path, the expected events along this path like acceleration, steering or others. As explained before, the immersive driving simulator is a highly interactive environment and requires constant feedback from the user. The user interaction and his interpreted driving behaviour is continuously populated. If the driving student steers left or right, if he is shifting or accelerating, all those events are updated in the semantic layer.

The *driver interaction* with the simulator interface affects the virtual car and its position in the virtual world. That is why the system continually checks for occurred *driving events* such as if one of the four wheels crosses a street marking or the car passes a street sign, if there is a significant change in the distance to the planned path or if there is a collision with another virtual object. All this information is essential for the tutoring system, allowing the system to evaluate if the tasks are completed according to all relevant rules.

## Reasoning

The reasoning system is the main interface to *query information* from the semantic layer. For each query, it traverses the knowledge base and applies basic logic to infer new information.

The tutoring system sends the reasoner queries to resolve *complex problems*. For example it asks the reasoner in regular intervals if the user committed *driving errors* or if the current task is performed according to the given instructions. The reasoner can answer based on the *knowledge populated* in the ontologies in interactive times, as described above.

The first step of the tutoring system is to find out what tasks can be done from where the user is located. The task to be assigned depends first on the current driver position in the virtual world and on the user's current performance. The tutoring system selects and assigns a suitable task based on the valid paths. The task is defined by a route, which the user should follow and has planned events on its path (see Fig. 5.24). So the reasoning system checks if the driver uses the predefined road lanes and handles according to traffic and weather conditions. The rules defined in the generic ontologies help the reasoner to *evaluate* the driving behaviour and what *driving errors* did the driving student commit.

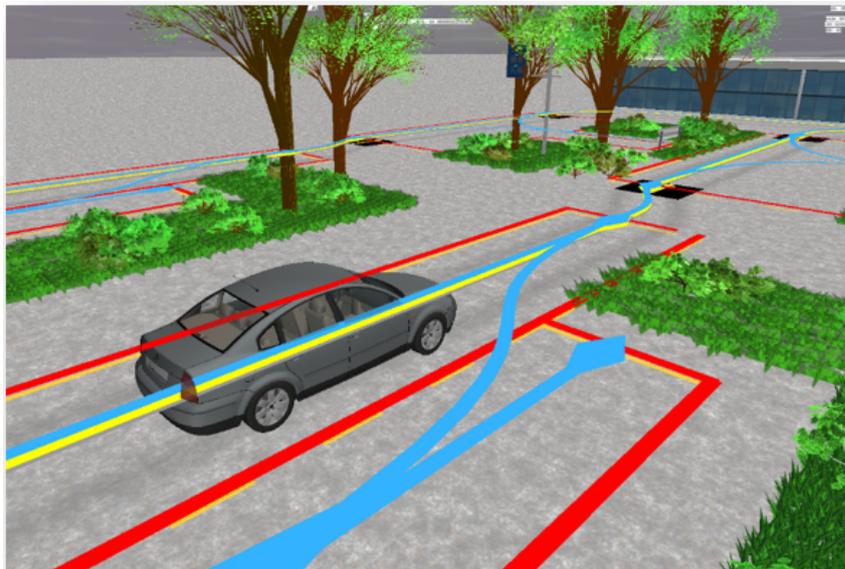


Fig. 5.24: Visualisation of the semantics paths

### 5.1.5 Tutoring System

#### Objectives of the Intelligent Tutoring System

The main objective of the tutoring system is to segment, classify and analyse each interaction of the user with the immersive system in real-time. Then the system should record and aggregate the collected information into a user profile. Based on the previous user behaviour, the virtual trainer can generate new tasks and give hints based on the individual learning curve of the student.

Another essential aim of the intelligent tutoring system is to *give assignments* to students, that correspond to the current performance without under or overstraining them and without interruption of the learning flow. As we know, everyone learns at his own pace. Under-straining can cause boredom and overstraining can cause frustration. That is why the system must adapt to the learner aptitudes, preferences and current progress.

Each assignment contains a task or a series of task that should lead to achieving a particular skill. The tutoring system should consider the time factor, such as the time elapsed between learning sessions and provide spaced repetition. The system should have an adaptive evaluation and provide less *feedback*, the more skill a driver shows in a specific task. There should be the possibility the trainee decides to which level the provided feedback should be.

Based on those requirements, several questions for the developers can be derived.

- How the system decides, which skills should acquire the user first?
- How to evaluate when a skill is acquired?
- How to analyse the driver behaviour and detect his errors?
- How to communicate with the user?

The answers of these questions are presented in the following paragraphs.

### **Top-Down Skill Analysis**

Driving is a highly complex task. It is affected by different *factors*, which can be *internal* for the driver, such as his physical and mental state as well as *external* such as the current traffic or road and weather conditions. The driving task can be *subdivided* in less sophisticated tasks and sub-tasks, in a way that both human and machine, can understand. For this purpose, we analysed first the needed skills based on a *top-down* analysis and created a skill tree. A task is a complex structure containing smaller tasks (sub-tasks) or steps. A task can be described as a continuous interaction between the trainee and the immersive system. An example of a task can be as simple as ‘*fasten the seat belt*’ or more complex like ‘*overtake the red car*’ or even ‘*drive from A to B*’.

For the goal of the project, we analysed concrete exercises and tasks from real driving instructors as well as *typical mistakes* by driver learners. The evaluation and points system for the errors were then designed based on *official regulations*. Further analysis examined which errors could be *detected* by the immersive system, by the available sensors and controls.

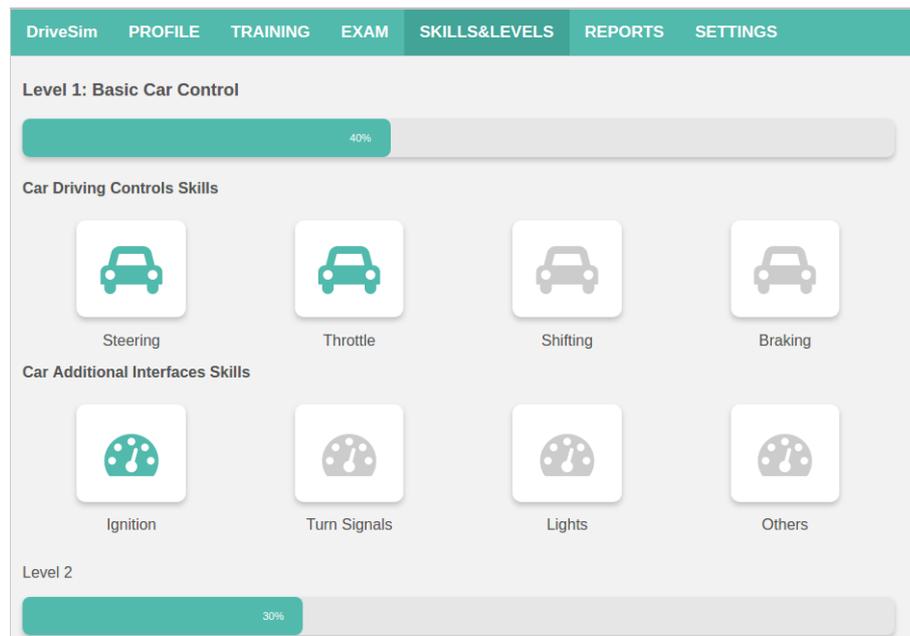


Fig. 5.25: *DriveSim* skill levels presented on an web user interface

The *skills* were categorised with the help of *complexity* levels. The basic level consists of the driving control skills and the car interface (see Fig. 5.25). The *driving control* skills include the manipulation of the primary car interface such as steering, throttle, shifting, braking or using mirrors. The car interface encompasses other cockpit elements like ignition, turn signals, lights, wipers, horn and others. Before starting to drive in real traffic conditions, the driver should learn how to control the car interface. At the beginning, it does not seem very easy because of many controls, especially in cars with manual transmission.

The *second level* has more complex manoeuvring skills for reverse and forward driving. It includes tasks like stop and go, turning left or right, slalom, u-turn as well as more complex manoeuvres like parallel or reverse parking. As mentioned above, the first two levels have tasks that are connected to necessary skills like car control and can be performed without involving traffic regulations.

The skills-based on traffic regulations are introduced in the *third level*. The manoeuvring skills are trained in the context of traffic rules like intersections. The intersection complexity level then varies based on the type, layout, signs and signals. For example, there are not regulated intersection, those regulated with signs or traffic lights, roundabouts and many others.

The driving under *city conditions* is enhanced with more vehicles and traffic elements like bus stops, schools, or pedestrians. In the same level are added the driving skills for a highway like entering and leaving the highway, lane change, overtaking and others.

The *next level* combines the night driving with other weather conditions such as fog, rain and snow. Last but not least is the level that includes some emergency and safety traffic rules. Such rules can be the passing of an ambulance or police as well as reactions on an animal or an accident on the road.

We want to give an example for the analysis of one basic skill, in order to demonstrate the complexity of the tasks and the necessary evaluation by a computer system. For this goal, the steering skill is selected. The *steering* is defined as the correct control of the steering wheel by rotating it depending on the road course. The tutoring system has to evaluate the user performance of steering the wheel, based on the task path instructed to him and visualised by the immersive system. Here arises the question, how the correctness of the steering is defined? For instance, the system can check if the virtual car derives strongly from the given path based on a threshold. A driving instructor can easily see and evaluate if the trainee has its both hands on the wheel or if his hand position while turning is ergonomic and safe. It is well known that for the correct steering, it is essential that driving student looks where he wants to go, instead of looking at the pedals or gear lever while steering.

Furthermore, driver learners find it challenging to switch between different cars as the controls can be significantly different in economy and configuration. In order for the system to provide excellent tutoring in those cases, there is a need for additional sensors, like such for tracking of the gaze direction and hands positions. In our case, we had to ignore those aspects as they went beyond the scope of the project, thus somewhat reducing the range of the driving behaviour to evaluate possibly.

### **Task Generator Approach**

The role of the tutoring system is to generate and evaluate tasks in an automatic manner. The user should gain new skills and improve old ones in order to achieve the best proficiency level. The tutoring system is based on predefined scenarios that try to cover all kinds of tasks. The tasks should be generated automatically concerning the skills and proficiency level of the user.

The task in the DriveSim project is defined with a start point and endpoint. The driving student should drive on the *prescribed route* and to accomplish the task successfully, he should get to the endpoint without any vehicle control errors or violated traffic rules. The task generator defines the route based on the current skill level of the user. For instance, if the driving students have difficulties with left turns, the system generates a route that has more left than right turns.

The *complexity* of the tasks can be customised by using different road configurations, traffic density or weather conditions. Each condition is weighted, depending on how difficult it is. The difficulty level can then be defined with a number, that is the sum of all condition weights.

Additionally, the system or user can decide if there is a need for assistance and additional feedback.

A low-level algorithm necessary for the task creation is a search and evaluation of traffic elements in a specific part of the road system. It uses the semantic layer and queries such as “*give the nearest route that passes through two traffic lights*” (see also *Implementation of the Semantic Layer* 5.1.4). Other complexity levels are proportional to the configured parameter, such as traffic density or weather conditions.

When the driving student uses for the first time the immersive driving simulator, he can choose a specific level or task from the UI interface or let the intelligent tutor generate the first task. The *first task* given to a driving student is to start the car engine. The system can evaluate if the user can drive the car, starting from knowing how to start it. For our use case and driving simulator, we have an ignition switch based on the original car key, having two positions. The first position activates the central electrical system, and the second position starts the engine. The driving student should first turn the key to the first position to activate the central electrical system. Then he can start the motor turning the key in the next position. It is assumed that the key is already in the ignition switch. On the side of the tutoring and the immersive system, it looks much more complicated. The system should provide the initial conditions to start the engine, which means that:

- The immersive driving system generates the virtual driving environment with all visual elements such as roads, markings, traffic lights, buildings and many others;
- The immersive driving system initialises all parameters of the virtual car, which means that the gear lever is in neutral position, the speed, steering and all other related parameters are set to their initial values;
- The immersive driving system initialises the users profile and loads his skills and his proficiency levels;

Only then the tutoring system can set the values based on the user input and evaluate the correctness of his behaviour. The *next task* presented to the user is then based on the current parameterisation of the car and the local environment.

The tutoring system has a function called *autopilot*, that can show the driver student what the optimal way to solve a task is. The simulator will drive autonomously the task that has been given or selected by the user. The car follows the optimal road path, steers, accelerates and gives turn signals.

## Bottom-Up Driver Behaviour Analysis

In the domain of driving, there are plenty of events that happen in a short time. Just imagining how many complex or small events are happening between starting the car in a parking lot and driving onto the highway. This gives a perspective on the overall complexity. Next to handling the car and car controls, the driver should take care of the traffic regulations and the other participants in road traffic and take correcting actions if necessary. In order to make it possible for computers to evaluate the driving behaviour, all user interactions, as well as the reactions of the virtual environment on this interaction, should be recorded and *discretised* in events.

Driving behaviour consists of a sequence of driving manoeuvres and is a *continuous process*, that varies in time and space. The driving process in a driving simulator can be monitored and analysed based on the hardware input caused by the user as well as the driving simulation output. The data captured during this process represents *time series* with all relevant driver input (e.g. signals of the pedals, steering wheel) and simulation output (e.g. speed) data. This data is recorded for each frame. The basic actions performed by a driver are the manoeuvres, which can be further divided to *atomic events* like accelerating, brake pedal release.

In automotive, they usually do the hardware signal processing based on the *time series analysis* [SKH17]. Where a fixed time window is used to segment the data and identify the events, features that have been proven to be useful in practice for recognition of *driving events* are throttle pressure, brake pedal pressure, steering wheel angle and speed of vehicle [SKH17, ZBB18]. For the goal of this learning application, additional signals like gear and clutch pedal are also analysed.

Those times series are analysed in order to extract meaningful *characteristics of the data*. For the goals of the tutoring system, the driving behaviour was segmented in small atomic actions or events, that should be later recognised by the system and used for the evaluation of the driver performance.

The recorded driver training data were analysed with the help of exploratory analysis and segmentation. The time sequences were plotted inline charts with the help of a spreadsheet program, and the characteristics of the curve were interpreted as different *events*.

For instance, the user presses the gas pedal for a specific time, and the pedal has position value coming from the sensor between 0 (released) and 1 (fully pressed). The measurement is taken at 60Hz and results in a continuous curve. This curve can be broken down into areas where it is rising, falling or constant. For instance if the user accelerates then, the curve will rise, and this segment can be labelled as an “*Acceleration*” event.

One of the first tasks in a driver training is usually to steer the car in a city, where the driving instructor takes care about starting the engine, pressing pedals and other controls. The driver student should get a feeling about the control of the car over the steering wheel and learn to follow the road. Additionally, the student should learn passing intersections, for instance, turning left and right on intersections and at the same time trigger the correct car turn signal.

Here follows an example of the analysis process for the *turning exercise*. The Fig. 5.26 shows the data for the steering wheel recorded each frame, while the user steers right into a 90-degree curve.

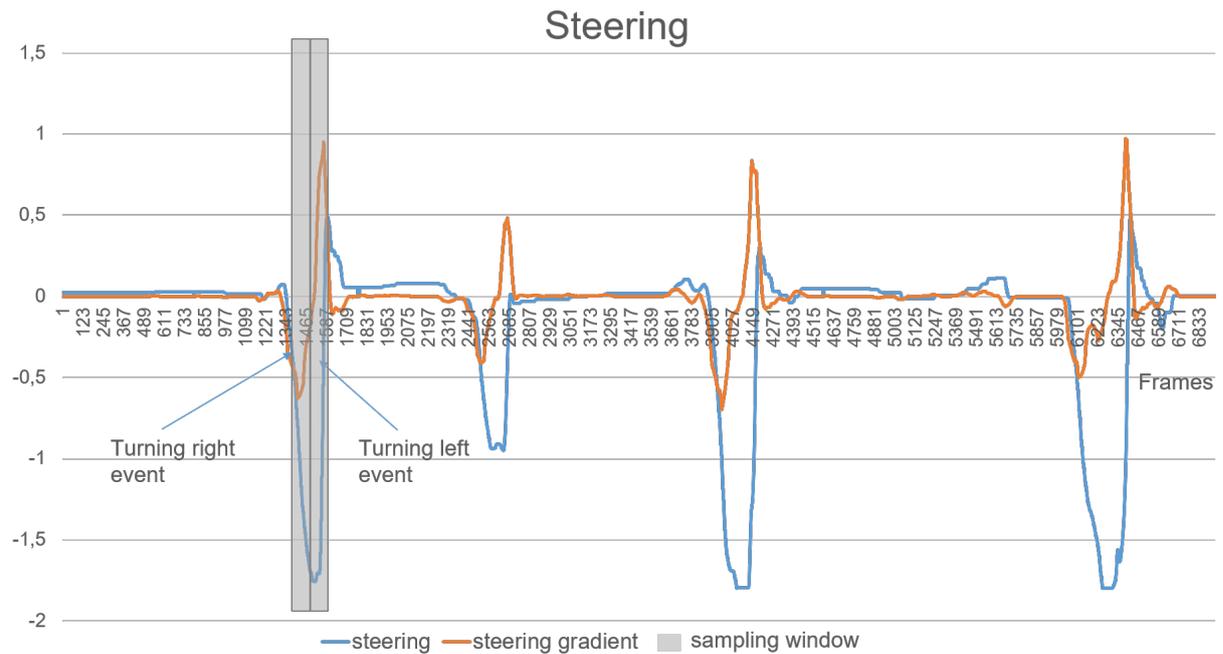


Fig. 5.26: Driving events - rotation of the steering wheel, while turning right

The program allows to reset the task back to the initial position, and the right turn was executed four times in a row. At this point of the development, the driving simulator setup used automatic transmission, that is why the gear lever position is not considered in this data set.

We can see that the user first drives straight because there is no rotation of the steering wheel, then shortly before entering the curve he turns first slightly to the left to open the curve and then sharp to the right. The next segment shows the rotation of the steering wheel to the centre and in most cases a little bit to the left and then driving straight again. There are two assumptions for the slightly left turn after the centring caused by the used hardware setup at the current development. The first assumption is that there could be high latency in the hardware in particular between the steering wheel and the simulation visual output, which brings the user to oversteer and then correct his course. The second issue might be the missing steering wheel force feed-

back, this makes the “automatic” centring of the wheel impossible, and the user has to centre the wheel himself.

The data curve has specific features that are typical for a left or right turn. The car speed is the main difference between data sets; it squishes or stretches the resulting curve or individual features (see Fig. 5.27). The speed itself depends on the environmental conditions like the traffic, is there a stop sign or red traffic light, lousy visibility or other factors.

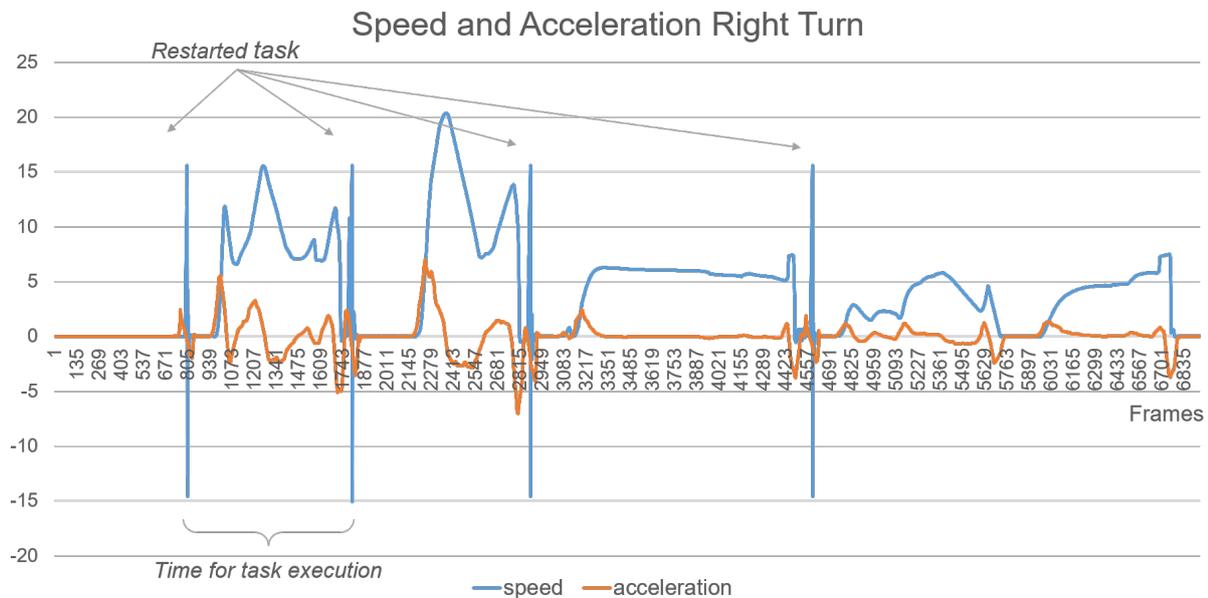


Fig. 5.27: Driving events - speed and acceleration, while turning right

## Semantic Layer of the Tutoring System

The tutoring system uses the semantic layer through the reasoning system to generate tasks for the user and detect wrong user behaviour. *Two ontologies* are mainly relevant for the tutoring system. The first ontology describes the *tasks*, their *evaluation* and the user *feedback* (see Fig. 5.28). The other ontology contains the *driving skills* (see Fig. 5.29).

## Task Generation

The application could teleport the user to a generated setup and situation, or it can work with the user position and the current surrounding to give the user a new task. The system can still adapt to the situation in a more or less seamless manner. For example, it can spawn a car behind the user to set up a situation where the user has to check behind before changing the lane to avoid a collision. The tutoring system needs to decide on the next task, and then it can set up the traffic situation.

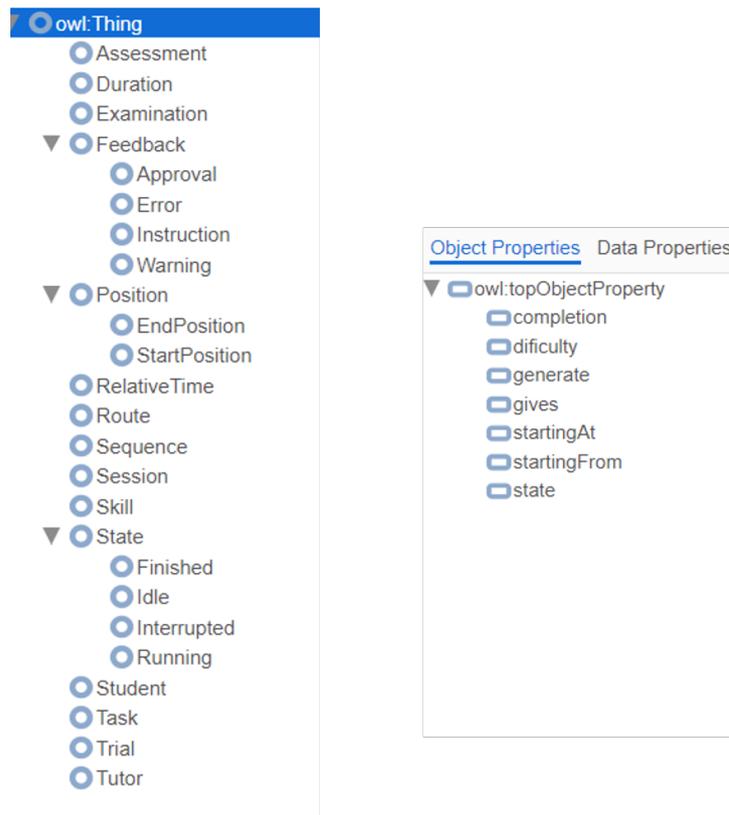


Fig. 5.28: Tutoring ontology

The following aspects are taken into account to choose the next task:

- What are the previous tasks the user just completed?
- What skills should the user further practice?
- What road features are ahead of the user or easily reachable from his current position?

After assessing the potential for the next task, the tutoring system can prepare the situation by, for example, adding the following elements to the environment:

- Cars, pedestrians and other road users controlled by the traffic simulation.
- Traffic lights, signs and special road markings
- Changes to the environment, certain building features, trees and much more.

For this, the tutoring system has to interact with the world generation module and the traffic simulation. The changes will also be reflected in the semantic layer. Once the task is chosen, and the situation prepared the system can generate the actual task components, especially the

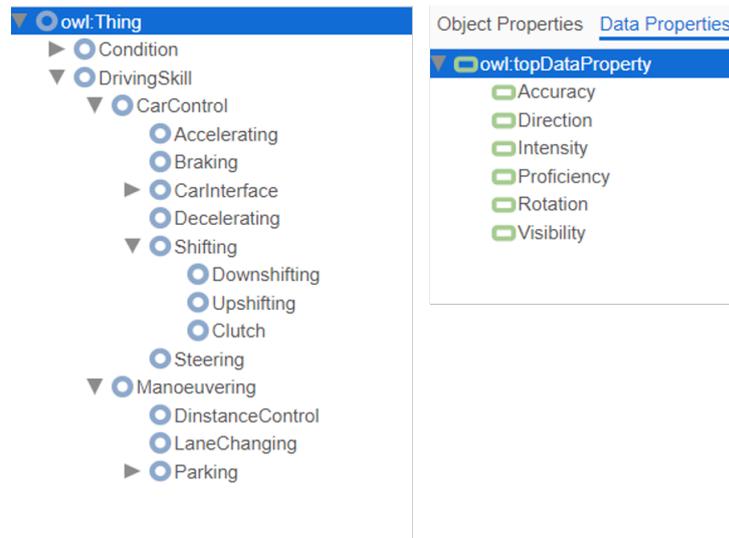


Fig. 5.29: Driving skills ontology

task route and the events, hints and other localised elements along the route. Each task has a *route*, which consists of the paths, mathematical trajectories in 3D space, the user should drive along. The progress of a path (value between zero at the beginning and one at the end) determines the progress of the car on the path. All possible paths are based on the lanes of the road network. The world generation module already has those in his underlying data model. A *pathfinding* module using state of the art  $A^*$  algorithm allows to traverse the road network graph and compute the necessary routes.

Finally, the system has to provide the user with visual clues and instructions to start the task. More clues will guide him along the task.

### User Evaluation

As described in the section on the DriveSim semantic layer 5.1.4, the virtual world is populated on initialisation and updated depending on the user position in the virtual world. The tutoring system runs its main routine in regular intervals. There it first populates the driving and world events based on changes in the world and the segmentation of the driving behaviour in the previous section. Table 5.4 shows some of the skills and related tasks and events. The data is then used by the reasoner to deduce driving errors, task progression and user skill increase.

Each event has a timestamp, and this allows to clear old events after a certain period, which can be configured as needed. It is important to note that certain aspects in the ontology are modelled as a persistent entity. However, at the same time, related events spawn when the parameters of the entities change. For example, the day-night-cycle has its persistent entity which holds the state, day or night. When the immersive system changes from one to the other, a corresponding

Skill	Tasks	Events
Steering	navigate intersections, follow winding roads, lane changes	turn left/right, drive straight, follows path
Driving	start and stop, hold certain speed, shift gears, overtake car	accelerate, decelerate, discretised speed changes, gear shift
Controls	Turn on specific car light, Turn on screen wipers	Weather changes like rain and fog, the day night cycle, cockpit controls events
Intersections	Respect right of way, respect signaling, use correct lanes	key position changes in intersection, traffic situation events, signaling events

Tab. 5.4: Sample of driving skills and their related tasks and events

event is spawned and added to the ontology. After a certain period, it will be removed. This is the basis for a simple example of user evaluation, turning on the headlights at night.

The inner workings of the reasoning is explained using two examples. The first example is about not forgetting to turn on the car headlights when night falls. In this case, the following rules are involved:

1. `Error(e) : Lights(l) ; forgotLights(l) ; set(e.type,forgotLights)`
2. `forgotLights(l) : DayNightCycle(d) ; Lights(l) ; nightJustCame(d) ; is(l.state,off)`
3. `nightJustCame(d) : Event(e) ; is(d.current,night) ; is(e.type,night)`

Each rule follows the simple pattern of:

```
statement ; statement1 ; statement2 ; statement3 ; ...
verb(parameters) : verb(parameters) ; verb(parameters) ; ...
```

A rule or query has a left and right-hand side separated by a “:”. The left-hand side is true if all statements on the right-hand side are valid. Each statement has a verb and parameters. The first rule is already a special case, its a constructor rule, it allows the reasoning system to create new entities if the conditions are met. In this case, it is the first constructor to spawn an *Error* entity. The condition is that the lights have been forgotten, the statement with the *set* verb sets the type property of a new Error to *forgotLights*. The error construction rule references the next rule, which is resolved to true if the nightfall was recently. The last rule defines just that as

the day-night cycle being set to “night”, and that the event of the nightfall exist, this means that it has not timed out. Thus the nightfall happened recently. The tutoring system has to check for errors with the following query:

$$q(x) : \text{Error}(x)$$

The reasoning system will look for errors and constructor rules. In this case, it will find such a rule and start evaluating the statements required to spawn the entity. If all the requirements are met, the system will return an error:

Entity x of type (Error) with properties: type(string)=forgotLights

The second example is about crossing an unregulated intersection. The most important rule here is to respect the right before the left rule. In this example, the intersection has four roads with two lanes each. The driver is on the road 0 (zero), and the other car is a van that can be placed on any of the roads to simulate various situations. Here follows the automated print-out of the semantic entities that constitute the road intersection:

- Entity intersection of type (Intersection)
  - with properties: roads(Road) = {road, road1, road2, road3}
    - Entity road of type (Road)
      - with properties: lanes(Lane) = {lane, lane1}
        - leftOf(Road) = road3 rightOf(Road) = road1
          - \* Entity lane of type (Lane)
            - with properties: cars(Car) = car direction(string) = forward
          - \* Entity lane1 of type (Lane)
            - with properties: direction(string) = backward
      - Entity road1 of type (Road)
        - with properties: lanes(Lane) = {lane2, lane3}
          - leftOf(Road) = road rightOf(Road) = road2
            - \* Entity lane2 of type (Lane)
              - with properties: cars(Car) = van direction(string) = forward
            - \* Entity lane3 of type (Lane)
              - with properties: direction(string) = backward

- Entity road2 of type (Road)
  - with properties: lanes(Lane) = {lane4, lane5}
  - leftOf(Road) = road1 rightOf(Road) = road3
  - \* Entity lane4 of type (Lane)
    - with properties: direction(string) = forward
  - \* Entity lane5 of type (Lane)
    - with properties: direction(string) = backward
- Entity road3 of type (Road)
  - with properties: lanes(Lane) = {lane6, lane7}
  - leftOf(Road) = road2 rightOf(Road) = road
  - \* Entity lane6 of type (Lane)
    - with properties: direction(string) = forward
  - \* Entity lane7 of type (Lane)
    - with properties: direction(string) = backward

In addition to the initial setup, the system tracks the user car position in the virtual world, detects when the user drives into the intersection, and populates an event accordingly.

Here are the rules related to the example:

1. Error(e) : Car(car) ; takeRightOfWay(car) ; set(e.type,tookRightOfWay)
2. takeRightOfWay(c) : enteredIntersection(c) ; Car(v) ; isRightOf(v,c) ; Intersection(i) ; has(i,c) ; has(i,v)
3. enteredIntersection(c) : Event(k) ; is(k.type,inIntersection)
4. isRightOf(v,c) : Road(r) ; has(r,c) ; Road(p) ; is(r.rightOf,p) ; has(p,v)

If the user drives into the intersection the event with type “*inIntersection*” will be populated. If the tutoring system queries the reasoning system with the same query as in the first example ( $q(x) : Error(x)$ ), the reasoning system will detect the wrong behaviour and output an “*Error*” entity with type “*tookRightOfWay*”. If the van is placed on another lane, there will not be an error, as expected.

To summarise the results of this section, it is possible to use a reasoning system to implement a tutoring system in a virtual environment. The benefits are the generic way the knowledge is

structured in the semantic layer as well as the high reusability of the ontologies and rules. The potential issues for the use of this system are the high initial work to model the knowledge base and the thorough testing required for every aspect and rule. It may also be difficult to debug the logic in complex scenarios.

A technical issue is the performance which can drop significantly depending on the queries, rules and the number of entities involved. To manage this, it is again important to test but also to limit the amount of populated entities. This can be done by only considering entities in proximity to the user when processing queries.

## **Validation of Semantic Layer and User Feedback**

### **Development and Validation Environment**

Several developers worked in parallel on the immersive driving simulator in an agile manner. After an initial basic implementation of the open-world generation, it was necessary to create a small world to start implementing and testing the tutoring system and its semantic layer. The selected approach was to use a small subset of various environmental elements to validate the concept in a setup with reduced complexity. The system was scaled up in complexity after the underlying implementation of the tutoring system was ready. The implementation of the tutoring system and the world generation was continued iteratively, and the tutoring system could be tested in several steps, updating it with after every change of the world-generator and traffic simulation algorithms.

For the small test world, we used the *OSM data* of the training ground from the Fuyang driving training centre (see Fig. 5.30).

The scene was build step by step while continuously improving the algorithms for terrain, road network and vegetation generation.

The *training ground* in China is part of the traditional driving training and practical examination. It contains several driving exercises which were an excellent base for the development of the semantic layer for the intelligent tutor. There are five stations to be accomplished by the driving students in the following sequence: uphill stop and go, turning right (also called L-Turn), slalom (S-Curve), as well as two stations for parallel and reverse parking.

At the beginning, we made an analysis of all exercises with their road paths, the traffic regulation elements and rules, the driver skills as well as the possible errors and the penalty points used from the original Chinese driving training. For instance, the goal of an uphill exercise is to stop the car on a slope and to start without rolling backwards (see Fig. 5.31).

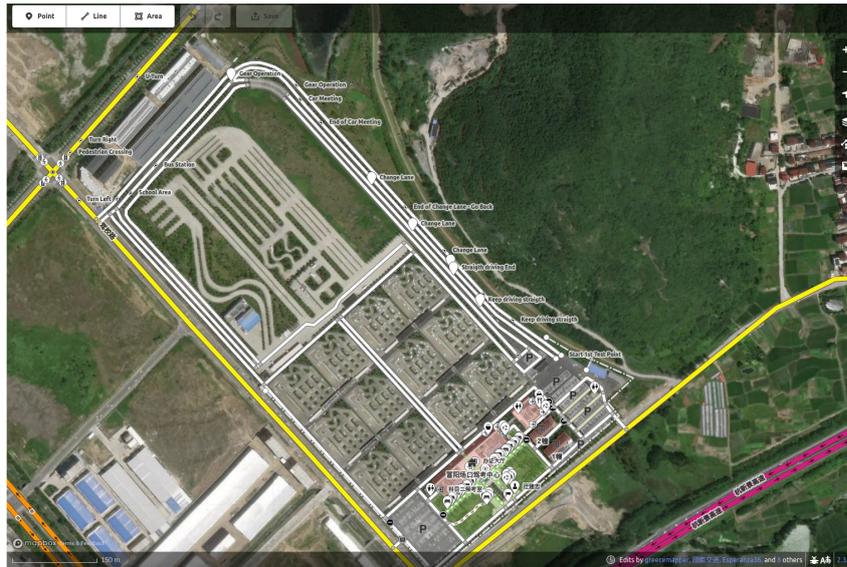


Fig. 5.30: View on the training ground data with the online editor of *OpenStreetMap*

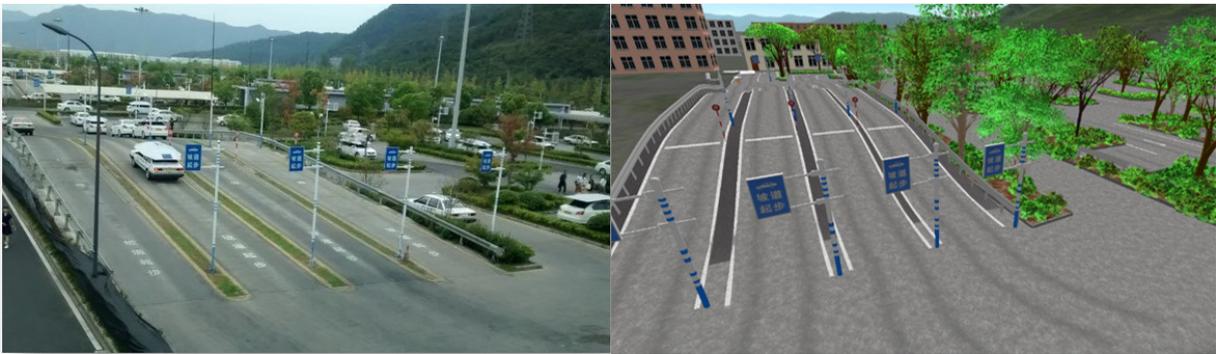


Fig. 5.31: Fuyang training ground, uphill training exercise - real vs. virtual

During this exercise, the user can make several errors like missing the stop line and stop sign, start rolling backwards after releasing the break or during the start and some other minor mistakes like forgetting a turn signal or seat belt. The sequence of the right car manipulations and the detection of errors during task execution was implemented first with the help of state machines and continuously replaced with the semantic layer.

### Feedback of the Tutoring System

The tutoring system presents the information about tasks and the feedback in several ways. First, the user can see information in front of him like on a head-up display (see Fig. 5.32).

This includes the visualisation of the car controls (such as steering angle and pedals), safety hazards or navigation instructions (such as road arrows showing where to turn) are helpful for beginners. At the same time, the additional information can interrupt the feeling of presence, disrupt the immersion. That is why the display of information is sparse and can be hidden and

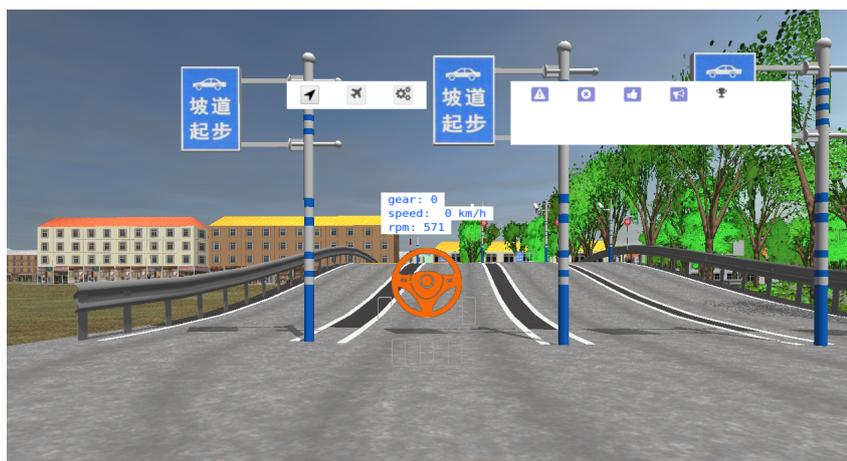


Fig. 5.32: Starting scene for the uphill exercise

displayed on-demand over the user's smartphone or with a tablet integrated into the car (see Fig. 5.33). This feature was implemented based on a web interface so that it can be easily accessible for all devices.



Fig. 5.33: User interface for the tutoring system via tablet

Furthermore, we implemented audio feedback using a text-to-speech system that can give voice instructions on the task performance. Since the driving instructors usually speak to the trainees, we found this output very intuitive. The driving student can configure the kind, type and amount of feedback he wants to receive.

The driving assessment and feedback was organised in sessions, which represents one whole period without prolonged interruption, devoted to the driving training in the immersive driving simulator. In one session (for instance, 30 minutes), the driver can accomplish many tasks. The tutoring system evaluates the driving behaviour and creates a profile of the user. This profile documents the users learning progress based on the sessions and the tasks.

Furthermore, the profile serves as a basis for the generation of new tasks to achieve a gradual learning progress. Some of the implemented performance indicators are distance kilometres, average time, average speed, learning performance for each task and skill progression. During a task execution, the user can see the recent events (see Fig. 5.34). Those events can be instructions, approvals, warnings and errors.



Fig. 5.34: GUI with recent events and users feedback on errors

The instructions describe the next step of the current task. The approval feedback confirms if the task or sub-task has been accomplished. There are also warnings to help the user prevent a driving mistake. For instance, if the driving student is driving too close to the markings, a warning will appear. The errors are also displayed when they occur. Additionally, a list of all occurred errors is displayed at the end of the task. Each error is listed together with the penalty points and a screenshot of the driving mistake.

The graphical web interface has several information tabs. The first tab enables the user login and start of the system. The next tab displays the current driver profile data, which come from the user management server and contain information needed from the tutoring system like user ID, nickname, age, sex or image. The user also has an overview of his learning progress based on the levels and tasks that he performed with the driving simulator so far. The driving student has the choice to manage his training and start a specific task or select the free mode, where the tutoring system generates the tasks automatically. Another possibility of the user is that he can simulate a driving exam. The user interface also allows the configuration of some additional features and settings. There is a setting for autopilot mode, which should show him the right task execution. He can decide which feedback and where to be displayed. Furthermore, the user can set the weather conditions and the day and night cycle.

## Summary

The implementation of the immersive learning environment for driver training was a *highly complex task* with many different working fields. The exception for the *DriveSim* project was the development of algorithms for an *open-world generation* and a *semantic layer* for the realisation of an intelligent tutoring system. This use case covers some aspects of the management and educational layer, but the main focus lies on the technical development. It provided close insights in the analysis, design and implementation of an intelligent immersive training environment.

The *DriveSim* project shows how *knowledge-based AI* methods can be implemented as a foundation in order to help educators to minimise the efforts for further development and customisation of immersive learning applications. The created prototypes demonstrated in-depth the complexity of an immersive system and the steps needed to build a virtual world and the hardware environment.

## Outlook

The tutoring system in the *DriveSim* research project serves as *proof of concept* for the utilisation of *knowledge-based engineering* in immersive learning environments. The next steps foresee the complete implementation of the ontology rules and *evaluation* of the learning system with driving students.

The developed prototype of the tutoring system can be further improved with features such as *spaced repetition*, gaze and hands *tracking* or even assessment of *emotions*, in order to provide better user *feedback* and learning outcomes. For the spaced repetition, the tutoring system needs a mathematical model, which creates an adaptive and customised repetition, to handle the *forgetting* issues coming with the elapsed time between the driving sessions.

The *head tracking* can not only be used for the achievement of immersion, but could also provide additional information to the system about the orientation of the user gaze. The tutoring system could use the gaze for *evaluation of users performance*. For example, if the driving student looked at the gear level while driving or have not looked in the rear mirror during the overtaking manoeuvre.

Another possible extension to the driving simulator hardware that should be from great benefit for an intelligent tutoring system are devices and algorithms that give feedback about the *emotional state* of the user. For instance, the measurement of the eye pupils, the skin conductance

or heart rate, can give additional information, which can be used for better *interpretation* of the user *learning state* and performance.

The project results can be also applied in other fields than learning. The developed automatic generation of semantically *rich open-world* environments with *realistic road network* can be further used for testing environments for *self-driving cars*. Furthermore, the *GIS* features can serve as a basis for *urban planing*, analysis and simulations such as new road intersection and even infrastructure for *renewable energy* solutions.

## 5.2 Teaching Authoring of Immersive Applications in Higher Education

In this section, we present the virtual reality practical course (VRPC) as a validation of the methodology. This course was initially designed for undergraduate and graduate students from *multidisciplinary engineering fields*.

The main goal of the virtual reality practical course is to teach students the *authoring of immersive applications*. Furthermore, it aims at helping students to acquire knowledge of virtual reality hardware, software and applications through a project-based learning approach. Students get the chance to design a solution to a complex task in a team. They must take into account the interfaces between the sub-tasks and then integrate the results into a complete product. Further skills that should be acquired are the methodical approach to practical engineering problems, teamwork, working in multidisciplinary groups, time management and many others.

This course was successfully offered to students by the *Karlsruhe Institute of Technology*. It was held each semester for ten years now (as of 2010), and over 300 students could take part in the course. The first publication on the course methodology in 2013 was very well accepted by the scientific community [HHO13]. The publication was cited in more than 100 other publications so far. We explain this by the fact that virtual reality hardware becomes more affordable over time and that the immersive software matures. At the same time, many educators seek for proven didactic methodologies to provide quality educational programs for higher education that apply immersive technologies.

### 5.2.1 Initial Analysis

#### Analysis of the Current Situation

We proved in chapter *Introduction 1* on page 1 that immersive technologies help businesses expand and that the need for qualified specialists in this area will grow. However, what exactly does make a VR or AR specialist and what are the knowledge and skills they should bring? Here we can differentiate between three perspectives: the employer perspective, the employee (or trainee) perspective and the educators' perspective. The first question is what the industry expects from a VR specialist. From the trainee perspective, it is essential which skills should be acquired. Last but not least, from the educators' perspective it is essential to learn how to design courses in order to meet the requirements and expectations of both industry and trainees.

Immersive technologies have their base on the interactive computer graphics domain, and the required skills are very similar to game development. Additionally, specific hardware knowledge

and experience are necessary. The online marketplace Toptal published an article entitled “*How to Hire a Great Virtual Reality Developer*” after interviewing hiring executives of some of the most successful VR production houses. Their insights show which essential skills and roles the companies are looking for [Top18].

First, they describe the *three usual roles* in a VR engineering team: gameplay engineers, (core) engine programmers and high-level scripting engineers and distinguish them from the artistic roles like 3D modellers, texture artists and animators. The gameplay engineer is defined as the architect or designer of the interactive user experience in the virtual world and does not work on graphics or core programming, but on high-level programming. A core engine programmer works on the low-level programming, usually with C++, and the rendering. They will require in-depth knowledge of linear algebra and analytic geometry which includes vector and matrix operations, as well as the mathematics involved with advanced rendering and shading techniques or physics simulations [Top18]. The third role consist of the high-level scripting engineers who are programming the interaction with high-level scripts like Lua or Python and have a very similar role as the gameplay engineers.

All mentioned roles are people who have programming skills and eventually a computer science degree and should have a sound basis in mathematics. They need a good understanding of software architectures, code optimisation and real-time performance constraints [Top18].

Further *soft skills* that are important when hiring VR developers are collaborative potential, problem-solving, passion and enthusiasm for the VR field and tasks, willingness to improve skills and ability to learn on the job as well as creativity and innovation [Top18].

After describing the necessary immersive technology skills, the question arises as to whether teaching a virtual reality course can contribute to STEM training.

A new generation of engineering students is beginning their higher education, and academic institutes have to introduce them to appropriate technologies for their successful transformation into the industries. University students require more courses with practical application of the acquired theoretical knowledge and want to be better prepared for their *professional future* [HHO13]. Universities should develop the courses in line with the real and constantly evolving requirements of the industry, including those for soft skills.

The number of students enrolled in universities rises. For example, the rate of first-semester students in 2017 in Germany was 56% compared to 33% in 2000 and the number of students in universities during the winter semesters 2017/2018 was over 2.8 million [Sta18a, Sta18b]. Those numbers show that it is of great importance to create *new up-to-date courses* and to improve the quality of the old ones despite the *rising student number*.

We notice an increased number of courses introducing students to immersive technologies. One of the reasons is the more affordable consumer hardware, ideal for classroom environments. Educators search for new teaching methods in order to achieve fast and good quality results and to avoid traditional teaching approaches based on direct instruction or lecturing.

Another question here is how to meet the challenges of the digital transformation, in particular the lack of qualified specialists.

In *universities*, it is always necessary to create innovative educational programs to provide innovative education based on the newest research and technology developments. The curriculum of the Institute for Information Management in Engineering (IMI) at the Karlsruhe Institute of Technology consists of different kinds of educational programs like lectures, seminars, practical courses which cover topics from the computer science in mechanical engineering. Some concrete examples are lectures in virtual engineering, product lifecycle management (PLM) as well as practical courses in Computer-Aided Design (CAD). The infrastructure of the IMI institute consist, next to some processing machines and industrial robots, in virtual reality laboratories equipped with high-end immersive systems. There were many reasons for the development of the virtual reality practical course. For instance, the goal to provide students with access to the technology in the newly opened *Lifecycle Engineering Solution Center (LESC)* back then in 2008, as well as the students desired to practise the knowledge they gained during lectures.

### 5.2.2 Analysis of the Target Group

Usually virtual reality courses are offered worldwide as a capstone of a computer graphics course, under the faculty of *computer science*. This makes sense because virtual reality is close to *interactive computer graphics* and game development which are in-depth topics of computer graphics. At KIT, the virtual reality expertise and equipment is situated under the faculty of mechanical engineering and is used to teach students on how to solve engineering problems using immersive technologies.

The target group consists of graduate and undergraduate students of KIT. This means that the students differ sharply in age and experience. At the same time, the participants come from *multidisciplinary* fields of study with a focus on mechanical engineering, computer science and business engineering and are open to other engineering fields of studies like electrical engineering, mechatronics, mathematics or physics. Furthermore, the high quality of German higher education attracts many international students. This results in a target group of *multicultural* character. The number of students interested in the practical course can vary between fifteen and thirty.

Usually the participants of the VRPC have a solid *STEM background* and a high level of digital literacy. However, mostly only the computer science students have experience with programming or some computer graphics paradigms.

The students are usually *highly motivated* and wish to put their theoretical knowledge into practice. Further, they want to practise their *soft skills* in multidisciplinary projects and learn to use high-end immersive technologies.

The fact that the practical course participants have different bachelor and master degrees, come from different cultures and have different experiences makes the teaching on how to build virtual reality applications very challenging.

The course design and methodology were significantly improved with the experience, the extensive evaluation and students feedback gained throughout the years. This work describes in detail how to design such a course and narrates its concrete implementation. The insight into the methodology should enable educators to design new courses in the area of IT and in particular with immersive technologies in order to close the gap between the growing IT market and the lack of well-qualified experts.

### 5.2.3 Design of the Virtual Reality Practical Course

#### Teaching and Learning Goals

The main goal of the practical course is to teach the students on immersive technologies and how to build virtual reality applications. The students should understand what is behind the magic of an immersive environment and how it is done, based on the current hardware and software technologies. The main topics for the virtual reality applications are from the mechanical engineering domain, but are not be limited to it.

The initial learning outcomes defined for the course were, that the students can operate and use hardware and software for virtual reality applications to:

- design solutions for complex tasks in a team,
- solve subtasks within a specific work package in small group,
- keeping the interfaces to other work packages in mind and
- integrate the solutions in the final product.

Next to the technical skills, we also defined a set of soft skills that the students can train during the course:

- methodical approach to practical engineering problems
- problem-solving
- interdisciplinary and intercultural teamwork
- project management and marketing
- time management
- both autonomous and group work

Using a *problem-based learning* approach provides us with the possibility to simulate an industry-like project setup, such as the one the students will have to handle in the future. Hence, we provide students with a sandbox where they can practice their soft skills, make mistakes and see the consequences of their actions, without being punished by the supervisors.

We train the problem-solving skills in the context of an *engineering problem* in the form of project work. Next to the learning of virtual reality, the students learn unconsciously additional topics from science, technology, engineering, mathematics and other fields.

How the methodology of the VRPC meets all six kinds of learning defined by Fink in his Taxonomy of Significant Learning (see Fig. 2.5) is showed in Tab. 5.5.

## Resources

### Human Resources

The initial instructional design and the preparation activities of the virtual reality practical course were a collective and iterative work by the colleagues Jurica Katicic and Polina Häfner [HHO13]. The human resources for the design task were one research associate and one research assistant. Their experience was in mechanical engineering and pedagogy, as well as in computer science and virtual reality technologies. Both had experience with immersive systems and building immersive environments. Later the concept and topics were enriched with the help of further involved colleagues, by the supervisors' experience and the students' feedback.

The number of supervisors during the delivery of the VRPC is different in each semester. It depends on the number of students and mostly on the projects number. The number of students varied between 12 and 30, and the members number was from 5 up to 12 per project.

Virtual reality practical course goals	Kinds of Learning
Learn about virtual reality theory, hardware, software	Foundational knowledge
Learn about a STEM subject as project use case	Foundational knowledge
Able to operate and use hardware and software for virtual reality applications	Application
Gain programming skills	Application
Project management and marketing	Application
Time management	Application
Problem-solving	Application and Integration
Methodical approach to practical engineering problems	Integration
Interdisciplinary and intercultural teamwork	Human dimension and Caring
Both autonomous and group work	Human dimension and Caring
Self reflection	Learning how to learn
Further after course activities like publications, work as research assistant and others	Learning how to learn

Tab. 5.5: Learning goals of the virtual reality practical course and their classification into the six kinds of learning by [Fin13]

Per semester there were usually two to three projects simultaneously. For each project, there was one research assistant as a supervisor (see also the diagram with the recommended organisation and communication between learners and educators in the methodology (see Fig. 4.10 on page 98 ). The assignment of the supervisor to a project depends strongly on his experience and interests.

In the case of several parallel projects and high number of project members, best practices show that next to the primary supervisor, it is recommendable to assign a further supervisor (a research assistant per project). The primary supervisor takes care of the overall course management and should also own expertise in virtual reality.

### Technical Resources

For the virtual reality practical course the laboratories of the *Lifecycle Engineering Solution Center (LESC)* at KIT were used. *The Institute of Information Management in Engineering (IMI)* established the centre in 2008 as a central platform for the institute's research results, the interdisciplinary exchange of knowledge at KIT, and the transfer of technology into practice. At the LESC there were four laboratories equipped with state of the art VR hardware and software. In the VR lab a *high-end virtual reality environment* with a distributed stereoscopic visualisation

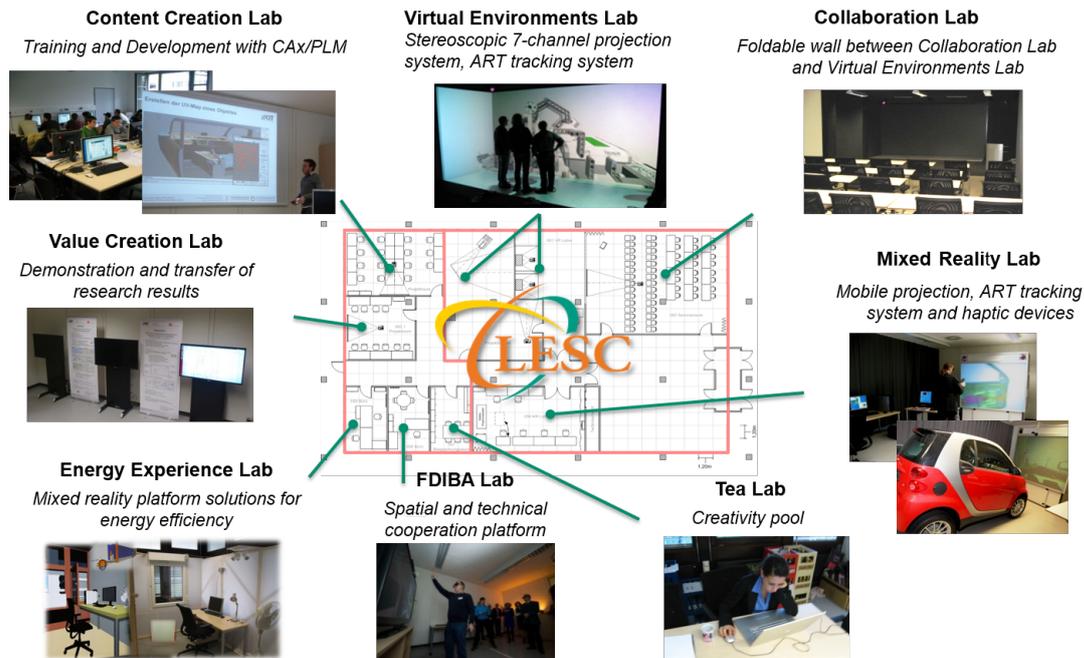


Fig. 5.35: Infrastructure of the *Lifecycle Engineering Solution Centre* at KIT, stand 2018

in a three-sided CAVE setup allowed to dive into virtual worlds, see Fig. 5.35. The CAVE had a size of 4,93 m x 1,95 m x and 2,6 m and used circular polarisation for the stereoscopic effect with a 12 million pixel resolution. Later it was renewed with active stereo projectors. Furthermore, it was equipped with a high-quality tracking system by ART company to realise head and device tracking for interaction. The so-called mixed reality lab consisted of a mobile powerwall (2 m x 1,5 m) with tracking system as well as two haptic devices. Many other immersive devices like 3D monitors, VR-Headsets, depth cameras, data gloves were available and gave the possibility to research and experiment with low-cost VR environments.

Researchers and students used the computer pools with powerful graphic workstations for the authoring process like 3D content creation, application development and teaching courses. Furthermore, seminar rooms were available to provide a place for the presentation and further meetings.

The software platform used for the VR practical course at the beginning of 2010 was *3DVIA Virtools* from *Dassault Systèmes*. The advantages of this software were the provided visual programming paradigm allowing students to develop applications with greater ease as well as the present documentation. During the work with *3DVIA Virtools*, we noticed some drawbacks: There was no large community centred around it, the “*visual code*” becomes too complicated with each semester, and the code was hard to understand and sustain. Complex manual configuration of underlying VR hardware was needed and high costs for licenses incurred.

Lacking sustainable and free available virtual reality software back then, we started to develop our virtual reality engine called “*PolyVR*” ( for more details see *Virtual Reality Software* 3.1.2 on page 42). This software supports our high-end-visualisation centre *LESC*, as well as the institutes’ research and teaching courses. At the beginning, it was harder for students without programming experience to write Python scripts, compared to the visual programming. Besides, the supervisors compensate for the missing documentation with an intensive support.

### **Financial Resources**

The university has at its disposal budget for new teaching courses and financed the design and development of the virtual reality practical course. Furthermore, there is a budget available for further materials and equipment needed. Supervisors give the students the possibility to plan the project budget, which is a beneficial experience for the students. They could get economic experience and learn how to search for a specific product that fits best their needs and budget, how to compare offers and purchase in the context of a big company.

### **Time Constraints**

The lectures at KIT are organised in two semesters per year. Usually the winter semester is from October to February and the summer semester from April to July. Each semester has approx. *15 weeks*. To achieve four credits, a student should spend 120 hours on the learning process. Usually, the educators spread the hours over the semester. This means in our case three academic hours per week. However, the project workload usually varies during the semester. That is why we provide the students with the information about the necessary *workload*. They should spend about thirty-two hours on course work, about seventy-three hours independent work and approximately fifteen hours preparation for evaluation. This information should help them to plan better the project goals and needed efforts.

We planned *six months* for the course design, preparations and creation of learning materials. The next section describes in-depth information on the implementation of the preparation activities and learning materials (see *Preparation Activities and Development of Educational Resources* 5.2.4 on page 237).

### **Course Structure**

The course structure follows the methodology and contains *three overlapping phases*. In the first three weeks, the students were introduced to the course (overall introduction), the virtual reality (theoretical introduction) and the authoring tools (practical introduction). The most prolonged phase (approx. 9 weeks) contains project work in small groups on a given task and is organised

as described in the *Educational Layer* in Tab. 4.5 on page 78. The phase started with the task assignment and project groups composition in the first week and continues with the project planning. The presentations of the project plan and the intermediate one alternate with the project work. Students demonstrate the project results at the end of the course. This overlaps with the summative evaluation in the third phase.

## **Learning Activities**

### **Introduction**

The supervisors give a presentation about the overall course *organisation* during the first unit. The supervisors supply students with a detailed explanation on the course organisation, project work and evaluation, so students can better prepare for the course tasks and organise their schedule for the semester.

#### *Initial Design of the Theoretical Introduction*

The initial course design used lectures and demonstrations for the theoretical introduction. Short presentations on the topics around virtual reality like definition and application, hardware, software techniques and solutions, were alternated with demonstrations in the labs. By *alternating* activities, students could stay focussed during the lectures and gain a better understanding of the VR concepts. During the *demonstrations*, students can try existing applications and have a first contact with virtual reality interaction devices, projection technology and thus can understand better the effect of head tracking and immerse in the virtual environment. At this point, students can experience several different virtual reality setups and applications. A good practice is to show VR applications of students from the previous semester, so the new students can have a notion for the possibilities and limits of what is possible to create during one semester.

The *problem* arose with the students' assessment, which was in written form at the end of the semester. Students found very *stressing* to provide at once all demanded evaluation materials like a working VR application, documentation and presentation, and additionally to prepare themselves for a written exam on the theoretical background. Since there are other parallel courses which also demand submissions or preparations for evaluation at the end of the semester, the instructional design was changed.

### ***Design Improvement of the Theoretical Introduction***

We solved the issue with the written exam by using the *flipped learning* approach and shifted it to the beginning of the course. Students become a *homework* after the overall introduction, with the task to create and give a *presentation* on a topic from the area of immersive technologies. They get an *instant assessment* and at the beginning of the course have already 20 percent of the evaluation. The supervisors performed the *demonstrations* in the first course unit after the overall presentation, in order not to interrupt the students' presentations. The students are required to create up to 4 slides in English about a term from virtual reality. They can use different multimedia, such as a combination of text, diagrams, images. The students' task requirements include scientific writing, providing references for their sources and summing them up in a fifth slide. They have then five minutes to present their topic in class during the next course unit. This change brings *numerous advantages* for both students and educators. There is a very high chance that the content provided will be up to date because of the rapid development in this area. Furthermore, the students get or can practise some soft skills like frontal presentation, time management, autonomous work, research on a specific topic and learn to concentrate on the essentials, in order to bring all vital information on four slides. The presentations make the course more *dynamic*, through the changing presenters and topics. The learning outcome is guaranteed, at least for the one specific topic in details and the overview of the other presented topics by the peers.

The supervisor can give *individual feedback* to each student about his performance and can get to know them better. Both can improve the teaching quality, providing individual advice for the further learning activities.

### ***Practical Introduction Activities***

A central tool is the virtual reality authoring system *PolyVR*. With this tool, the students will create their virtual worlds. Further essential tools are those for content creation, in particular *Blender* for 3D modelling and *SolidWorks* or *CATIA* as CAD tools. To manage the source code and the assets, we provide the version control management system *GitLab*, which is web-based and open-source. *GitLab* comes with a wiki and issue-tracking features, which students can use for project management.

In the second and third week, we provide labs for the before-mentioned tools. Each lab involves two academic hours. At the beginning of a lab, the supervisors introduce to the students the interface and features of the 3D modelling, construction or the virtual reality authoring tool. Afterward, the students can do the exercises themselves and compare them with a sample solution. Of course, the supervisors are available for questions all the time. Some students already have experience with some of the software programs and are not obliged to visit the labs.

Some tools like Blender have a huge pool of online tutorials aimed at beginners as well as advanced users. The students are encouraged to go through such tutorials at home or on-demand during the project.

### **Project and Team Work**

The supervisors decide on the project topics, some weeks before the semester starts. The topic and the goals of the project should cover the learning goals of the course. That means that the students should implement a virtual reality application and deploy it on virtual reality hardware. The project goals should be doable during the three months, including the planning and training phase and should not exceed 90 to 100 hours per person. Usually, the topic we chose is connected to a current research project or near to the institute's research area of virtual reality and Virtual Engineering. Additionally, we ensure that the supervisors possess the necessary experience to support the students during the semester. Each topic and the project tasks are presented to the students before the course starts. They can define their priorities during the introductory questionnaire.

As described in the methodology, the course supervisors decide which students are going to work in which project and subgroup. At the beginning, it is essential to define precisely the project goals and task and then divide them in two or three groups. The supervisors should estimate how many students can work on the specific project, and depending on this number, subdivide them into smaller groups.

The groups are built in a *multidisciplinary* manner and include students from the mechanical engineering, computer science and business management fields of study. The group assignment depends on criteria such as the students' background, their interests and learning goals. This information comes from the introductory questionnaire and talks.

A project leader who is usually an engineering management student is designated. He helps to simulate a working environment similar to an industrial project. The hierarchy and communication between the course members are those proposed by the methodology (see Fig. 4.10 on page 98). The project leader looks after the project planning, organisation, budget and progress, team coordination, conflict management and communication with the course supervisors. In some projects, there can be a technical leadership role as well, if it appears reasonable.

## 5.2.4 Preparation Activities and Development of Educational Resources

For the initial preparation and development activities, we allocate *six months*. Some of the learning and evaluation materials are created once and are further optimised on-demand. Other preparation activities like *ILIAS* setup for course registration and preliminary talks are provided each semester.

### Course Marketing

In a university context, it is necessary to register a lecture or course six months ahead in the so-called handbook of modules. In this handbook, students can choose between different courses to organise their modules based on the credits they need.

Furthermore, the institute's *web page* contains actual information about all offered lectures and courses. On the web page of the virtual reality practical course, are presented all needed details. On the one hand, we provide some information about the learning goals and activities, which should help students to compare different courses and make a decision if and when to take the course. On the other hand, we publish information about supervisors, their contacts, the course starting time and date, exam date, location as well as registration formalities and links to the learning management system *ILIAS*.

Useful reference for students can provide information about laboratory equipment, recent project results, co-operations with companies or other organisations, as well as achieved awards.

The current *IMI* web page provides information about the *previous projects* with links to the result videos. Our experience showed that a video channel with project results is very beneficial to presenting the course scope and helping decision making (see Fig. 5.36).

### Course Registration

For the students, the course starts with the registration through the web-based learning management system *ILIAS*. Usually, the registration opens two weeks before the start of the semester. Students can find all organisational information (as in the official web page) and further documents like the presentation with a short description of the student projects for the coming semester, a detailed schedule of the course, a presentation on the evaluation criteria and evaluation documents. Furthermore, templates for course documentation, presentation and poster are provided in the system (see Fig. 5.37). Later all presented in-class materials, and additional helpful documents are uploaded.

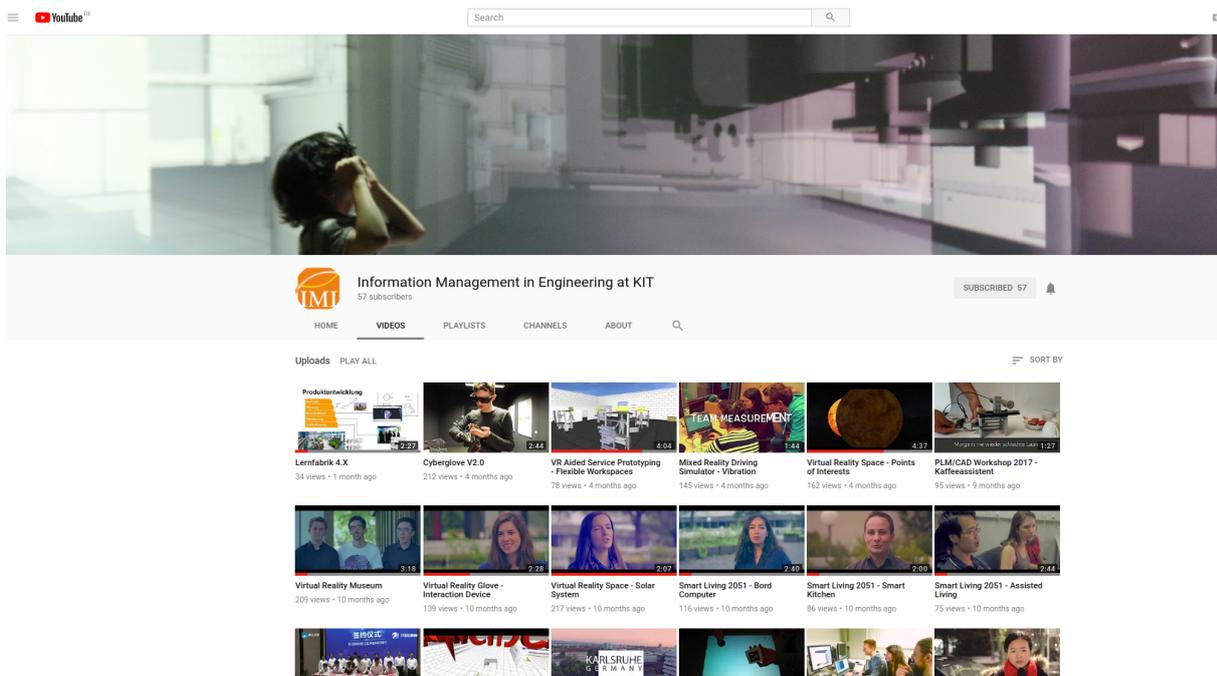


Fig. 5.36: Institute's Youtube channel with the project result videos [Ins20]

The course currently offers 30 student places. The acceptance criterion is first come first served. A waiting list is also enabled. As a following step, students are invited to introductory talks and, or are required to fill out a questionnaire as described in the next paragraph.

### Introductory Questionnaires and Talks

The individual preliminary talks are the first meeting of the supervisor with the students, and this happens a week before the first course unit. We plan *fifteen minutes* for each student's *interview*, in the case the student filled a questionnaire ten minutes are enough. The goal is to present themselves together with their background and the knowledge they gained during the degree programme, but also in previous internships, current job, as well as the learning interests, motivation and expectation for the upcoming course.

The time can also be used by the student to ask questions to the supervisors. Most of the students are well informed about the learning goals and organisation from the provided information, since the usual questions are concerns on the demanded background. This information about the level of their competences, skills, motivation and expectations, makes the task specification easier and ensures that we take the interests of students into account. This practice leads to higher motivation, better project results and acquirement of targeted knowledge and skills.

Later in practice, we developed a method to shorten the time for preliminary talks, because the number of students rose from around 15 to 30 per semester (sometimes over 50 registrations).

The screenshot shows the ILIAS course interface for 'Virtual Reality/Engineering Praktikum SS18'. The page is organized into several sections:

- Navigation:** Includes 'PERSONLICHER SCHREIBTISCH' and 'MAGAZIN' at the top, and a breadcrumb trail: 'Magazin » Organisationseinheiten » Fakultät für Maschinenbau » SS 2018 » Virtual Reality/Engineering Praktikum SS18'.
- Course Title:** 'Virtual Reality/Engineering Praktikum SS18' with an 'IMI' logo and an 'Aktionen' button.
- Menu:** 'Inhalt', 'Info', 'Einstellungen', 'Mitglieder', 'Lernfortschritt', 'Metadaten', 'Export', 'Rechte', and 'Voransicht als Mitglied aktivieren'.
- Actions:** 'Zeigen', 'Verwalten', 'Sortierung', 'Seite gestalten', and 'Neues Objekt hinzufügen'.
- INHALT (Content):** A list of course items:
  - '2018\_04\_17-VRP-TeilnehmerlisteNachProjekte+Mail' (pdf, 13 KB, 18. Apr 2018, 15:07)
  - 'Bewertungsunterlagen'
  - 'Homework'
  - 'Kursunterlagen' (Note: 'In diesem Ordner werden die Folien von den Veranstaltungen hochgeladen')
  - 'PolyVR Advanced Exercises' (Link to den Übungen git clone [http://imi-dev.imi.kit.edu:443/annebx/VRP\\_polyvr\\_exercise](http://imi-dev.imi.kit.edu:443/annebx/VRP_polyvr_exercise))
  - 'Pre-Interview Questionare' (Eine generelle Umfrage über eure Kompetenzen und Präferenzen. Dient dazu den Bewerbungsprozess für alle zu beschleunigen. Sie haben an dieser Umfrage noch nicht teilgenommen)
  - 'Zusagen\_Teilnehmer2018' (pdf, 312 KB, 17. Apr 2018, 12:34)
- Nachrichten (Messages):** A list of recent messages, each with a date and a note 'Die Datei wurde hinzugefügt.' (The file was added).
- Kalender (Calendar):** A calendar for June 2018, showing dates from 22 to 30.

Fig. 5.37: An example for *ILIAS* course contents in summer semester 2018

After the registration in *ILIAS*, the students should fill a short inquiry about their experience, expectations and skills (see *Appendix A.4.1* on page 338).

The first questions are of *administrative* nature such as full name, matriculation number, degree program and number of semesters already attended. There are several categories of *knowledge and skills* like experience in programming, CAD construction, 3D modelling, teamwork, interdisciplinary work, time management and project management. Those are the most critical skills that students should learn and need to acquire to accomplish the tasks. Students evaluate them according to the *three categories*: want to learn, want to practise or already experienced. Those categories help building the multidisciplinary groups in such way that the students can define which skills they want to learn during the semester and learn from one another and help finding the right balance in the groups.

Each student comes to the course with his *motivation* and *background*. That is why some questions concern the motivation and interest in the course. They should also try to grade their experience as a beginner or advanced user.

*Additional information* about a bachelor thesis, seminars or internships as well as relevant hobbies are also essential for the teachers in order to get to know each student. *Introductory talks* help to gather many details about a student like his character and current skills. That is why we find them of central importance for a successful semester. Teachers can thus later steer

successfully the individual learning process of each student in a large multidisciplinary group. As a following step, students are invited to introductory talks and, or are required to fill out a questionnaire as described in the next paragraph.

In the *introductory questionnaire* the students should evaluate the projects proposed for the new semester according to their *preferences*. This categorisation is essential for a good learning process because it keeps the students more motivated, engaged and excited during the semester.

## **Project Work Preparations**

The preparation for the project work consists of the selection and description of the project topics and tasks. Furthermore, the supervisors develop the requirements for the project work and the templates for the deliveries. All resources and IT infrastructure should be ready to use before the semester starts.

## **Project Tasks**

Usually, the supervisors provide a short description of the project topics and tasks in the form of a presentation slide or a document file. Each file includes an introduction to the topic and projects main goals or problems, followed by the requirements.

The project description also includes the initial separation in the different types of subtasks and groups, and a description of the provided resources. In case former students have already worked on this topic, there may be some information about previous project results. The project-specific supervisor has to present the students' assignment to the projects and projects groups and his or her experience in the project area.

## **Presentations Requirements and Templates**

As described in the course design and structure, students should manage several project milestones and deliveries. The main milestones are the presentations starting with the project plan at the beginning, the intermediate results and the final presentation. Each presentation has its specific requirements that students should follow. The supervisor supplies students with a general presentation template, but each presentation has its requirements.

The project planning presentation should contain a description of the group tasks and the assigned course members, the results of a research on the state of the art, a description of the procedures and approaches to the solution (ideas, concepts, design), the identified interfaces between the groups or even the projects, a time plan with milestones (e.g. Gantt chart) and a budget plan. Besides, students should provide their decisions on team rules and organisation,

project management, communication channels, meetings' rhythm, documents storage, administration of resources like keys, laboratory equipment and others.

The intermediate and the final presentation have many similarities, because they should describe the results according to the initial plan and concepts. The project manager introduces the overall project description and group interfaces and provides a conclusion and outlook, whereas each group member presents his results in the central part. The time constraints for the final presentation depend strongly on the students number and should not exceed the defined time limit. Half an hour is usually available for demonstrations and feedback.

### Project Documentation

The main goals of the project documentation are to teach the students to write reports, to facilitate the individual evaluation and to achieve the project's sustainability over more than one semester. To meet those objectives, we provide some requirements on the final report.

There are some minimal formatting requirements, like title page, table of contents, page numbers, as well as summary, outlook and references. The title page should include the name of the project, semester, the name of the group and the group members with their matriculation numbers. Students should provide a short description of the project goals and task, with a maximum length of one page. They should dedicate one to two pages to the project plan, team organisation and the group interfaces. We recommend that every single task with its solution approach, issues and results is described in the form of a table (as shown on Tab. 5.6). Students should write a user manual on how to set up and start the application on the dedicated immersive hardware. Some requirements may sound trivial, but students often overlook them, if they are not mentioned explicitly.

Task	Short name and/or number of the task as in project plan
Team member	Who worked on the task? Provide the team member(s) who have worked on this task. If more than one member, provide below the work share in percent or hours spent
Planned time	The estimated time to achieve this task according to the plan, in hours
Actual time	The actual time needed to achieve the task, in hours
Task description	Provide short description of the task goals (one to three sentences)
Issues	Describe the issues that have arisen during the work on the tasks and the solution approach or taken correction actions
Results	Describe shortly the results

Tab. 5.6: Requirements on the tasks description in the documentation

## Preparation of the Laboratory Equipment

Supervisors and system administrators have to ensure that the laboratory equipment is working properly and is ready to use. The same applies to the computer pools. They have to install the most recent version of the software tools used. In our case, this is the current long term support version of the open-source operation system *Ubuntu*, the virtual reality authoring system *PolyVR*, the *Blender* modelling tool as well as the *GitLab* server, where the students should manage their source code. Further preparation activities concerning the immersive systems were the purchase of new devices or licences.

## Development of Educational Materials

### Schedule

One central element is the detailed schedule for the concrete semester. It includes the date and place of each class activity, each topic, and assignments. This task entails the reservation of all necessary resources, supervisors and facilities for the practical course. The schedule of a virtual reality practical course is attached in the *Appendix A.2* on page 340.

### General Introduction

The general introduction is given in form of a presentation. The presentation contains all relevant information about the course as follows:

- Introduction to the institute, the main research areas, its teaching portfolio and infrastructure,
- Introduction of the supervisors with their role, experience and contact data,
- Course objectives, scope and organisation
- Detailed timetable as attached in the *Appendix A.2* on page 340
- Organisation and requirements for the project work
- Some examples of previous students' projects
- Students assessment and course evaluation
- Short introduction to virtual reality and its application areas as a transition to the demonstration

## Homework and its Evaluation

The virtual reality theoretical background can be divided into many topics, depending on the number of students. The supervisor selects the topics carefully, so that they do not overlap and takes care that first the key topics are covered. It is allowed for two students to work together on one topic. Both students should separate it into well distinguishable subtopics and promise to cooperate. An example for the topics are listed in the *Appendix A.4.3* on page 341.

The supervisor provides a presentation template for the homework through the learning management system and defines the deadline for uploading the ready presentation. The deadline for uploading is one for all students, even if the presentation time for all on one date is not enough and should be scheduled for the next week.

## Labs and Tutorials

Supervisors perform both laboratories differently. Some of them use autonomous work based on scripts, and others apply the approach “supervisors show - students repeat” approach.

For the labs based on Blender, the supervisor needs excellent skills in the tool, to present its different operations and to introduce the modelling process. The laboratory starts with an introduction of the Blender central interfaces for 3D modelling and texturing as well as navigation and short keys. Then the supervisor shows on a projector small subsequent steps of geometry creation, manipulation and texturing, giving the students time to execute each step on their computer. When issues arise supervisors help students to solve them and proceed with the next step. We choose this approach because there exist numerous online tutorials on Blender, and the tool is excellent documented, which makes the creation of further scripts and materials unnecessary. Furthermore, Blender is a free tool and students can install it on their private computers and practise when they have time.

One most time-consuming preparation task is the laboratories’ development for the VR authoring system. It follows all requirements for the authoring of an immersive environment as described in *Design of Immersive Applications* 4.2.2 on page 125 and at the same time, should present the possibilities of the authoring system with easily manageable steps. The developer of the labs provides all resources, including the assets creation and the source code implementation. He also writes instructions in the form of a document and comments in the codebase.

## Assessment and Evaluation Materials

During the preparation phase, supervisors create in details the overall evaluation based on the design and planned activities. As described in the section *Students and Course Evaluation* 5.2.6 on page 256, there are two kinds of evaluation materials. Some of them are necessary for the students' assessment and others for the course evaluation. The development of the assessment materials include the evaluation sheets and the grading system. The evaluation sheets are mostly in the form of tables and include the criteria, and the maximum points students can get. Each teaching activity has its evaluation form. The *Appendix A.4* on page 338 contains the evaluation sheets for the practical course such as those for the assessment of project work, project presentation and documentation. The grading system developed for the evaluation of the practical course is presented in Tab. 5.7.

Points or Percents	Description	Grade
Over 90 to 100	Excellent	1,0
Over 85 to 90	Very good	1,3
Over 80 to 85	Good	1,7
Over 75 to 80	Good	2,0
Over 70 to 75	Good	2,3
Over 65 to 70	Average	2,7
Over 60 to 65	Average	3,0
Over 55 to 60	Average	3,3
Over 50 to 55	Satisfactory	3,7
Over 45 to 50	Satisfactory	4,0
45 or less	Failure	5,0

Tab. 5.7: Virtual reality practical course grading system

Two *feedback sheets* cover the specified course evaluation. The university provides the first, and the course supervisors developed the second. As preparation for the *midterm KIT questionnaire*, supervisors request the actual sheets and are obliged to warn the students of the deadline for filling it out. The development of the *VRPC feedback sheet* (see *Appendix A.4.3* on page 346) rests on the essential instruction design elements like the course organisation, the methodology and didactics, as well as the supervisors and the satisfaction with the acquired competences. All of the categories have five questions, with the possibility to answer based on a five-point Likert scale. The questionnaire includes a place for further comments and suggestions for improvement.

### 5.2.5 Delivery of Instructions and Project Examples

The delivery of instruction usually happens according to the proposed instruction design and based on the developed materials. To give a good idea for the delivery of the course, we provide some examples of the students' projects.

Supervisors stay *flexible* to react to changes, if they cannot deliver some of the activities according to the plan. A good example is the COVID-19 pandemic 2020, which made the face-to-face communication at the beginning of the course impossible. The supervisors gave all presentations, labs and project work online. Another example was the necessary relocation of the institute and thus the VR labs during the semester.

In a multidisciplinary and multicultural course, supervisors should be always on the alert and try to avoid misunderstandings and conflicts. In this phase, the most essential is to create and keep a *cooperative learning* and working atmosphere, where students can enjoy a creative learning process. Supervisors are always available for students' questions, and if students do not ask, supervisors regularly check if they experience difficulties.

The *project work* phase starts directly after the task specification. The students have two weeks for research and planning. After that period, they present the *time plan* with milestones, the *budget* preparation and the *solution approaches* for all tasks. During the planning phase, the students should identify as early as possible the interfaces between the groups and sub-tasks. It is up to the practical course members to decide how frequent and where to meet for teamwork, discussion of the project progress or occurred problems. During this phase, the course members are free to choose project supporting software tools like project management tools, communication tools or ticket systems.

After the *practical introduction*, students have an idea for the authoring process of virtual reality applications and start working autonomously according to their plan. If not communicated by the students in advance, supervisors notice potential problems during the intermediate project results presentation. The problems the students encounter or the mistakes they are likely to make are the same each semester and should be mastered to achieve a better learning outcome.

At the latest during the *midterm presentation*, supervisors notice the problems and give some advice how to solve them. Often students plan more features that they can implement for the available time. Together with the supervisors, they decide which tasks are from central importance and will further be developed and which tasks they can label as nice-to-have.

The *last two weeks* of the practical course are the most intensive time for the students. They have already collected good experience with the authoring process and the teamwork, and are faster in implementation. At the same time, they prepare the documentation and presentation materials

for the final presentation. During this period, students spend most of the time in the laboratory working with the immersive systems to test and optimise the virtual reality application and the user experience.

The number of course participants and current boundary conditions determine the organisation of the *final presentation*. It should not exceed a specific duration for all projects. Usually, with 15 to 20-course participants, there is enough time for each student to present 5 minutes long what he or she has done during the semester. Supervisors ask questions at the end of each project group presentation to see if the student has done the presented task himself and has understood the learning matter.

The challenge for the students is in the creation of a narrative presentation with good red line where, for instance, ten project members have five minutes to present their tasks. The project manager has about ten minutes to present at the beginning the project goals, team and management and to conclude the presentation with a summary and outlook.

## **Examples of Sustainable Projects**

### **Immersive Driving Simulator**

The first and many other following projects in the virtual reality practical course were on the topic “Immersive Driving Simulator”. Due to its complexity, each semester, we could achieve small advances in the development or even start from scratch due to changes of software tools or hardware.

#### ***Immersive Driving Simulator - Summer Semester 2010***

The very first application realised during the virtual reality practical course was an immersive driving simulator, see Fig. 5.38. The hardware for visual output was a powerwall equipped with ART tracking system for head tracking, and a computer cluster. The students built a seat-box with a real car seat and used the gaming controller Logitech G25 as car interface (steering wheel, pedals and gear). The software solution was realised with 3DVIA Virtools. The students had to implement a virtual world, which contained a 3D model of the car, a track, the environment, weather conditions and sound. The most important part was the driving simulation and physics (e.g. collision detection). For this task, the physics pack of 3DVIA Virtools was used, ensuring that a change in weather conditions resulted in a respective change of friction parameters and textures. The students learned to implement a virtual camera, head tracking and set up the visual output using a computer cluster.

Over the next semesters, students improved different elements of the virtual environment. The latter got more and more complex over time. For example, students developed an algorithm for the generation of the track to allow its customisation before starting the simulation. They implemented manual gears for the driving simulation as well as many other features.



Fig. 5.38: First semester of VRPC in 2010 and the first prototype of the immersive driving simulator

### ***Immersive Driving Simulator - Summer Semester 2013 and Winter Semester 2013/2014***

The further versions of the driving simulator were developed based on a real car (Smart Fortwo) donated by the Daimler AG company, see Fig. 5.39. The challenge was to integrate the car into the already existent simulation. This was achieved within two semesters using different approaches. The first implemented approach was to embed the Logitech sensor in the car and use the existing software interface for the controllers.

During the next semester, the students used reverse engineering methods in order to utilise the CAN-bus system of the car. They made it possible to send signals from the car to the computer and back. This achievement allows accessing all of the cockpit instruments and common interfaces. At the same time, the students started to work with the virtual reality framework PolyVR. Many tasks, such as the physics simulation and creation of a virtual environment, had to be performed again. Furthermore, students implemented sound effects using a 5.1-channel

sound system integrated into the car. The car roof occluded the head of the driver, and it was not possible to track the user's head with the ART tracking cameras mounted on the projection wall. The students tried to develop a new solution for head tracking based on the Kinect depth camera. The results of those two semesters were captured in a publication (see [HSG<sup>+</sup>13]). The students took part in the writing process under the support of the supervisor. Furthermore, they could present their work during the conference.



Fig. 5.39: The immersive driving simulator in 2013 [HSG<sup>+</sup>13]

### *Immersive Driving Simulator - Summer Semester 2014*

The virtual reality practical course in the summer term of 2014 focused again on the immersive driving simulator. However, this time the main task was to integrate the CarMaker software from the IPG Automotive company. The partner company is located in the same city, and the students could work directly with its employees to achieve their tasks. The CarMaker software served as a back-end for the simulation of the driving behaviour. The virtual world described in the CarMaker software was visualised in the virtual reality through the VR authoring system PolyVR. Furthermore, the students in this project worked on methods for capturing and automated editing of textures for streets and buildings to achieve a more realistic virtual environment.

Over the following semesters, the projects' focus was on the further development and improvement of the immersive driving simulator. Some examples are the implementation of a realistic sound and a force feedback. The results of those semesters are available on the institute's video channel [Ins20].

### **VR Space Project**

The VR Space project is a multiple purpose tool to learn and understand the world of virtual reality in combination with our solar system. People of each age can easily use the system to gain more information about planets, their moons and satellites. Since the set foundations in

summer semester 2017, students continuously improve the system and add functionality in a further semester of the virtual reality Practical Course.



Fig. 5.40: VR Space project

### ***VR Space - Solar System - Summer Semester 2017***

The VR space project started in the summer term of 2017. A team of six female students set the foundation. The project team decided to divide the task into three subtasks that created the subteams:

- Team Planet Model - Modelling of the orbital elements,
- Team Orbits - Modelling of the orbits according to the celestial mechanics and
- Team Navigation - Development and implementation of a user navigation system.

The main objective was the development of a scientifically funded model of the solar system and the deployment of the application on a cave automatic virtual environment (CAVE). As a basis for a realistic description of the elements of the solar system, such as planets, moons and space stations, the students collected and structured many data. The different data, e.g. 3D models, textures, typologies and further characteristics, were pre-processed using the modelling tool Blender and the virtual reality authoring tool PolyVR. Besides the implementation of the celestial bodies itself, students added the animations along their orbits. They modelled the orbits and their rotation according to the laws of celestial mechanics. Furthermore, students used a skybox that displays the Milky Way. Users of the application can navigate through the displayed solar system using a flystick, keyboard or a mouse as a controller device. They have a menu to control the navigation and can interactively select scientific facts about the object observed. The main goal of this project was the creation of a realistically displayed model of the solar system that can serve as an immersive learning tool to its users. The *Appendix A.4.3* on page 347 summarises the project results in the form of a poster. A video is also published under [Stu17].

### ***VR Space - Solar System - Winter Semester 17/18***

The project VR Space was offered again in the following semester. This time there were five project members, who worked on it. One of them took the role of a project coordinator. The students defined three main groups:

- Research
- Modelling
- Programming

For this semester, the students planned to add more interactivity and to enrich the VR Space experience. This task was solved by developing different Points Of Interest (POIs) in the Solar system. The POIs were carefully selected, along with the available information and 3D models. Students used the Blender software for the import preparation of the 3D models. They integrated them into the existent VR Space project in PolyVR VR authoring tool. Students decided to develop a new interaction concept to achieve better control and usability of the virtual environment. Furthermore, the user can navigate through the Solar System and to the points of interest by clicking on labels displayed above the objects. They implemented the information fields as websites, which PolyVR renders on a 2D plane in the virtual world. Additionally, the students added some sound effects and customised animations for some scenes, which further improved the immersive experience. More information about the results for this semester can be seen in the video at [Stu18c]. A flyer is added into the *Appendix A.4.3* on page 348.

### ***VR Space - Solar System - Summer Semester 2018***

In this term, the VR Space team consisted of six people (see Fig. 5.41). At the beginning, students divided the team into two groups according to the software tools used: Team PolyVR and Team Blender. However, soon they realised that the most important tasks include interdisciplinary activities like importing Blender models in PolyVR and the coordination of organisational tasks and consequently loosened the previously defined structure.

With the development of the last two semesters, the user can navigate through the Solar System and see the Sun, the eight planets Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and the dwarf planet Pluto. In this semester, the students decided to implement the moons of each planet, that have a diameter over 10 km. Additionally, they extended the Earth orbit by the ISS and the Hubble Telescope, adding the information fields for those POIs. The students set their main task to show and give an accurate representation of the space debris problematic by adding a vast amount of satellites and rocket bodies and finally improve the orbital behaviour of space objects by applying Kepler's law. For the visualisation of the space debris, the students



Fig. 5.41: Students from the *VR Space* project 2018 in the CAVE

have received data from the ESA in Darmstadt, with data about over 19.000 unnecessary objects floating in space. In addition to that, they re-factored the existing code according to object-oriented principles and tried to create new code in a clean and comfortable to read manner. Now, coming groups can work easier on the *VR Space* codebase. A flyer with the project results can be found in the *Appendix A.4.3* on page 348. Further information about the project can be seen in the video of the summer semester 2018 [Stu18a].

## Examples of Engineering Projects

### Virtual Twin - Winter Semester 2015/2016

For future product development, virtual twins of machines can provide instant results, without any need of resources. They can be used for production planning, virtual commissioning and even forecasting. It provides advantages like saving time, materials, energy, costs, improving the product quality, mainly when producing lot size one products. The vision for a virtual twin is a fully functional realistic model of a machine, including the 3D geometry, its dynamics, the simulation of the process and interfaces between human and another machine. In the practical course in this term, the project was about an Industry 4.0 demonstration project (see Fig. 5.42). The project tasks were to create a virtual twin of a milling machine named “Easy300mini” and to develop an intuitive user interface. This interface should allow to create a milling profile without any knowledge in G-Code (machine code).



Fig. 5.42: *Virtual Twin* project definition of a milling profile via the touch interface and the result

The students implemented a touch interface as an intuitive interface for creating the milling profile. The user can edit the profile that should be drilled, with different editing tools like straight lines, polygons, free forms and points, just using his finger. The students developed a 3D web application as a generic method to ensure the editing through all kinds of touch devices (tablet, smartphone) but also with standard WIPM interface on the computer via the web browser. When the profile is sent via a wireless network to the virtual environment, a machine code which simulates the virtual milling process in the virtual environment is generated. The most intensive work in the implementation of the virtual milling machine was the visualisation of the process simulation. Sophisticated algorithms for the real-time calculation of the simulation of the machine code were implemented. The user can experience the virtual milling process in any virtual reality hardware setup, e.g. the CAVE used for the project.

The real milling machine uses the same machine code to mill the profile into the work part. Additionally, an interface allows the import of ready machine-profiles (G-codes) in the system. Furthermore, this project allows a synchronised virtual process-copy when the real milling machine is working. In that case, the virtual twin also provides real-time meta-data (i.e. energy consumption) visualisation from the real machine and time-based statistics. The visualisation paradigm used is a 3D model of a car dashboard, which should be more intuitive for machine operators. The project results are captured in a short video see [Stu16] and in a flyer see *Appendix A.4.3* on page 352.

### **Flexible Workspaces - Winter Semester 2017/2018**

This practical course has the goal to use virtual reality in the process of service prototyping and concrete to make a specific logistic services visible. The students' team consisted of two computer science students, two mechanical engineers, and three business engineers. They decided to establish three sub-teams:

- Business Team, which covered the offered service as a whole, meaning consideration of processes, costs, service risk and parts of the interaction layout.

- Modelling Team, which was responsible for all the 3D-models and the positioning of these models in the virtual environment.
- Implementation Team, which puts everything together and makes the environment come alive.

Generally, the students set out to develop a virtual environment that can demonstrate a service and show customers how their business will improve. To achieve their goal, they implemented a real use case from the Elabo company, who is a producer of workstations. The students delivered a virtual reality service prototype based on a real production facility which experiences a fictitious improvement “overnight”. Their VR prototype has two scenarios. The preliminary phase outlines the chaotic and at the same time, wasteful logistic management of a sample SME. The improvement process between those two phases is demonstrated as an overnight process and reduces the number of workspaces from 8 to 4, changes them into flexible workspaces, re-arranges the material flows and reorganises the practical steps and responsibilities of the actors. The final phase shows a highly organised and efficient logistic flow within the production facility. Both the preliminary and the final phase arose from previously self-defined processes that have evolved over the time. The use case of this project was used by the supervisor to validate a research approach for rapid service prototyping, developed during a project called “dimension” [EvHH17, HEHO16]. The students evaluated the virtual space, costs and risk against the four dimensions defined by this project: actors, artefacts, environment and processes. They applied numerous tools to make a lean service visible and tangible for the customers. Based on a realistic use case and products from the Elabo company, they analysed requirements and necessary steps for the implementation of flexible workspaces within a selected production environment. By showing multidimensional aspects, they provided a feasible solution to understand the impact of the service better. In the course of this project, they set out to develop a virtual reality, to allow SMEs to experience what the impact of a logistic service could look like in virtual reality. See also the video [Stu18b] and the flyer in A.4.3 on page 349.

## **Examples of Projects with Sustainable Topics**

### **Energy Experience Lab - VR Demonstrator Winter Semester 2012/13 and 2013/14**

The research in energy and resource efficiency gets more and more popular. The students had the task to develop a virtual reality application, that simulate the user behaviour in a public building (e.g. office) and visualise the collected data, i.e. of the consumed energy. The Energy Experience Lab objective was to be able to reproduce a public building environment in real-time, thereby automatically and remotely monitoring and controlling its energy efficiency. The

project had two main components, a system for collecting energy-related data, which represents a real office space and the virtual reality system, which uses virtual buildings and visualisation metaphors.

In this project, the students realised a real mock-up of an office room as well as its virtual twin (Fig. 5.43). The interface between the two systems allows bidirectional communication. Smart devices (smartphones or tablets) take care of the interaction with the physical sensors and actuators. As an immersive demonstrator, a 3D passive TV set provides the visual output. The user behaviour and the animations were implemented in PolyVR using a very detailed three dimensional Blender model of the institute's building. On the physical part of the demonstrator, the students integrated different sensors (temperature, humidity, CO<sub>2</sub>) and actuators (for opening and closing the door or window, switching on and off the lights or the computer). At the beginning, students had to plan the real office environment providing them a budget to purchase the necessary appliances, sensors and actuators. They implemented different 3D and 4D visualisation paradigms, known as immersive visual data mining, for displaying the sensor data in the virtual environment. The students and supervisors published the results of both semester in a scientific publication during the EuroVR Conference in 2014 [HSD<sup>+</sup>14].

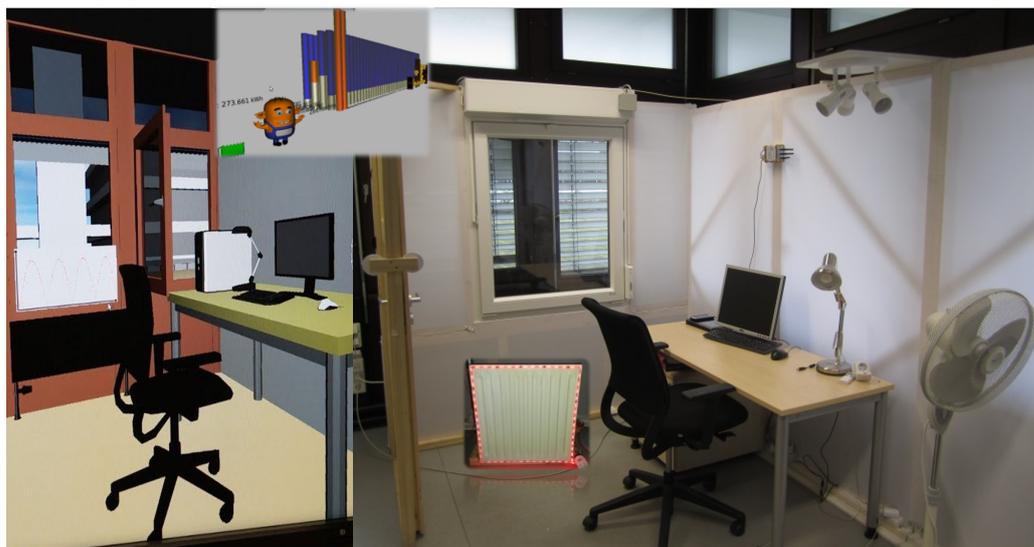


Fig. 5.43: The real and virtual environment of the *Energy Experience Lab*

### **Energy Efficiency VR Game - Winter Semester 2014/15**

The goal of the virtual reality project was the realisation of a virtual reality application in the form of an energy efficiency game. The game lets the user immerse into a virtual environment and interact with it. Additionally, the game should sensitise the user to the critical topic of en-

ergy saving at the workplace, utilising built-in scenarios. The edutainment approach or playful learning was supported and promoted by the use of virtual realities.

The game requires some interactions between the player and virtual objects or virtual characters, which should teach the user the correct handling of electricity. The aim of the game is that the user identifies and solves new problems himself, thus reducing energy consumption to a minimum. The difficulty of the problem increases throughout the game. If the user carries out an interaction, it is visualised whether the interaction was target-oriented or not. The analysis happens with a realistic processing of the energy data of the different energy components or interaction elements using so-called Energy Efficiency Index (EEI). The EEI index is a complex construct, based on all possible influences on the energy in a building and was developed by the students from the previous semester.

The player has the task of managing the energy efficiency of a building. He/she receives the relevant game information at the beginning of the game and has to increase the energy efficiency of the building through energy-efficient measures. The students build the game on several scenarios and a subsequent free mode. For better navigation in the building, a two-dimensional map shows the current position of the player. The user can navigate in the game with a virtual tablet. On this tablet, the user see the EEI of the building and the individual rooms (see Fig. 5.44). Several types of control were implemented, first the desktop control with mouse and keyboard,



Fig. 5.44: *Energy Experience* gameplay

then the Leap-Motion-Control, which allows a contactless control of the system. Furthermore, the use of a powerwall, as available in IMI, was made possible. Through the tracking systems of the powerwall and the flystick a direct and indirect control could be implemented. The video [Stu15] shows the gameplay.

Over the years, students' teams created numerous projects, but we could present only some of them. Those project examples show how the concrete delivery of the practical course looks like and what are the possible learning outcomes in such a setup.

## 5.2.6 Students and Course Evaluation

We make a difference between two kinds of evaluation: the assessment of learners' performance and the course evaluation through learner feedback.

### Students' Assessment

The VR practical course encompasses a *complex evaluation* with a continuous assessment during the semester. The students' assessment was initially designed as depicted in Fig. 5.45. The soft skills were evaluated during the semester and accounted for 10 percent of the grade. As mentioned in the instructional design section, the learning activity for the theoretical introduction was changed. The supervisors cancelled their presentations at the beginning and the written exam at the end of the semester. The students were asked to prepare and give presentations and had a parallel assessment. There was no change in the maximal points for this activity. The documentation was delivered separately in the form of a so-called individual project portfolio, which included the task description of each student with his reflection. The documentation accounted for 30 percent, and the final project work presentation for 40 percent of the overall evaluation.

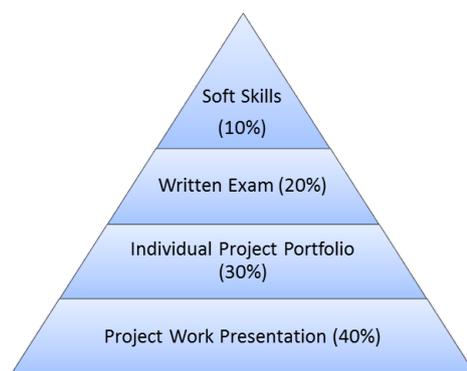


Fig. 5.45: First version of students' assessment [HHO13]

Based on their *feedback* collected over the years some changes in the students' assessment were performed. Now, there are *two types* of evaluation criteria: individual and *collective* criteria. The *individual performance* accounts for 70% of the overall assessment. This prevents that mistakes or unsatisfactory results of a group member do not affect too much the individual performance. There is a formative assessment after the main learning activities like the students' homework presentations on theory topics at the beginning of the course and after all presentations during the semester. The final summative evaluation is a combination of all individual and collective criteria, as depicted in Tab. 5.8.

Furthermore, to pass the course, there are some basic requirements like uploading all relevant documents in *ILIAS* and checkin of the complete and final source code in *GitLab*.

There can be some additional tasks that are not mandatory but give some bonus points like commenting or editing the online documentation of the VR authoring system or the creation of a project video. Nevertheless, most of the students produce a video of their project.

Criteria	Type	%	Delivery
1) Students' Presentations on Theory Topics	Individual	20%	
2) Project Work and Documentation	Individual	50%	
- project work during the semester			in class
- description of the tasks in the documentation			ILIAS
- delivery of the personal reflection			ILIAS
3) Presentations and Demonstration	Collective	30%	
- all presentations during the semester			in class
- demonstration of the project results			in class
- project marketing - poster, flyer, video			ILIAS

Tab. 5.8: Overview of evaluation criteria and weighting

## Individual Criteria

### *Students' Presentations on Immersive Technology Topics*

The first points students can get at the very beginning of the course based on their performance on the theoretical background and in particular, on the students' presentations on an immersive technology-specific topic. The homework accounts for 20% (or 20 points) of the overall course performance. Tab. 5.9 presents the evaluation criteria for the students' presentations.

### *Project Work and Documentation*

The evaluation of the project work and the documentation is done based on several criteria (see *Appendix A.4* on page 338). The students' performance is measured based on the goals that they set themselves in the project planning phase. Hence, the main criteria and the most points are for the *completeness* of the tasks implementation and its functionality. The supervisors take into account the *quality* of the learning process because students cannot achieve all defined goals until the end of the semester. There are often changes in the plan communicated in the midterm presentations.

Criteria	Top Score
Completeness and Quality	6
Structure and Design	3
Meeting the Formal Requirements	5
Meeting the Time Requirements	2
Independent Content Specification	2
Presentation Style and Verbal Ability	2
Total	20

Tab. 5.9: Criteria for evaluation of the students' presentations on immersive technology topics

Furthermore, the supervisors evaluate how the students *deal with interfaces* to other team members and occurred problems. Furthermore, they use assessment criteria like *creativity*, *time management* and *soft skills* such as motivation, teamwork, discipline, autonomy and communication. The students are rewarded for the delivery of a *reflection* on motivation, learning goals and success. Additionally, we assess the quality of the documentation and compliance with the specified requirements.

In order to evaluate the individual project work supervisors should have a detailed *overview* of the learners' tasks and issues during the whole semester. With the help of the documentation, educators can assess each learner's progress and compare it to that of the other team members and practical course participants. Furthermore, there are other helpful methods for educators to estimate the students' involvement in the project. During the *presentations*, questions on specific tasks can be asked to a particular student, so educators can check if there is an understanding of the matter and if this person has solved the task autonomously. A good impression can also be gained from the *students' reflection* as well as from the software version control system or learning management system history. For instance, *GitLab* tracks the number of commits, the intensity and contribution of each student during the project.

### ***Students' Reflection***

At the end of the semester, the students reflect on their learning process based on the following questions:

- Why did I participate in the VR practical course and what were my expectations? Please describe your motivation, expectations and desired learning goals.
- What did I learn during the semester? Please provide reflection on your learning process and success.
- What problems and difficulties did I have during the practical course? How does the overall experience (and what I have learned) will help me in my further studies or professional future? Please conclude your learning experiences, successes, difficulties and provide some outlook.

Using *reflection on learning*, students can look at the course content, the knowledge acquired, the decisions made, their objectives and expectations set at the beginning, and can evaluate the situation critically, objectively and comparatively. Students can analyse what they have learned, how they felt in specific situations. They can look back at the set goals and expectations and check, which of them they have fulfilled and which not. Besides, students can list why they did not achieve specific goals, how their behaviour affected their feelings and which influences their behaviour had on the others (students or supervisors). On the basis of the third question, students should evaluate how this experience will help them in the future. Students can indicate what they would do differently and how they will use the knowledge gained in the *further course of life*.

Here some citations from the students' reflections are provided.

*“The VR practical course brought me much closer to the less known for me field of virtual reality. For me, it was very enlightening to work in an interdisciplinary team, especially since I was the only computer scientist in the group. This made the work sometimes difficult, and the learning effect increased. I have improved my understanding through my detailed explanations to the others and also could learn about the perception of the engineer management students.”*(Computer science student, WS 2011/12)

*“Each team member has learned to work independently, and to share the fruits of this work with the rest of the team. During the planning phase, each member has had the experience to make contact and negotiate with a company, not as a student but as a service provider. I have also learned how important is the internal agreement and dealing with interfaces within the group.”* (Business Engineering student, SS 2013)

## Collective Criteria

### Presentations and Demonstration of the Project Results

There are three *project presentations* to be done during the project phase: Project planning, midterm and final presentation. One of the evaluation criteria refers to the two final and interim presentations and evaluates the quality and content of the presentation according to the sub-criteria. We give points for the completeness of the content and evaluate the quality of the presentation. Another criterion evaluates the *demonstration* of the project results, which students deploy on the project-specific hardware. We pay attention to how skillfully, competent and safely the course participants handle the hardware (such as operating the controllers, setting up the camera for the CAVE environment) and how they solve problems with the software (e.g. changes of the parameters in the program). It is essential to consider whether the features presented in the presentation are also to be experienced in the demonstration and whether they work well. Students get points for the delivery and the *quality* of the promotional materials (e.g. flyers and posters). They have to deliver them at a specific time. Educators should consider how balanced and fair the students distributed the tasks for the presentations and the project. Furthermore, they should evaluate if the selected distribution has a positive or negative influence on the presentation or project. Students should meet the *time criteria*, for instance whether they presented the project within the assigned time frame or not. The creation and usage of video for the project presentation can be considered as a bonus or be obligatory, and is added to the collective criteria at the end in the total score. The allocation of the points to the different criteria can be found in the *Appendix A.4.3* on page 344)

#### *Promotional materials*

Next to the learning of creating and performing a presentation and demonstration of the project planning, development and results, the students have the task to create promotional print materials.

Learning how to present a project or product is also very important for the set of soft skills a student should have. Which information should be conveyed and how should it be presented so that other people who are not aware of the project or are not experts in the field understand what they have done in the project.

Students can use the KIT official template or use previous examples of the practical course as a template (A1 format). The flyer should be formatted in A4 and may serve as a handout on demand. The students are allowed to use the same layout, design and contents for the flyer and the posters, in order to save effort and time for project marketing.

At the end of the semester, the posters are hanged in the corridors of the Institute or the specific project labs and can be seen by other students or lab visitors. It has proved to be very useful to show lab visitors the results of previous projects which cannot currently be presented due to missing hardware or software support. We can thus easily show the evolvement steps of sustainable and perennial projects.

Currently, a video is optional and brings only bonus points for the collective criteria of the evaluation. There are no requirements for the video storyboard or creation. This leads to a significant diversity in the video styles and gives space for creativity. Examples from previous semesters are used for inspiration, but do not prevent students from developing their own ideas. At the end of the semester, we upload the videos on the official *Youtube channel* of the Institute for Information Management in Engineering [Ins20].

### **Course Evaluation**

We provide two kinds of evaluation during the semester. The first one is informal, and the students are encouraged to speak with us, if they have issues with the didactics, organisation, technology or supervisors or if they have some suggestions for improvement. The other kind of evaluation is in written form. It is the so-called „Paper and Pencil Evaluation“. Two different evaluation sheets collect the feedback. The university provides the one evaluation sheet in the middle of the semester. At the end of the semester, students fill out another evaluation sheet, that has been created by the VRPC instructional designers and has more course-specific questions to the methodology, organisation, supervisors and learning outcomes (see *Appendix A.4.3* on page 346).

The KIT Evaluation sheet has several objectives depending on the actors involved. Educators should acquire the most critical feedback from students about their learning success as well as they get some empirical data to check the quality of their teaching. Furthermore, this kind of evaluation allows to collect empirical data for ensuring the feasibility of study programs at the university level and the transparency of the quality of studies to the public [oT20].

One of the main results of the KIT course evaluations is the students' satisfaction with the courses they attended and is measured with the so-called teaching/learning quality index (LQI). The LQI is formed from six quality guidelines, starting with the total grade (or overall course evaluation weighting with 50% of the LQI), the required workload (10%), the structure of the course (10%), commitment and motivation of the lecturer (10%), the lecturer's response to the questions and concerns of the students (10%) and the students' learning growth (10%) [Kar20]. The learning quality index is calculated based on a scale from one to five and is divided into three intervals. A course has LQI of “100” if the mean value is in the interval between 1 and

2.5. The LQI of “0” is assigned if the result is in the lowest interval between 3.5 and 5. More details about the LQI are published in [Kar20].

The teaching quality index (LQI) and the overall evaluation results for the virtual reality practical course are displayed in Tab. 5.10.

Semester	LQI	Overall Evaluation	No of Students
SS 10	–	1,4	7
WS 10/11	–	–	3
SS 11	100	1,3	7
WS 11/12	100	1,5	7
SS 12	93,8	1,3	6
WS 12/13	93,3	1,5	13
SS 13	100	1,5	11
WS 13/14	100	1,1	9
SS 14	100	1,4	9
WS 14/15	100	1,7	13
SS 15	94,4	1,8	17
WS 15/16	99,6	1,5	31
SS 16	100	1,3	15
WS 16/17	100	1,5	28
SS 17	100	1,4	25
WS 17/18	98,8	1,7	26
SS 18	99,1	1,4	20

Tab. 5.10: Results of the KIT evaluation of the VRPC from 2010 up to 2018

The VRCP evaluation form has questions in four main categories (for all questions see *Appendix A.4*):

- Teaching Methods and Didactics
- Organisation and Management
- Educators and supervisors
- Learning outcomes

We summarised the results for each criterion and semester in Tab. 5.11 and showed the correlation between the student's grade and the supervisor's grade in the form of total feedback.

Semester	Overall Evaluation	Organisation	Methodology	Supervisors	Acquired skills	Avg Students' Grade	No of Students
SS 10	1,8	2,1	1,9	1,3	2,0	1,7	7
WS 10/11	1,4	1,5	1,2	1,3	1,7	1,0	3
SS 11	1,9	2,1	2,0	1,5	2,0	1,1	7
WS 11/12	1,6	1,4	1,8	1,2	2,0	1,2	11
SS 12	1,6	1,6	1,5	1,6	1,7	1,1	7
WS 12/13	1,8	2,1	1,7	1,5	1,8	1,0	14
SS 13	1,3	1,5	1,3	1,2	1,3	1,1	12
WS 13/14	1,3	1,6	1,5	1,1	1,3	1,0	11
SS 14	1,4	1,5	1,4	1,2	1,5	1,1	10
WS 14/15	1,4	1,8	1,5	1,1	1,4	1,0	16
SS 15	2,1	2,1	2,3	1,7	2,5	1,0	21
WS 15/16	1,7	1,8	1,8	1,4	1,9	1,1	29
SS 16	1,8	1,7	1,9	2,0	1,4	1,0	17
WS 16/17	1,4	1,5	1,4	1,2	1,5	1,3	29
SS 17	1,7	1,8	1,7	1,3	1,7	1,1	25
WS 17/18	1,6	1,5	1,7	1,3	1,8	1,2	27
SS 18	1,6	1,5	1,7	1,4	1,8	1,4	19

Tab. 5.11: Results of the VRPC evaluation from 2010 up to 2018

## Summary

The *virtual reality practical course (VRPC)* is an educational unit for *higher education* that uses *constructive* immersive learning environment and a *project-based* learning approach to teach virtual reality technology, engineering and soft skills. The long-term experience with the delivery of the VR course contributed most for the proposed methodology and validated *all layers* and processes. This course provided a *sandbox* for experimentation of novel teaching methods. Those methods were optimised continuously based on the measurements of students' satisfaction and performance. The evolved methodology can be applied for a *wide range* of target groups, particularly multidisciplinary, multicultural and multi-age learners.

Furthermore, we can answer the research questions on how to apply immersive technology in an educational context *systematically* and which are the *main aspects* that should be considered during a course design. The growing number of students over the semesters shows the *increasing interest* in the course and the *scalability* of the developed methodology. Moreover, most of the students that finished the VR course and graduated from KIT were very successful in their future professional lives. Many of them took key or management positions in big companies; some get a doctorate or pursued an academic career.

## 5.3 Virtual Reality for Teaching STEM in Secondary Education

This section presents the implementation of the didactic methodology for a *virtual reality-based workshop*, which should supplement the school curricula of secondary education institutions and support the learning of *STEM subjects*. This project validates the educational and technical aspects of the proposed methodology, as described above.

The project named *MINT-Box* was initiated and implemented by a team from the *Institute for Information Management in Engineering* at the Karlsruhe Institute of Technology in 2011. The team consisted of the research associates Jurica Katicic, Johannes Herter, Victor Häfner, Iliyan Palauzov and Polina Häfner. The project was delivered with the help of teachers and students from two partner public schools the *Einstein Gymnasium* and the *Tulla Realschule in Kehl*, Germany. The foundation funded the financial resources during an initiative called “MINT-BOX: hands-on experiments” (in German MINT refers to STEM) [Bad11]. The project resources are available for download from institutes web page [Ins11] and presentation of the results were published 2014 in the scientific publication “Experiencing Physical and Technical Phenomena in Schools Using Virtual Reality Driving Simulator” [HHO14].

### 5.3.1 Analysis and School Workshop Design

There are numerous benefits of using immersive technologies in secondary education (as listed in *Benefits of Immersive Learning Environments* 4.2.1). They make the lessons more attractive for the students and at the same time, help their *imaginative faculties*. Immersive simulations enable the learners to employ their theoretical knowledge in STEM subjects in order to make decisions and observe the results in a safe, controlled environment. Realistic scenarios can be represented virtually, thus saving the costs of lab equipment. Further VR enables students to gain knowledge and understanding of the subject matter [HHO14].

The method for decision support described in the methodology could be only partially applied for this use case (see 4.3.1). The decision process for implementing the project had other requirements and was conducted by the *Baden-Württemberg Stiftung* foundation. The project proposal included an analysis of the benefits of immersive learning environments for pupils, the course design, as well as the budget necessary to conduct the pilot project.

#### Target Group

The target group included public school students from *Baden-Württemberg region* in Germany, grades nine through twelve. The determination of the students’ background and skills was easy

due to the available detailed school curriculum. Students from two schools had the possibility to choose the course as a *learning group* (in German “Arbeitsgemeinschaft”) in the afternoon voluntarily.

The challenge in this project was that the students were in *mixed grades*, from ninth through twelfth, and they had different theoretical backgrounds and skills. Those differences required the explanation or the refresh of specific theory foundations, before the practical assignments could start. A delicate balance between the younger students, who should be able to keep up and understand new concepts, and the elder ones, who should not bore themselves, should be achieved.

### **Teaching and Learning Goals**

The idea behind the project is to enhance the students understanding of different *physical and technical phenomena* using immersive application. The choice fell on a simple *virtual reality driving simulator*, as a learning environment, which was an appropriate technology to visualise the effects of those phenomena. The aim of this project was the creation of a virtual reality experimental kit for secondary education institutions containing the required hardware and software components along with all necessary teaching materials.

Using the *VR experimental kit*, the students could acquire and strengthen their interdisciplinary knowledge in the areas of computer science (visual programming), physics (Newtonian mechanics) and technology (control loops). The main focus of the subjects lied on STEM topics.

Furthermore, there were lessons on *VR technologies*, basics of computer graphics programming and 3D content authoring. The immersive representations should aid the students in absorbing new information with greater ease, as they can perceive it in an adequate manner using multiple senses, thus seeing and hearing simultaneously.

The following goals were defined for this project [HHO14]:

- to increase the students interest in science and engineering through creative work and hands-on learning;
- to promote the development of skills required for identifying and solving complex, interdisciplinary problems from STEM fields;
- to create situations that reinforce the connection between thinking, action and intuition;
- to stimulate individual and self-determined learning;
- to strengthen the students imaginative faculties using modern media;
- to create a sustainable inner drive for further education in engineering and science;

### Teaching Strategies and Learning Activities

One of the didactic methods used in this project was the so-called “*sandwich strategy*”. The learning activities in this method should be short and different types of activities should *alternate*, in order to achieve a more dynamic learning environment. The specific implementation in the school setup looks like follows. The teaching unit consists of 90 minutes and is divided into multiple activities with a maximum duration of 20 minutes each. These activities can consist of theoretical explanations in front of the class, presentations, discussions, individual programming sessions and testing (experiencing) of the results with the VR setup. This strategy should improve the focus and motivation of the pupils and help them to understand the subject matter better.

The labs were designed in a *modular* manner, so that they can later be easily *reconfigured* for students of varying grades and educational backgrounds. The teachers can arbitrarily select the topics depending on their schools curriculum. Each topic comes with a standalone programming exercise, which fosters the concentration of the students on the specific subject and the *problem-solving* process. The proposed solution is designed to support conventional science lessons in the form of extracurricular activities (further referred to as workshops). Another important aspect is the possibility of collaborative work, which supports *peer-to-peer* learning, *interdisciplinary* communication and problem-solving. The exercises can grow in complexity providing fewer hints than the previous one, to achieve advances in the area of *programming skills*. At the same time, the number of basic functions can grow with each following exercise as

more advanced features are implemented. This approach is recommendable if the educational units will be presented in a specific sequence during a one-term workshop.

The problem with the *heterogeneous*, multi-aged class was solved by applying the peer-to-peer learning approach during the theory introduction. The elderly students were asked to explain some of the concepts during the theory introduction and could later support help younger students accomplish their task.

The workshop can be structured in the following four parts over one term:

- Introduction to virtual reality technology ( including the authoring tool and visual programming),
- teaching units (in the form of laboratory assignments) and
- evaluation (assessment of learners performance and feedback).

## Resources

### Human resources

For the usage of the VR educational kit, one teacher is required. This teacher should be able to *supervise* the afternoon course. To do so, this teacher should be trained in the authoring of virtual reality applications with the particular software and in maintaining the hardware system.

We additionally involved two research associates and three research assistants for the *implementation* of all learning materials and the deployment of the pilot project. The research associates were involved in the creation of the instruction design, preparation of the immersive system as well as project management. The research assistants took care in the building of the driving simulator hardware, the implementation of the software as well as the lab exercises.

### Time Constrains

The teaching methodology can be used in *two different ways*. The immersive system can be incorporated into a lesson that covers the specific STEM topic in order to engage students and improve their understanding. The other possibility is to provide an optional workshop for the pupils in the afternoon and to provide one exercise per week during one term. During the development phase, 18 educational units were created, each with a duration of 90 minutes.

## Technology resources

### *Hardware*

The central technology resource that should be used for the workshop was the *virtual reality driving simulator*. Its software, and in particular, its development environment should serve as a basis for the exercises and students should get the possibility to test their results on the simulator. The requirements for the immersive resources were to be low-cost and affordable for schools.

At the laboratory *LESC* at the KIT university, there was already a virtual reality driving simulator, which was developed by students during a practical course on virtual reality [HHO13]. This concept was replicated for the school project purpose. The original hardware used for the stereo visual output consists of a powerwall equipped with head tracking, but this was too expensive and was replaced by a *low-cost VR headset* for a single user and a monitor for the other students (see Fig. 5.50 on page 5.50).

The *seat-box* was built with a real car seat, and the gaming controller *Logitech G25* was used as a car interface. This setup has a good immersive level, is low-cost and thus affordable for schools, that want to adopt the project's methodology. The total hardware cost was approximately € 2000, which included a computer, HMDs, a sound system and a seat-box.

### *Software*

The project was realised with the VR authoring tool *3DVIA Virtools* from *Dassault Systemes* (currently distributed as *3DVIA Studio Pro*). The decision was taken since the software provided an intuitive *graphical programming* interface, where lines connect functional blocks that either represent the work-flow or the parameter references. The graphical programming paradigm allows an easy prototyping of logic in a virtual world, which makes it suitable for usage in secondary school. The employed software tool allows to implement application logic in the virtual world easily. The visual paradigm decreases the programming difficulty level that the students have to achieve and eliminates the need to learn a programming language.

Furthermore, the software comes with a proper documentation. One of the limitations was the *high price* of software licences, and another was the lack of a broader *community*, which makes it difficult to solve problems through the use of forums or mailing lists.

The university students already developed the driving dynamics and the virtual world of the driving simulator. The solution contained a 3D model of the car, a racing track, the landscape, weather conditions and sounds of the car and environment. One essential part of the package was the simulation of the *driving dynamics* and other physics features like collision detection.

This system was used as a foundation to create suitable STEM-based exercises for the school workshop.

The schools should be well equipped with *computer pools*. Each student should have a laptop with internet connection available. The provided computers should be good enough to support the software tool and allow the programming exercises.

### **Financial resources**

The pilot project budget was covered by the *Baden-Württemberg Stiftung* foundation. The budget included mainly personal, travel, software and hardware equipment costs.

### **Course Structure**

The course was built based on three phases as recommended by the proposed methodology (see Fig. 4.8 on page 76): introduction, application and evaluation, where the application is the most extended phase during the term. The structure of each exercise unit is described below.

#### **Introduction Phase**

The first teaching unit starts with an introduction to the *project specifics*, followed by a presentation about virtual reality, its definition and characteristics. It is essential to differentiate between the perception of virtual reality from the entertainment point of view, such as science fiction literature and cinema, and the concrete educational goals. The virtual reality development environment that will be used for the exercises should also be presented.

#### **Application Phase - Exercises**

Each exercise is designed based on a typical structure, following the sandwich strategy described above.

##### ***Introduction to the Subject Matter***

First, the topic is introduced, describing the problem with its definition, formula and real-life examples. The selected subjects include already familiar and studied topics as a part of students' curriculum. If possible, it is beneficial to organise a group discussion and ask the students to explain the presented problem in their terms, meanwhile writing down all suggestions on the whiteboard.

### ***Individual or Group Task Assignment***

The central part is a tutored exercise where each student works on the same assignment. The students are asked first to finish a visual script that is partially developed in advance. Here they should use programming logic to define the execution sequence of the script. At the same time, they could be asked to adjust some parameters. The students get the task to investigate and learn the influence of system variables on the exercise outcome independently. For example, an exercise from the field of Newtonian mechanics could be conducted by simulating the free parabolic trajectory of a car launched from a ramp. The students are assigned with a task to create a visual script that would allow to alter the car power output as well as the angle at which the car is launched. The students would then experiment several times, note down the variation among distances the car travelled depending on the entered parameters. The recorded distances, as well as the entry parameters, can then be presented in a tabular form and verified with their correspondence to established physical models and formula.

### ***Experiencing the Results with Virtual Reality***

The solutions from the exercises are presented at the end of the lesson. The best solution can be deployed on the VR setup to experience it in an immersive environment. The chance to test the results in the driving simulator should keep the students motivated while they are completing the tasks. The first contact with immersive virtual reality environments should be as early as possible, preferably during the first unit. It is essential to demonstrate different VR hardware, software and applications at the beginning of the workshop, combining both theory and practice.

### **Evaluation Phase**

Teachers can decide if and how they can assess the students' performance. The proposed methodology does not recommend any written and oral examinations. Instead, a friendly learning atmosphere should be created. The attractiveness of the immersive technology should serve as motivation and engagement factor, should keep the students focused on the goals and tasks in order to have the possibility to test their results on the immersive hardware.

## 5.3.2 Project Development

### Preparation Activities

#### Students Management

All management activities related to the new workshop at both schools were conducted during the pilot project. The tools already established at both schools were applied for the students' management.

#### Train-the-Trainer

Two teachers teaching STEM subjects and at the same time responsible for the computer lab prepared the IT infrastructure for the workshop. Furthermore, they were trained in the *authoring of immersive applications* in the specific development environment as well as in operation and maintenance of the immersive hardware system. Additionally, a documentation for installation, licences management, troubleshooting of the system and others was provided. After the pilot project, the teachers should be able to conduct the workshop and the educational units independently from the project developers.

#### Immersive Resources

The immersive hardware components were reproduced as described in *Resources 5.3.1* on page 268, and the immersive driving simulation application was further developed to meet the requirements of the exercises (see below). Before the start of the project, the transportation of the immersive car driving simulator was accomplished. For the easy indoor transportation in the school, the simulator was equipped with caster wheels.

#### Learning Materials

##### Theoretical and Practical Introduction

The introduction to the workshop goals and immersive technologies was done in the form of *presentation*. Next to the main characteristics of immersive technologies like stereoscopy, the limitations and the application areas of virtual reality were introduced. Furthermore, essential notes on the use of VR headsets were introduced in order to avoid health issues like headache, motion sickness or even addiction.

The practical introduction consisted in the presentation of the main features of the virtual reality software as well as the usage of the immersive car driving simulator.

## **Exercises**

The preparation of learning materials consist not only in the software development of the exercises, the creation of assets and scripts, but also written assignments and a sample solution. For each exercise, students get an assignment, that includes a short description of the theory, the task assignment with a screenshot of the visual script to be finished, as well as some additional explanations if necessary (see Appendix A.5.1). The sample solution should help teachers to provide better instruction and supervision during the exercise. It consists of an illustration of the final script as well as which parameters should be set and how.

We structured the educational unit in the form of laboratories around three main topics. Energy is the first topic where we address the energy management in a car. The second topic introduces control loops, the third some basic Newtonian mechanics. All selected topics have the goal to fit both, the theme of car dynamics simulation and the secondary education curriculum.

### ***Energy***

The first exercise addresses the topic of fuel consumption. The task is to program in an appropriate consumption rate that varies depending on the use of the throttle. Students should model the gas tank and the fuel gauge at the same time. They learn the relations between the different variables. For instance, they have to model the fuel consumption using a Bèzier curve. The second exercise implements a visual feedback for the wind resistance. Again a Bèzier curve is used to map two parameters. The last exercise consists of recovering energy from the car brakes when slowing down. A booster meter fills up every time the car slows down using the brakes. Once the booster meter is filled, a keypress releases an additional torque on the wheels.

### ***Control Loops***

The first exercise in the control loops unit features an automatic car light control. The intensity of the car lights is adjusted, depending on the output of two sensors: the car light sensor and the daylight sensor (see Fig. 5.46).

The second exercise is an automatic windshield wiper. The third is an extension of the first with an indicator for the lights state. Here, we introduce the concept of RGB colours. The final exercise in this unit is about the automatic control of the car's sunroof. The automation works through the use of a rain sensor. Furthermore, the students had an opportunity to implement the ability to control the sunroof directly through a push of a button on the Logitech wheel.

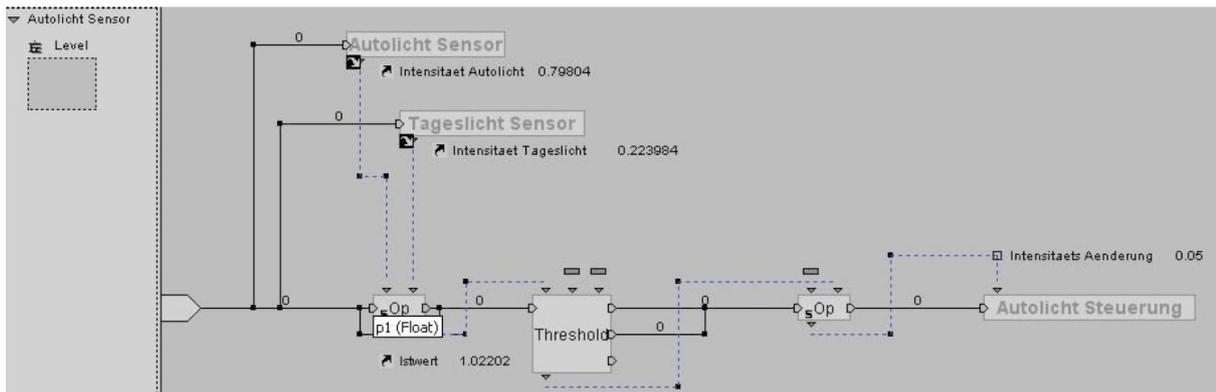


Fig. 5.46: Sample solution for the automatic car light control

### *Newtonian mechanics*

The Newtonian mechanics unit is the largest of the three STEM topics and consists of six units. It starts with a free jump simulation where a launched car has to cross a trench. While the width of the trench is constant, students can adjust only the height between the two sides of the trench and the engine torque. They should record the speed at the beginning of the jump, which allows them to verify the theoretical height for a successful jump.

The second exercise puts the free jump in another setup. Now the car is launched from a ramp, which effectively changes the starting angle of the jump (see Fig. 5.47). This exercise also includes loading a 3D model in the scene, as a skill for authoring of immersive applications.

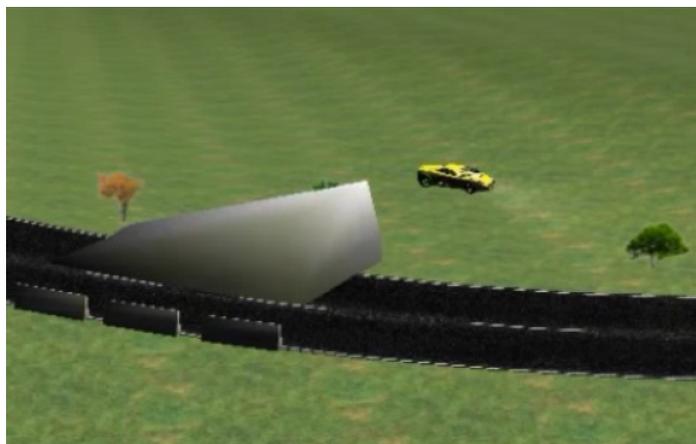
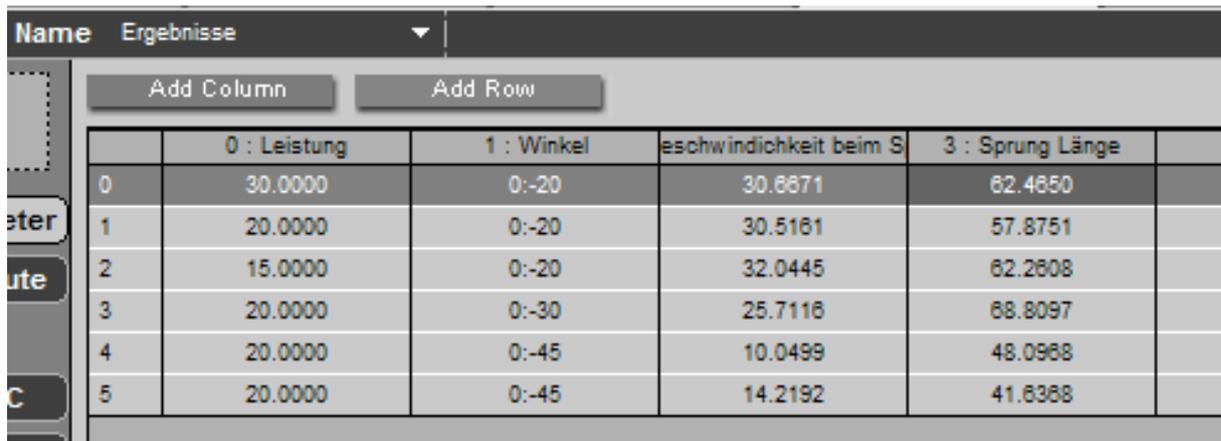


Fig. 5.47: Virtual world of the free jump exercise

Another task based on the free jump is the storage of the different parameters in an array-like angle of inclination of the jump, car speed, the engine power and the length of the jump. Then students can vary the different parameters and analyse their correlation with the help of a table (see Fig. 5.48) and known formula from the theory.



	0 : Leistung	1 : Winkel	Geschwindigkeit beim S	3 : Sprung Länge
0	30.0000	0:-20	30.6671	62.4650
1	20.0000	0:-20	30.5161	57.8751
2	15.0000	0:-20	32.0445	62.2608
3	20.0000	0:-30	25.7116	68.8097
4	20.0000	0:-45	10.0499	48.0968
5	20.0000	0:-45	14.2192	41.6368

Fig. 5.48: Storage and analysis of parameters

The third exercise focuses on friction, demonstrating the driving behaviour depending on the adjustable friction coefficient of the road. An advanced feature of this exercise is the use of a quad generating function that represents the road surface depending on the friction coefficient.

The fourth exercise builds on the previous one. The braking distance has to be computed and displayed depending on the friction coefficient and the speed just before pushing the brake.

The fifth exercise allows to tilt the track in a curve sideways at an angle. The goal of this exercise is to discuss the centrifugal and centripetal forces acting on the car. Students can understand how those forces change the car behaviour when tilting the track in a curve sideways at an angle. The last exercise illustrates the law of conservation of momentum, where the students have to observe and discuss the behaviour of the car by a crash. The first part handles the crash into a static object of a mass lesser, equal or greater than that of the car. The second part consists of crashing into a moving object.

### Schedule

For the particular term of the pilot project, we provided a detailed time table, where 21 events of 2 teaching hours each week were planned (see Tab. 5.12). To develop the time plan, we had to consider all school holidays.

### 5.3.3 Workshop Delivery

The workshop was delivered according to plan and with the developed learning materials. At the beginning, the supervisors present the theoretical background. Depending on the students' current mental state, teachers organised a discussion, or some elderly students explained to the others the subject matter on the blackboard. After the theoretical introduction, students are

Nr.	Date	Activities and Topics
1	Feb 2	Introduction
2	Feb 9	Control Loops
3	Feb 16	Control Loops
4	Feb 23	Control Loops
5	March 2	Control Loops
6	March 9	Energy
7	March 16	Energy
8	March 23	Energy
9	March 30	Energy
10	April 6	Energy
11	April 13	Mechanics
12	May 4	Mechanics
13	May 11	Mechanics
14	May 18	Mechanics
15	May 25	Mechanics
16	June 1	Mechanics
17	June 8	Meeting with Developers/Visiting VR Lab
18	June 29	Mechanics
19	July 6	Mechanics
20	July 13	Final Drive
21	July 20	Evaluation

Tab. 5.12: Detailed schedule of the workshop

provided with a task *assignment sheet* (see an example on friction in Appendix A.5.1 on page 352) and have the possibility to work alone or in pairs on the assignment (see Fig. 5.49).

Supervisors are there to answer questions, to provide technical support, if there are issues with the development environment. The first student ready with his task is allowed to test the result on the driving simulator, until all others can finish the assignment. There is a sample solution that the teacher provides to the students at the end. Students can use it to finish their task or compare it with their solution. The results are then discussed in the group to be sure that all understood them. Depending on the time left until the end of the class, all other students can test their solutions on the immersive car driving simulator or have some fun while driving (see Fig. 5.50).



Fig. 5.49: Students working on assignments at the computer lab

At the end of the term and before the evaluation, workshop organisers planned a *special event*. It was possible to organise an excursion to the *Lifecycle Engineering Centre* at Karlsruhe Institute of Technology, where university students initially developed the immersive car driving simulator. Students could *meet developers* of immersive technologies and ask them questions. They got the opportunity to *visit* the laboratories, which have *state-of-the-art VR* hardware and software equipment. The first lab had a high-end virtual reality environment with a distributed stereoscopic visualisation in a three-sided CAVE setup, which allows the user to dive into virtual worlds. The second lab consisted of a mobile powerwall, and the students could also experience force feedback with a haptic device. Students could ask any questions to the lab personal.

## Workshop Evaluation

During the application phase, we observed that this methodology helps to *reduce complexity* and aid the understanding of the subject matter. VR can raise the *appeal of STEM* subjects and bridge the gap between theoretical knowledge and its practical application to problems in science and industry. The enthusiasm for the virtual reality systems kept the students motivated during the teaching units.

## Students Assessment

For the pilot project, we measured the success of the workshop, using *discussions* with all participants and *questionnaires*. The possibility to measure the improvement in knowledge acquisition with written tests, conducted at the beginning and the end of the workshop, was neglected in order to create a friendly learning atmosphere.



Fig. 5.50: Students test their results on the immersive driving simulator

## Feedback

Various aspects of the pilot project were of particular interest to the participants of the workshop, resulting in several suggestions and heterogeneous feedback. Eleven of the twelve surveyed students would recommend the workshop to a friend. During this project, the students also made minor, voluntarily expansions to the driving simulations program code.

The teachers also considered the project to be a success. They intended to organise the workshop again at a future point in time, but also decided to use the examples from the pilot in the schools *regular STEM lessons*.

In the long-term, the project succeeded to motivate students to consider STEM careers. Some of the students from the pilot project decided to study mechanical engineering and computer science at the university.

## Outlook

The project was successful, and we could prove the efficiency of the immersive environment on the learning outcome and the teaching methodology. However, we had issues with the *sustainability*. More in-depth evaluation after the finalisation of the project showed some limitations of the concrete project implementation. Teachers decided not to offer the course anymore for several reasons. They *felt difficulties* in gaining the necessary experience in immersive technology

in short terms and conduct the course alone. The most concerns were in the area of *maintenance* of the hardware and the student support with the programming exercises.

The selected authoring tool provided significant benefit for the teaching methodology using a visual programming paradigm, but the licences were *too expensive* for schools. Another issue with the software was that the company stopped the support of the current version and there was no backwards compatibility with the new one. That means that the created virtual worlds and application logic could not be imported and further developed in the newest software version.

In the future, this issue can be solved by selecting another virtual reality software, which is maybe open source and has all the necessary features. To achieve this not only the immersive car driving simulator, but all exercises should be developed from scratch. The recent fast development of the virtual reality market allows the usage of better and cheaper VR headsets for usage in a classroom. This also requires additional developments of the immersive system interfaces.

## **Conclusion**

The *enthusiasm* for virtual reality systems kept the students engaged even though some of the less exciting parts of the exercises. For this reason we assume that VR approaches result in superior motivation, retention and intellectual stimulation, as well as a better conceptual understanding of the subject matter.

The methodology has been validated by acquiring feedback from the students. The driving simulator was recognised as a valid and beneficial tool for imparting a better understanding of physical concepts and phenomena. The students were able to recognise connections between physical principles and their application in vehicles. Furthermore, by performing the tasks offered by our approach, they were able to understand better the interplay between physics, computer science and technology.

## 5.4 Sewing Machine Training with Haptic Simulation

### Introduction

This project aim was to analyse, if immersive technology is applicable and beneficial to train *sewing of leather products*. In particular, the needs of high-quality luxury leather goods producer in France were examined, and a prototype of a *sewing machine simulation with haptic feedback* was implemented. This use case focuses on the validation of the proposed decision-making process presented in the *Decision Support Method* 4.3.1 on page 161. The project was realised at the virtual reality laboratory *CAIT at IMI* and divided into two main parts. The first was the development of the *decision-support method* by the research associates Jana Deckers and Polina Häfner as well as the master student Charline Schlatt. The second part was the implementation of the *virtual sewing machine prototype* by the students Adrien Heinzlmeier and François Marceau [Hei18, Mar18].

### 5.4.1 Analysis and Design

#### Analysis of Current Situation

The luxury goods market worldwide has been on the upswing in recent years, and the demand rises. Many goods, especially the luxury leather products, are handcrafted, which infers the need for *highly qualified craftsmen*. The current craftsman training in the area of leather goods shows differences between the countries. In France for instance, it is a two years long education with a technician certificate called “Brevet de technicien supérieur (BTS)”, which is a diploma of higher education. The education is *project-based*, and many skills are further improved during the working experience. This is because each company has its products and designs, which are unique. Each model needs specific tools, procedures and specialised training.

Usually, the experienced *senior craftsman* train on the job the new or *less experienced* workers. A new model comes with a handbook with detailed description of the product specifications and production steps. The training itself is usually based on a “dummy model”, which is handled close to the original product to reduce material waste. Trainees can repeat some complicated production steps and to make errors at lower costs. The last is valid for operations like sewing that can vary sharply from model to model or in the used material. Some skills, like glueing or skiving, are usually always the same and are already good practised.

Concrete example for complex and product-specific operation is the final stitching of a leather bag. Confident and experienced craftsmen could do this operation because *errors are very*

*costly*. All other production steps are already made, and an error during the last one means that the whole product is wasted. This is very costly due to the high quality and fragile materials used like crocodile or snake skins. Furthermore, it needs additional time and costs to correct the mistake and to produce a new one.

The listed problems in this area lead to the question of whether a training based on immersive simulation would help to train craftsmen on specific operations and reduce the high costs of mistakes in the production of luxury goods. An in-depth analysis was made, and a prototype of a sewing machine simulator was developed to answer this question. The analysis was based on *interviews* with key company representatives from different departments, management and craftsmen. Six *training participants*, the responsible of the training and two *members of management* were asked to assess the current situation and to fill the developed questionnaire on potential benefits of immersive technology training. Additionally, virtual reality experts could visit the workshop and make a tour in the production and logistics. Interviews with the *craftsmen* were necessary to capture the concrete training and *production steps*, possible mistakes, the specification for different tools, materials and machine equipment.

## Requirements

Since it is not possible to replace the traditional craftsmen training with a virtual one, the project should concentrate on a *complementary training* of specific skill, that can vary in time due to new machines, new models or new materials or even new workers. Based on the benefit analysis, the main requirements for the training system include the implementation of a tool for improving the *security and ergonomics* as well as specific worker needs, like a better *understanding of new processes* and the *reduction of errors*.

The concrete prototype has the goal to visualise the sewing process, to simulate the touch and feel of a sewing machine and different types of materials as well as the simulation of the accompanied machine sounds, that should give, in addition to the visual signals, acoustic cues for correctness [Mar18].

## Benefit Analysis

After the analysis of the current situation, the presented problems and the needs of the target groups, it is required to check if using immersive technology solution will help to solve these issues and to satisfy the needs. For this purpose, the methodology prescribes the carrying out of a benefit analysis and proposes a questionnaire as a tool based on *nine categories of potentials*

(see Appendix A.2.1 on page 326). The concrete results of the identified potentials could be seen in the Fig. 5.51).

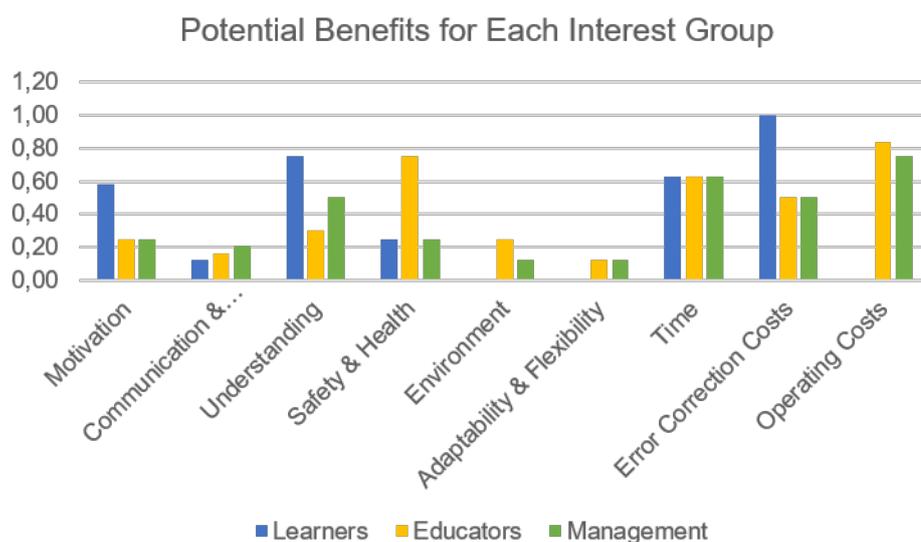


Fig. 5.51: Potential benefits deduced from the questionnaire [HDSO18]

The results of the questionnaire show that the trainees are *open to new technologies* and have an interest in virtual reality (0.58). The educators and management, however, estimate that there will not be a high motivational impact using this new technology (0.25 / 0.25). The average value for all target groups (0.38) reflects a significant potential, according to the proposed evaluation table. Concerning the category *communication and evaluation*, there is a small potential according to all target groups (0.13 / 0.17 / 0.21), because most tasks could be explained well and the services could be evaluated relatively obviously with traditional methods [Sch18].

The trainees evaluate that immersive technologies will have a high potential for *raising the learning outcomes* (average 0.75) like the increased understanding of the learning content by *frequently repeating* of tasks (0.75) and by going through *different scenarios* (1.00) as well as the illustration of the dynamic behaviour of the learning environment (0.5). The educators and management share this opinion only to a limited extent (0.3/ 0.5) [Sch18].

There are different estimations of the potential benefits of *safety and security* according to the statements of the person responsible for training (0.75) and the training participants or management (0.25/ 0.25). Depending upon how leather is processed, it can have harmful environmental impact. According to the participants of the questionnaire, there is a slight potential for *environmental protection* by avoiding wastes showed mainly by the educators (0.25), but not confirmed by the trainees or management (0/0.13).

Concerning the adaptability of the training to *individual needs*, the respondents all see minimal potential for improvement (0/ 0.13/ 0.13). The traditional training can easily be adapted to changes in the learning content, so that the use of VR can generate no advantages [Sch18].

In the last categories *time and costs* that are firmly connected, all three interest groups see high potential. For the time saving and optimisation, all three stakeholders have almost the same estimation (0.625/ 0.625/ 0.5), which also leads to some cost savings. The trainees feel that the costs connected to their errors are very high, and their saving will have a high impact using virtual simulation (1.0). Both the training officer and the management forecast only a medium potential for improvement of the *error correction costs* (0.5/ 0.5), but expect more significant savings potential in the area of *operating costs* (0.8/0.75) [Sch18].

The Fig. 5.52 presents the *weightings* of the *benefit categories* for each interest group. The benefits with higher priority for all interest groups are the saving of time, the safety of human and environment as well as the improvement of learning outcomes. The company is ready to invest in immersive training technology, if the potentials can be realised, which is confirmed by the low weighted running and acquisition costs. The identified potential in the field of error correction and operating costs could cover those costs and a fast return on investment should be possible.

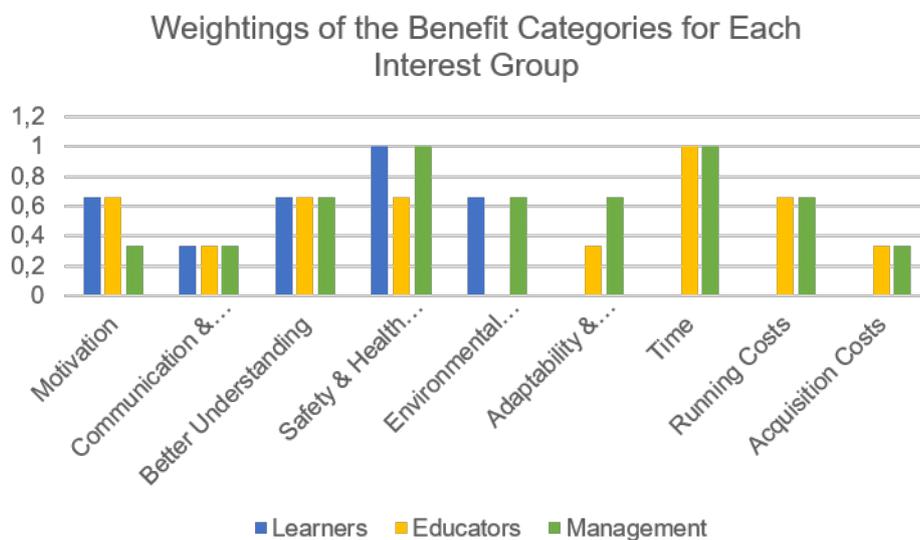


Fig. 5.52: Weightings of the benefit categories for each interest group resulted from the questionnaire [Sch18]

Based on the estimated potentials and their priorities, it has been decided to continue the analysis and to look at the benefit and cost aspects in more detail using specific VR solutions [Sch18]. In the further steps for costs identification and evaluation, the potentials regarding the costs are examined more closely.

## Design

An early *decision* was made to create first a minimum viable prototype based on available technology in the laboratory of a research partner to estimate if the benefits and especially the learning outcomes could be realised. The primary educational outcome of the *prototype* should be the learning of the sewing process to create a perfect seam on a leather bag. To achieve the learning of this skill and the feeling for the *sewing movements*, (if they are right or wrong) the trainee should feel the forces that come back from the sewing machine based on the force that he gives to the bag, i.e. a *haptic feedback* loop is necessary. The prototype of the virtual training system includes the simulation of a sewing machine using a haptic device with a *leather bag mock-up* and a pedal system (see Fig. 5.53).

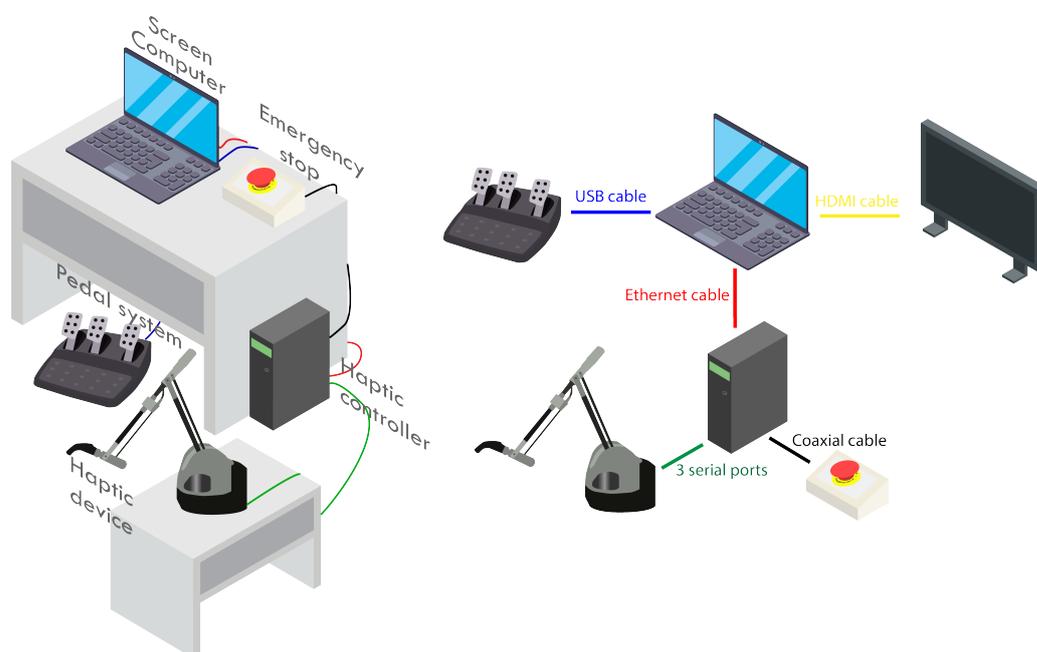


Fig. 5.53: Hardware architecture of the technology concept [Hei18]

For the *visual output*, a display versus VR-headset was taken into consideration. Additionally, sensors for head and hands tracking were considered. The VR training is initially to be implemented for five different handbag models.

The difference in the *hardware alternatives* lied only in the visual output devices. That is why the feasibility study was realised first only with a display. The costs for development and hardware are the same for both alternative solutions and will not be evaluated separately in the further economical analysis.

The software development consist of the following main work packages:

- Connection of interaction devices and haptic
- Design of the 3D environment
- Simulation of the sewing machine
- Implementation of the training with haptic interface
- Customisation of bag mock-ups

## 5.4.2 Cost and Benefit Evaluation

### Cost Estimation

The estimated costs for the prototype are categorised in one-time (see Tab. 5.13) and running costs (see Tab. 5.14) [Sch18].

Acquisition costs	Components	Costs
Hardware	Visual Output Device (with tracking)	1.000,00 €
	VR workstation	2.000,00 €
	Haptic device	99.000,00 €
	Controllers for bag mock-up	5.000,00 €
	Pedals	300,00 €
		107.300,00 €
Software	Connection of Interaction devices and haptic	10.000,00 €
	Design of the 3D environment and mock-up bags	40.000,00 €
	Simulation of the sewing machine	30.000,00 €
	Implementation of the training with haptic interface	20.000,00 €
	Customisation bag mock-ups	5.000,00 €
		105.000,00 €
Service	Training of customer	1.000,00 €
Total		213.300,00 €

Tab. 5.13: Acquisition costs estimation for the project

Because the project was realised as a feasibility study in the form of several master theses, the project costs were not considered in this calculation. Despite this fact, this example should show how the methodology steps could be conducted for different kinds of projects.

The associated *one-time acquisition costs* were estimated at a total of approximately € 213,300. This costs include the hardware costs (estimated at €107,300) together with the expenses for *software and development* (estimated at € 105,000) as well as the *training of educators*, which is € 200 per bag model.

Running costs (per year)	Current Solution	Immersive Solution
Maintenance	unknown	6.000,00 €
Worker Learning Time	150.000,00 €	15.000,00 €
Training Bags	20.000,00 €	-
Total	170.000,00 €	21.000,00 €

Tab. 5.14: Running costs estimation for the project

The *operating costs* are compared for the current training and the new training based on virtual reality simulation. Those of the current training is approximately € 170,000 per year, where € 20,000 of this amount is used for training bags. The loss of learning employees for production is valued at € 150,000 per year. The usage of virtual reality training, will save a considerable amount of *time for training* and with this the training costs. This time could be expressed in monetary terms, and the training is *estimated* at € 15.000 per year. Together with the *maintenance* for the immersive learning solution, whose costs are estimated at € 6,000 per year, the running costs are calculated € 21,000. A *saving* of 88.65% (€ 149,000) for the operating costs could be achieved if the virtual learning environment is adopted well for this use case.

### Utility Evaluation with Experts

Within the framework of the profitability analysis, an utility analysis of this solution was first carried out. For this purpose, the potentials identified by the questionnaire for the *qualitative benefit* analysis were used. The benefit values were calculated again, based on the opinion of experts (see Fig. 5.54). Due to *no significant changes*, it is assumed that the immersive solution can almost entirely realise the identified potentials. A difference was noticed only in motivation. The experts assume that the potential cannot be fully achieved, since training with real bags can be at least as motivating as VR-training on mock-up bags. This allows a qualitative statement about the added value of the virtual reality solution compared to the current solution in the considered benefit aspects, since there is no other alternative for the immersive solution at this

stage. The questionnaire revealed an *enormous monetary potential*, which was further verified with the cost estimation and efficiency analysis.

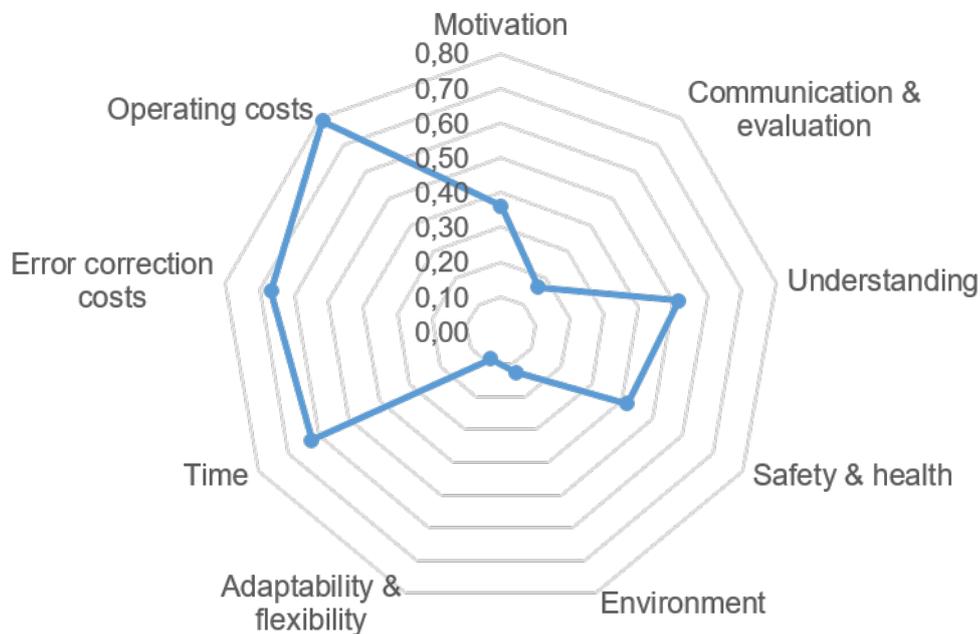


Fig. 5.54: Benefit evaluation of the ILE according to experts (for one solution)

## Amortisation

The results of the amortisation calculations are *impressive* due to the high potential in the area of monetary savings, and show 1.43 years. The calculation is made by dividing the acquisition value € 213,300 by the savings per year in particular € 149,000. Additionally, if the current interest rate for a 10-year federal bond is going to be taken into account (which was in 2018 0.75%), an amortisation period of 1.42 years results. The calculation is kept simple because the company could make no maximum duration of the usage of the virtual training environment, and no residual value for the immersive system could be estimated. However, the amortisation calculations show that the investment would be *profitable*.

## Profitability

Next to the amortisation, a profitability calculation could be made. The result is a very *high profitability* of 140%. This comes from the monetary savings per year (€ 140,000) divided by the average capital investment (€ 106,650) and presented in per cent. The average capital

investment is calculated by adding up the acquisition costs with the residual value, and the results are divided by two. In our example, the residual value is assumed to be zero, due to no information on how much the system will cost after amortisation. The short payback period and the 140% profitability show that the investment is *worthwhile* when we speak only for monetary benefits. Additionally, there are qualitative benefits that should be achieved, making the investment much more attractive.

## Decision Making

At this point, the stakeholders decided to create a prototype to test the feasibility, the possible limitations and benefits of ILE solution. At the same time, both sides leather goods producer and contractor could collect experience in both areas, and better estimate the alternative solutions for future applications. This is an excellent example of how the proposed method can be modified or refined in smaller steps based on prototypes.

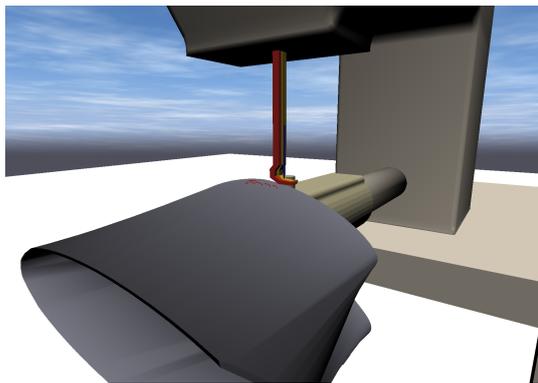
## Stability Analysis

To provide a stability (also known as sensitivity) analysis, the weighting factors used in the benefit analysis were slightly varied. The results were stable and showed that the high level of profitability remains.

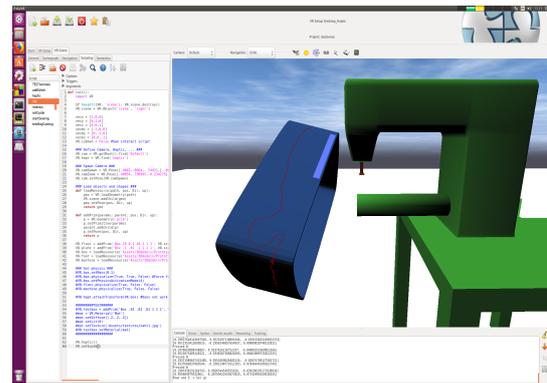
### 5.4.3 Prototype Development

The decision to develop a prototype for the ILE in the craftsman area showed many benefits. Experience could be collected on both sides. Educators from the company could learn more about virtual reality, and the developers of the ILE could experience in details the sewing process of leather goods.

The resulted prototype consists of the *haptic* interaction device *Virtouse 6D* with six degrees of freedom, produced by *Haption* company. This haptic device was connected to a special exercise handbag model (as showed in Fig. 5.55). For the foot control of the sewing machine, the *pedals* of the gaming controller *Logitech* racing wheel *G27* were used. The visual output was first realised with a usual display, where the main parts of the sewing machine, the thread and the handbag model were visualised. A sewing machine simulation was developed (see Fig. 5.56b), where the pressing of the pedal regulates the sewing speed. A ray cast method for visualisation of the thread was also implemented (see Fig. 5.56a).

Fig. 5.55: Prototype of the *Haptic Sewing Solution* [Hei18]

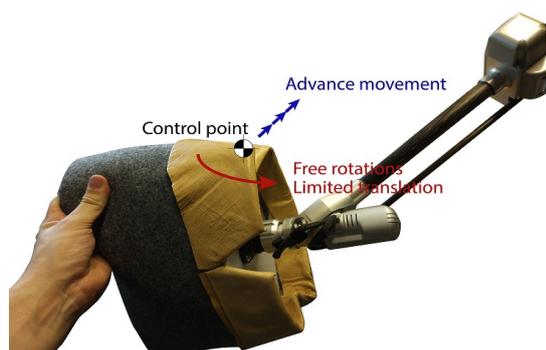
(a) Visualisation of the red seam with raycasting [Hei18]



(b) Simulation and visualisation of the sewing machine and process [Hei18]

Fig. 5.56: Virtual sewing simulator

One of the difficult part of the implementation was the interface between the visualisation and the *haptic simulation*, because both are using different working frequencies (updates per time). The experts assume that the realisation of a complete virtual simulation, where both the handbag and sewing machine are virtual, will not be beneficial for the learning experience. For this purpose, a complex haptic device, some combination of haptic gloves and haptic arm will be necessary, to provide the real feeling and handling. That is why a solution that use a *physical mock-up* of the handbag was realised [Hei18] (see Fig. 5.57a and Fig. 5.57b).



(a) Haptic feedback applied on the handbag [Hei18].



(b) Attachment of the physical mock-up of the handbag to the haptic device [Hei18]

Fig. 5.57: Hardware interface of sewing simulator

### Optical Feedback and Tracking

The trainee should be able to see what he/she is doing: the placement of his/her hands, the sewing process and visual inspection of the quality of his/her seam. Nevertheless, the main *focus* of the implementation lied more on the *haptic interaction* than on the visualisation and the prototype has two dimensional, but not an immersive visual output. Furthermore, there is only hand tracking through the haptic device possible.

The main reason for not implementing additional body tracking, was that the analysed optical sensors have many occlusions, so the hands could not be detected well. This requires the implementation of a more complex system, which was beyond the current project scope (time and budget). If an automatic evaluation of the trainee performance should be realised in the future, more sensors will be necessary to track precisely the learner behaviour.

Besides, over long periods, the current VR and AR headsets become too heavy. This affects the *ergonomics* of the training. Solution with headset will be possible only for short training sessions.

### Haptic Feedback

One of the haptic feedback applying to the handbag is the so-called “transparency”. It means that the trainee by handling the bag does not encounter a *force of resistance*. The motors actively compensate this. It means that the constant weight of the manipulated object and its inertia must be present. The manufacturer’s expertise consists mainly of recognising the textures of the leather material and its deformation. The material used and the form determine how the handbag is going to be held to make a good seam [Hei18].

The sewing machine also applies different *forces and torques* on the handbag. First, before the sewing starts, the bag is locked between the presser foot and the machine base, blocking all movements. During the sewing process, all degrees of freedom are possible, whereas a small resistance comes from the *bag deformations*. The quality of the sewing can be influenced by choosing the right angle and distances in all directions, which was one of the training primarily goals. Another interaction is between the handbag and the seam guide along which the handbag edge should be kept aligned, without a gap or deformation of the leather [Hei18].

## Summary

The project "*Haptic Simulation for Sewing Machine Training*" had two main objectives. The *first objective* was to analyse if immersive technologies are beneficial to train the sewing of high-quality luxury leather products. The *second goal* was to validate the technical feasibility of the learning application based on a pilot project. The developed method for decision-support described in the management layer was applied to analyse the benefits and the profitability of such an application. Though, not all steps of the method could be presented in-depth with this use case due to the lack of information or confidential data. Nevertheless, the validation of the business aspects was conducted by many key stakeholder groups like members of the company management, trainers and trainees, as well as virtual reality experts.

The *technical objective* of the project was the implementation of a sewing machine simulation with the use of immersive technologies, that should facilitate the training on-site and save resources. A prototype of a sewing machine simulation was implemented with a haptic feedback device on *proof of concept* level. With the help of the prototype, the training participant can practice the insertion of the handbag into the sewing machine and *experience* the sewing process. This *process* could be repeated as often as needed until the trainee has mastered the task well, without time pressure or high-cost expenditures. There are still many technical issues to solve, such as the immersive visual output, the occlusion of the hands by tracking as well as the implementation of acoustic feedback. With the help of this project, both developers of the immersive training system and luxury goods producer become *hands-on experience* at minimal costs, which provides them with an excellent foundation for future decisions on application of immersive technologies in education.

## Summary

The presented methodology could be *soundly validated* based on four projects. Each project gives in-depth insights into a particular part of the methodology along the educational life cycle or the proposed layers, as shown in Fig. 5.1 on page 179 and answers the specific research question.

Concerning the *educational layer*, the validation use cases included various learning and teaching goals and activities. Furthermore, they handle a different period of the education lifetime such as secondary and higher education, as well as on-the-job training. Regarding the incorporation of immersive technology, there are different examples related to the learning goals.

The *DriveSim* and *Haptic Sewing* projects deal with the application of immersive learning applications for training. The *MINT-Box* project showed how to playfully teach MINT subjects such as programming or physics with the support of virtual reality applications rather than learning by immersion in an ILE. The *virtual reality practical course* demonstrates how to teach immersive technologies with construction worlds. Moreover, it presented the application of project-based learning and the learning of soft skills, which are crucial for the further professional development.

Additionally, the different project issues and requirements provided great validation of the *analysis and design processes*. The proposed method for *decision-support* could be applied partially for some of the use cases. At the same time, some project management issues were discussed.

The presented projects also covered the *technical aspects* and development of immersive applications in *great detail*. Numerous examples of virtual reality applications and various immersive systems could be presented and explained. Furthermore, with the *DriveSim* project was possible to demonstrate how an *intelligent* immersive system can be implemented.

## 6 Conclusion

One of the essential possession we have in our life is our human capital. Especially in times of disrupt changes or crises, we are strongly dependent on our knowledge and skills. Currently, the digital transformation affects businesses in a way that creates an increased demand for suitably qualified specialists. Moreover, the established educational structures and traditional educational practices are not efficient enough and cannot meet current needs. Hence, we search for further educational methods, practices and media that can enhance and accelerate the learning process and make it more pleasant and productive.

From an early age, young people are confronted with modern information technologies such as computers, smart devices and game consoles with various interaction devices, as well as stereo output such as three-dimensional television and cinema. Their technical affinity should facilitate the integration process of novel technologies in education. Promising novel technologies that can solve most of the issues as mentioned earlier are the immersive technologies and artificial intelligence.

However, the incorporation of those technologies in an educational program is not as simple as investing in new devices or software. New educational programs have to be created or old ones reshaped from the ground up, which involves complex and extensive processes that key stakeholder groups should follow.

Furthermore, despite the current momentum of the virtual and augmented reality market, the user adoption of the technology has not reached the critical mass, that should force standardisation. Developers of immersive environments should perform a careful and extensive decision making process to find out which platform, tools and hardware are suitable for their project.

### **Achieved Objectives**

The main objective of the elaborated methodology was to provide a reliable framework for educational programs, which should incorporate immersive technologies following a holistic approach and to address the challenges mentioned above.

The three-layered methodology provides such a holistic approach, discussing all aspects (educational, technology and management) of the process of creating different educational formats

that embed immersive as well as artificial intelligence technologies. It presents the teaching of new knowledge and skills in immersive environments, such as the learning of virtual and augmented reality as a subject matter. Furthermore, it provides methods for learning and teaching of 21st-century skills in a novel way.

Applying the provided methods in this thesis, the key stakeholder groups can effectively and efficiently incorporate the immersive technologies in their educational practice. The main results are an adequate, high-quality and state-of-the-art education, which leads to more skilled and satisfied learners. Educators are being facilitated in the delivery process and can concentrate on individual learners' needs. Furthermore, key stakeholders save effort, time and costs for the design, development and maintenance of the immersive educational systems based on the proposed approaches.

The methodology iteratively evolves with each validation project, and the validation results show that the methodology is reliable and applicable for most educational levels, domains and target groups.

The adaptive methodology design, holistic view, and the deep insights into numerous aspects such as the didactic, technological and economic characteristics ensure the overall success of its application to educational programs.

### **Answers of the Research Questions**

In order to achieve the main objectives, the thesis formalised and systematised the expert knowledge methodically for all layers and presents them in an integrated manner. The results can be presented based on the research questions and their answers.

**Research Question I: How can immersive technologies support the teaching and learning processes?**

In order to answer how the immersive technologies support the teaching and learning process, a meta-analysis on the benefits and downsides of virtual and augmented reality learning applications was made. The meta-analysis consisted of an extensive paper review and expert interviews. The resulted data was then categorised in seven categories and 18 subcategories (see 4.2.1). Furthermore, it was analysed which characteristics of the immersive learning systems manifest those benefits, and various examples were provided. The later should help the instructional designer to decide if and how to utilise those technologies and define more precisely the system requirements. The categorisation of the limitations and downsides of virtual and augmented reality in eight categories should also support the specification of the system requirements (see 4.2.1). The designer team of the immersive learning environment will be

---

more conscious of the limitations and dangers. This awareness should increase the probability of success. To answer the last sub-question, how to decide when to use or not to use immersive technologies for the specific education program, a comprehensive decision-support method was developed (see 4.3.1). This method incorporates an extensive analysis of the target group, of the technology potential for the specific learning objectives and a cost-benefit analysis based on the elaborated solution concepts.

**Research Question II: How to systematically design an educational program that should use immersive technologies?**

To develop a methodology that guides systematically key stakeholders in the process of design and development of immersive learning applications, all aspects and their connections were identified. The main aspects were analysed and classified in three layers - education, technology and management (see 4). These three layers were organised in five phases: analysis, design, development, deployment and evaluation and this along the educational life-cycle. The methodology recognised six different roles and key stakeholder groups and provided tasks for each phase, each role and each team. The detailed description of the tasks should guide the teams to accomplish them seamlessly. Next to the methods for systematical incorporating virtual or augmented reality applications in the learning process, the methodology provides a novel approach for teaching the authoring of immersive technologies in higher engineering education.

**Research Question III: How to increase the efficiency of the authoring of immersive learning applications?**

To optimise or automate the processes of authoring an immersive application, they should be first analysed. The thesis provides a description of the technical knowledge and skills and the technical resources needed (see 4.2.2). Furthermore, it systematically lists the system design criteria and requirements for an immersive system (see 4.2.2) and describes the authoring workflow with all its elements (4.2.4). Two main directions for the optimisation of the authoring process were identified. The first solution for time and effort saving is in the area of content creation and recommends the usage of open-world generation frameworks as well as configuration systems. The second solution for automating the authoring process of the immersive application is to use methods from the area of artificial intelligence. The thesis presents a method and

its validation, how knowledge engineering methods using ontologies and reasoning engines can supplement or even avoid the programming of application logic (see 4.2.6).

## Outlook

Immersive technology and artificial intelligence in education are essential and *growing fields*. The number of courses that use virtual or augmented reality will rise in the future because the immersive technologies become more affordable with time. Next to the immersive hardware and the software systems, the educators will have more information on didactic approaches and technology incorporation practices to apply it successfully. The proposed methodology and the elaborated approaches will open many possibilities to teach complex concepts in a more visual, interactive and intuitive way.

Following topics from this thesis are essential to be further researched. However, the *benefits and downsides* of immersive technologies should be *further explored* based on well-designed studies. On the base of the extensive categorisation of the advantages and disadvantages of immersive technologies for education, *questionnaires* can be developed and *standardised*. Furthermore, their evaluation can be *automated* in order to be applied easily by organisations, that have less experience in immersive technologies, but want to evaluate their potential for their particular educational program. Next to the questionnaires, the economical *efficiency analysis* can also be *automated* to save time for the decision making process.

The current need of *distance learning* requires the elaboration of further methods, that enable the teaching of practical skills and learning of social skills, as it is possible during the real face-to-face collaboration. The tools for *multi-user collaboration* and training in immersive environments are to *mature* in terms of hardware support and features such as support of user roles, verbal and non-verbal communication, interaction with the environment and among the user.

The current *challenges*, such as missing eye contact and face mimics due to the covering of the face with the VR headsets or glasses, should be met. For this purpose, some novel non-invasive physiological sensors can be used to measure the *mental state* and *emotions* and to give further information for the *social presence* and the *group flow*. Another possible extension that should be from great benefit for an intelligent tutoring system are devices and algorithms that give feedback about the *emotional state* of the user. For instance, the measurement of the eye pupils, the skin conductance or heart rate, can give additional information, which can be used for better *interpretation* of the user *learning state* and performance.

Regarding AI, there is a need for more application use cases in education, such as personal virtual assistants or an automated evaluation of learners. The tutoring system in the *DriveSim*

---

research project serves as *proof of concept* for the utilisation of *knowledge-based engineering* in immersive learning environments. The next steps foresee the complete implementation of the ontology rules and *evaluation* of the learning system with students.

The project results can also be applied in other fields than learning. The developed automatic generation of semantically *rich open-world* environments with *realistic road network* can be further used for testing environments for *self-driving cars*. Furthermore, the GIS features can serve as a basis for urban planing, analysis and simulations such as new road intersection and even infrastructure for renewable energy solutions.



## Bibliography

- [AA04] Lynna J Ausburn and Floyd B Ausburn. Desktop virtual reality: A powerful new technology for teaching and research in industrial teacher education. *Journal of Industrial Teacher Education*, 41(4):1–16, 2004. ERIC.
- [AA09] Petek Askar and Arif Altun. Cogskillnet: An ontology-based representation of cognitive skills. *Journal of Educational Technology & Society*, 12(2):240–253, 2009. JSTOR.
- [Adv19] Advanced Realtime Tracking GmbH. Flystick 3. <https://ar-tracking.com/products/interaction/flystick-3/>, 2019. [Accessed: 20-11-2019].
- [Alb08] Alberta Education. Types of classroom assessment. <http://www.learnalberta.ca/content/mewa/html/assessment/types.html>, 2008. [Accessed: 30-04-2020].
- [Alp20] Ethem Alpaydin. *Introduction to machine learning*. MIT press, Cambridge, 2020.
- [AOCT10] Frederick Aardema, Kieron O’Connor, Sophie Côté, and Annie Taillon. Virtual reality induces dissociation and lowers sense of presence in objective reality. *Cyberpsychology, Behavior, and Social Networking*, 13(4):429–435, 2010. Mary Ann Liebert, Inc. 140 Huguenot Street, 3rd Floor New Rochelle, NY 10801 USA.
- [APB<sup>+</sup>09] CG Abreu, MR Parente, LM Brasil, APB Silva, and GD Souza. A study of virtual reality in mastology. In *World Congress on Medical Physics and Biomedical Engineering, September 7-12, 2009, Munich, Germany*, pages 1115–1118. Springer, 2009.
- [Arm18] Martin Armstrong. The worldwide virtual reality market is set to be huge. <https://www.statista.com/chart/6677/the-worldwide-virtual-reality-market-is-set-to-be-huge>, 2018. [Accessed: 08-08-2018].

- [Arn12] Karl-Heinz Arnold. Didactics, didactic models and learning. In Norbert M. Seel, editor, *Encyclopedia of the Sciences of Learning*, pages 986–990, Boston, 2012. Springer US.
- [AWP19] Rolf Arnold, Hans-Jürgen Wieglerling, and Thomas Prescher. W-fragen der allgemeinen didaktik. <https://service.zfl.uni-kl.de/wp/glossar/w-fragen-allgemeine-didaktik>, 2019. [Accessed: 27-11-2019].
- [B<sup>+</sup>56] Benjamin S Bloom et al. Taxonomy of educational objectives. vol. 1: Cognitive domain. *New York: McKay*, 20:20–24, 1956.
- [Bac17] Todd Leopold Backchannel. A professor built an ai teaching assistant for his courses — and it could shape the future of education. <https://www.businessinsider.com/a-professor-built-an-ai-teaching-assistant-for-his-courses-and-it-could-shape-the-future-of-education-2017-3?r=DE&IR=T>, 2017. [Accessed: 20-05-2020].
- [Bad11] Baden-Württemberg Stiftung gGmbH. Mint-box experiments from science and technology. [https://www.bwstiftung.de/uploads/tx\\_news/Broschuere\\_MINT-Box\\_Web.pdf](https://www.bwstiftung.de/uploads/tx_news/Broschuere_MINT-Box_Web.pdf), 2011. [Accessed: 30-05-2019].
- [Bar86] Howard S Barrows. A taxonomy of problem-based learning methods. *Medical education*, 20(6):481–486, 1986. Wiley Online Library.
- [Bar96] Howard S Barrows. Problem-based learning in medicine and beyond: A brief overview. *New directions for teaching and learning*, 1996(68):3–12, 1996. Wiley Online Library.
- [BC03] Grigore C Burdea and Philippe Coiffet. *Virtual reality technology*. John Wiley & Sons, Honoken, New Jersey, 2003.
- [Bet15] Elyse Betters. A brief history of oculus. <https://www.pocket-lint.com/ar-vr/news/google/132399-google-glass-a-brief-history>, 2015. [Accessed 12-11-2019].
- [BF95] John T Bell and H Scott Fogler. The investigation and application of virtual reality as an educational tool. In *Proceedings of the American Society for Engineering Education Annual Conference*, pages 1718–1728, Anaheim, CA, 1995.
- [BF97] John T Bell and H Scott Fogler. Ten steps to developing virtual reality applications for engineering education. In *Proceedings of the American Society for Engineering Education Annual Conference*, pages 1–8, Milwaukee, WI, 1997.

- [BF10] David Burden and Dave Fliesen. Virtual intelligence. <https://prezi.com/bcjqn-zkxvxh/virtual-intelligence/>, 2010. [Accessed: 25-06-2020].
- [BK13] Ahmad C Bukhari and Yong-Gi Kim. A research on an intelligent multi-purpose fuzzy semantic enhanced 3d virtual reality simulator for complex maritime missions. *Applied intelligence*, 38(2):193–209, 2013. Springer.
- [BKBN12] Tobias Blum, Valerie Kleeberger, Christoph Bichlmeier, and Nassir Navab. mirracle: An augmented reality magic mirror system for anatomy education. In *2012 IEEE Virtual Reality Workshops (VRW)*, pages 115–116. IEEE, 2012.
- [BL17] Ellen Lambert Bowman and Lei Liu. Individuals with severely impaired vision can learn useful orientation and mobility skills in virtual streets and can use them to improve real street safety. *PLoS one*, 12(4):1–20, 2017. Public Library of Science.
- [Blo18] Amy Blom. Virtual reality in mining: Pushing the boundaries. <https://australianminingreview.com.au/features/virtual-reality-in-mining-pushing-the-boundaries/>, 2018. [Accessed: 20-05-2020].
- [BMF11] BMF. Arbeitsanleitung einföhrung in wirtschaftlichkeitsuntersuchungen. <https://olev.de/w/BMF-Arbeitsanleitung.pdf>, 2011. [Accessed: 07-04-2020].
- [BNFCFLVM18] Oscar Blanco-Novoa, Tiago M Fernández-Caramés, Paula Fraga-Lamas, and Miguel A Vilar-Montesinos. A practical evaluation of commercial industrial augmented reality systems in an industry 4.0 shipyard. *IEEE Access*, 6:8201–8218, 2018. IEEE.
- [Bob18] Anastasiia Bobeshko. The vr market: An overview. statistics: Industries that benefit from vr. <https://channels.theinnovationenterprise.com/articles/vr-market-statistic-facts-trends>, 2018. [Accessed: 08-08-2018].
- [Bös16] Martin Bösch. *Finanzwirtschaft: Investition, Finanzierung, Finanzmärkte und Steuerung*. Vahlen, München, 2016.
- [Bri09] Manfred Brill. *Virtuelle Realität*. Springer, Berlin, Heidelberg, 2009.
- [Bro13] Wolfgang Broll. Augmentierte Realität. In *Virtual und Augmented Reality (VR/AR)*, pages 241–294. Springer-Verlag Berlin Heidelberg, 2013.
- [BRS13] Susanne Bernert-Rehaber and Gérald Schlemminger. Immersive 3D-Technologien optimieren das Fremdsprachenlernen: „EVEIL-3D-Lernen in virtuellen Welten“. *Babylonia*, 3:44–49, 2013.

- [BSdV<sup>+</sup>01] Robert G Belleman, Bram Stolk, Raymond de Vries, et al. Immersive virtual reality on commodity hardware. In *Proceedings of the 7th annual conference of the Advanced School for Computing and Imaging*, volume 7, pages 297–304, 2001.
- [Bur04] Grigore C Burdea. Teaching virtual reality: Why and how? *Presence: Teleoperators & Virtual Environments*, 13(4):463–483, 2004. MIT Press, Cambridge.
- [Bur08] Grigore C. Burdea. World-wide survey of universities teaching virtual reality. <http://vrtechnology.org/resources/public/survey.html>, 2008. [Accessed: 08-08-2018].
- [bus20] bussgeldkatalog.org. Pflichtstunden für den führerschein: Theorie- und praxis (inkl. Übersichtstabellen). <https://www.bussgeldkatalog.org/fahrschule-pflichtstunden/>, 2020. [Accessed: 15-03-2020].
- [BVHO15] Benjamin Bayart, Alexis Vartanian, Polina Haefner, and Jivka Ovtcharova. TechViz XL helps KITs Formula Student car "become alive". In *Virtual Reality (VR), 2015 IEEE, Arles*, pages 395–396. IEEE, 2015.
- [C<sup>+</sup>16] Allan Carrington et al. Professional development: The pedagogy wheel: It is not about the apps, it is about the pedagogy. *Education Technology Solutions*, (72):54–57, 2016. Interactive Media Solutions.
- [CAD20] CADEX Ltd. For CAD users. <https://cadexchanger.com/products>, 2020. [Accessed: 20-05-2020].
- [Cah97] Dennis J. Cahill. Target marketing and segmentation: valid and useful tools for marketing. *Management Decision*, 35(1):10–13, 1997.
- [CFO17] Jean-Rémy Chardonnet, Guillaume Fromentin, and José Outeiro. Augmented reality as an aid for the use of machine tools. *Res. & Sci. Today*, 13:25, 2017. HeinOnline.
- [Che10] Chwen Jen Chen. Theoretical bases for using virtual reality in education. *Themes in Science and Technology Education*, 2(1-2):71–90, 2010.
- [Cli06] D Cliburn. Incorporating virtual reality concepts into the introductory computer graphics course. In *ACM SIGCSE*, pages 77–81. ACM, 2006.
- [CMM15] J.-R. Chardonnet, M. A. Mirzaei, and F. Mérienne. Visually induced motion sickness estimation and prediction in virtual reality using frequency components analysis of postural sway signal. In *Proceedings of the 25th International Conference on Artificial Reality and Telexistence and 20th Eu-*

- ographics Symposium on Virtual Environments*, ICAT - EGVE '15, pages 9–16, Goslar, DEU, 2015. Eurographics Association.
- [CNSD<sup>+</sup>92] Carolina Cruz-Neira, Daniel J Sandin, Thomas A DeFanti, Robert V Kenyon, and John C Hart. The CAVE: audio visual experience automatic virtual environment. *Communications of the ACM*, 35(6):64–73, 1992. Association for Computing Machinery, Inc.
- [CTB<sup>+</sup>12] Pierre Chevaillier, Thanh-Hai Trinh, Mukesh Barange, Pierre De Loor, Frédéric Devillers, Julien Soler, and Ronan Querrec. Semantic modeling of virtual environments using mascaret. In *2012 5th Workshop on Software Engineering and Architectures for Realtime Interactive Systems (SEARIS)*, pages 1–8. IEEE, Orange County, CA, 2012.
- [Dav07] L David. Behaviorism. <https://www.learning-theories.com/behaviorism.html>, 2007. [Accessed: 22-11-2019].
- [Ded09] Chris Dede. Immersive interfaces for engagement and learning. *Science*, 323(5910):66–69, 2009. American Association for the Advancement of Science.
- [Def01] Defense Acquisition University. Systems engineering fundamentals, 2001. Defense Acquisition University Press Ft. Belvoir, Virginia.
- [DHJ17] Jeremy Dick, Elizabeth Hull, and Ken Jackson. *Requirements engineering*. Springer International Publishing Switzerland, 2017.
- [DHO16] Jana Dücker, Polina Häfner, and Jivka Ovtcharova. Methodology for efficiency analysis of VR environments for industrial applications. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics, Salento*, pages 72–88. Springer, Cham, 2016.
- [Dic05] Michele D Dickey. Engaging by design: How engagement strategies in popular computer and video games can inform instructional design. *Educational technology research and development*, 53(2):67–83, 2005. Springer International Publishing Switzerland.
- [DJ10] Carolyn Dickie and Leighton Jay. Innovation in postgraduate teaching: Mixed methods to enhance learning and learning about learning. *Higher Education Research & Development*, 29(1):29–43, 2010. Taylor & Francis Online.
- [DKU98] John V Draper, David B Kaber, and John M Usher. Telepresence. *Human factors*, 40(3):354–375, 1998. SAGE Publications Sage CA: Los Angeles, CA.

- [DPF<sup>+</sup>01] Juan F Dols, J Pardo, Torbjörn Falkmer, E Uneken, and W Verwey. The trainer project: A new simulator-based driver training curriculum. In *First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, pages 119–124. University of Iowa, Aspen, Colorado, 2001.
- [DS00] Nat Durlach and Mel Slater. Presence in shared virtual environments and virtual togetherness. *Presence: Teleoperators and Virtual Environments*, 9(2):214–217, 2000.
- [DSLA00] Chris Dede, Marilyn Salzman, R Bowen Loftin, and Katy Ash. The design of immersive virtual learning environments: Fostering deep understandings of complex scientific knowledge. *Innovations in science and mathematics education: Advanced designs, for technologies of learning*, page 413, 2000. Lawrence Erlbaum Associates Publishers, Mahwah, USA.
- [DSVdBG03] Filip Dochy, Mien Segers, Piet Van den Bossche, and David Gijbels. Effects of problem-based learning: A meta-analysis. *Learning and instruction*, 13(5):533–568, 2003. Elsevier.
- [Dü15] Jana Dücker. Analyse der Wirtschaftlichkeit der Virtual-Reality-Technologie für kleine und mittlere Unternehmen im Kontext von Industrie 4.0. Master thesis, Karlsruhe Institute of Technology, IMI, 2015.
- [Elv16] Endre Olsvik Elvestad. Evidence of learning in virtual reality. *Department of Computer Science. Norwegian University of Science and Technology, Trondheim*, 9, 2016. "<https://folk.idi.ntnu.no/krogstie/project-reports/2016/elvestad/Litteraturstudie%20-%20Endre%20Elvestad%20-2016.pdf>" [Accessed: 01-05-2019].
- [EON20a] EON Reality. Augmented reality assembly assistance. <https://eonreality.com/portfolio/augmented-reality-assembly-assistance/>, 2020. [Accessed: 20-05-2020].
- [EON20b] EON Reality. VR Maintenance Training. <https://eonreality.com/portfolio/vr-maintenance-training/>, 2020. [Accessed: 20-05-2020].
- [ESI19] ESI Group. Face up to your industrial challenges with IC.IDO. <https://www.esi-group.com/software-solutions/virtual-reality/icido/applications>, 2019. [Accessed: 19-11-2019].
- [EvHH17] Matthes Elstermann, Christian van Husen, and Polina Häfner. Dimension concept - approaching service prototyping from a multi-aspect description

- perspective. In *Proceedings of the QUIS15 International Research Symposium on Service Excellence in Management, At University of Porto, Porto, Portugal*, pages 233–242, 06 2017.
- [Exe20] Executive Agency for Small and Medium-sized Enterprises (European Commission) , PwC. Skills for industry curriculum guidelines 4.0: Future-proof education and training for manufacturing in europe. <https://op.europa.eu/en/publication-detail/-/publication/845051d4-4ed8-11ea-aece-01aa75ed71a1>, 2020. [Accessed: 10-05-2020].
- [FB06] Neil Fleming and David Baume. Learning styles again: Varking up the right tree! *Educational developments*, 7(4):4, 2006. SEDA.
- [FBGL18] Åsa Fast-Berglund, Liang Gong, and Dan Li. Testing and validating extended reality (xR) technologies in manufacturing. *Procedia Manufacturing*, 25:31–38, 2018. Elsevier.
- [Fin13] L Dee Fink. *Creating significant learning experiences: An integrated approach to designing college courses*. John Wiley & Sons, Published by Jossey-Bass, A Wiley Imprint, San Francisco, CA, 2013.
- [FO09] Mario Fallast and Hannes Oberschmid. Roduct innovation project”–a novel interdisciplinary student project. *Advances in production engineering & management*, 4(01/09):69–78, 2009. Production Engineering Institute (PEI), University of Maribor.
- [For18] Forbes Technology Council. 13 top tech skills in high demand for 2018. <http://blog.indeed.com/2018/03/29/video-gaming-spotlight>, 2018. [Accessed: 08-08-2018].
- [FTO11] Loïc Fricoteaux, I Mouttapa Thouvenin, and Jérôme Olive. Adaptive guiding for fluvial navigation training in informed virtual environment. In *Joint VR Conference of euroVR and EGVE, Nottingham, UK*, page 67, 2011.
- [Fur09] Hans Furrer. *Das Berner Modell: ein Instrument für eine kompetenzorientierte Didaktik*. Hep-Verlag, Bern, 2009.
- [Gab97] Joseph L Gabbard. *A taxonomy of usability characteristics in virtual environments*. Dissertation, Virginia Tech, 1997.
- [GAPD09] KS Gurusamy, R Aggarwal, L Palanivelu, and BR Davidson. Virtual reality training for surgical trainees in laparoscopic surgery. *Cochrane Database of Systematic Reviews*, 8(1), 2009. John Wiley & Sons, Chichester, UK.

- [Gau15] John Gaudiosi. This company dominates the virtual reality business, and it's not named oculus. <https://fortune.com/2015/03/19/unity-virtual-reality/>, 2015. [Accessed: 18-11-2019].
- [GCM<sup>+</sup>19] Scott W Greenwald, Wiley Corning, Gavin McDowell, Pattie Maes, and John Belcher. ElectroVR: An electrostatic playground for collaborative, simulation-based exploratory learning in immersive virtual reality. 2019. International Society of the Learning Sciences (ISLS), Lyon, France.
- [Ghi11] Beatrice Ghirardini. *E-learning methodologies: A guide for designing and developing e-learning courses*. Food and Agriculture Organization of the United Nations, Rome, 2011.
- [GHS18] Arthur C Graesser, Xiangen Hu, and Robert Sottolare. Intelligent tutoring systems. *International handbook of the learning sciences*, pages 246–255, 2018. Routledge New York, New York.
- [GKGBPS16] Alla G Kravets, Alexander G Belov, and Natalia P Sadovnikova. Models and methods of professional competence level research. *Recent Patents on Computer Science*, 9(2):150–159, 2016. Bentham Science Publishers.
- [Goo19] Google VR. Google cardboard. Virtual Reality erleben – einfach, unterhaltsam und kostengünstig. <https://arvr.google.com/cardboard/>, 2019. [Accessed: 19-11-2019].
- [Gru93] Thomas R Gruber. A translation approach to portable ontology specifications. *Knowledge acquisition*, 5(2):199–220, 1993. Elsevier.
- [GWW06] Willibald A. Günthner, Dennis Walch, and Johannes Wulz. Virtual Reality. Eintauchen in die digitale Welt. <https://docplayer.org/47127308-Virtual-reality-eintauchen-in-die-digitale-welt.html>, 2006. [Accessed: 09-05-2019].
- [Häf17] Victor Häfner. Modelling smart virtual environments. *4. Fachkonferenz zu VR/AR-Technologien in Anwendung und Forschung an der Professur Werkzeugmaschinen und Umformtechnik, 2017, Chemnitz, Germany, ISBN 978-3-00-058419-0, Pages 151-162*, 2017.
- [Häf20] Polina Häfner. Categorisation of the benefits and limitations of immersive technologies for education. In *Proceedings of the 19th International Conference on Modeling & Applied Simulation (MAS 2020)*. Ed.: AG Bruzzone, pages 154–159, Online, 2020.
- [Hap18a] Haption. Scale1. <https://www.haption.com/en/products-en/scale-one-en.html>, 2018. [Accessed: 20-05-2020].

- [Hap18b] HaptX. Technology | haptx. <https://haptx.com/technology/>, 2018. [Accessed: 20-05-2020].
- [HDFP11] Nicolas S Holliman, Neil A Dodgson, Gregg E Favalora, and Lachlan Pockett. Three-dimensional displays: a review and applications analysis. *IEEE transactions on Broadcasting*, 57(2):362–371, 2011. IEEE.
- [HDSO18] P. Häfner, J. Dücker, C. Schlatt, and J. Ovtcharova. Decision support method for using virtual reality in education based on a cost-benefit-analysis. In *4th International Conference of the Virtual and Augmented Reality in Education, VARE 2018; Budapest; Hungary; 17 September 2018 through 19 September 2018*. Ed.: A. G. Bruzzone, pages 103–112. Dime University of Genoa, Rende, 2018.
- [Hee00] Carrie Heeter. Interactivity in the context of designed experiences. *Journal of Interactive Advertising*, 1(1):3–14, 2000. Taylor & Francis Online.
- [HEHO16] Polina Häfner, Matthes Elstermann, Victor Häfner, and Jivka Ovtcharova. Virtual reality based rapid service prototyping tool. In *EuroVR Conference 2016*. EuroVR Conference, 11 2016. Athens, Greece.
- [Hei76] P Heimann. Didaktik als Unterrichtswissenschaft. *K. Reich, H. Thomas Stuttgart: Klett*, pages 229–230, 1976.
- [Hei18] Adrien Heinzmeier. Implementation of an immersive haptic training simulation of manual manufacturing processes in the leathergoods industry. Masterarbeit, Karlsruhe Institute of Technology, IMI, 2018.
- [HH20] Polina Häfner and Victor Häfner. PolyVR - Virtual Reality Engine. [http://www.imi.kit.edu/english/21\\_2274.php](http://www.imi.kit.edu/english/21_2274.php), 2020. [Accessed: 20-05-2020].
- [HHO13] Polina Häfner, Victor Häfner, and Jivka Ovtcharova. Teaching methodology for virtual reality practical course in engineering education. *Procedia Computer Science*, 25:251–260, 2013. Elsevier.
- [HHO14] Polina Häfner, Victor Häfner, and Jivka Ovtcharova. Experiencing physical and technical phenomena in schools using virtual reality driving simulator. In *International Conference on Learning and Collaboration Technologies*, pages 50–61. Springer, Heraklion, Greece, 2014.
- [HLR16] HLRS High Performance Computing Center Stuttgart. COVISE. <https://www.hlrs.de/covise/>, 2016. [Accessed: 19-11-2019].

- [Hol20] Holografika. HoloVizio C80 glasses-free 3D cinema system. <https://holografika.com/c80-glasses-free-3d-cinema/>, 2020. [Accessed: 20-05-2020].
- [HOS70] Paul Heimann, Gunter Otto, and Wolfgang Schulz. *Unterricht: Analyse und Planung*, volume 1. ICON Group International, San Diego, California, USA, 1970.
- [HRL10] Hsiu-Mei Huang, Ulrich Rauch, and Shu-Sheng Liaw. Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education*, 55(3):1171–1182, 2010. Elsevier.
- [HRWL83] Frederick Hayes-Roth, Donald A Waterman, and Douglas B Lenat. Building expert system. 1983. Addison-Wesley Publishing Company, Boston, Massachusetts, USA.
- [HSB06] Cindy E Hmelo-Silver and Howard S Barrows. Goals and strategies of a problem-based learning facilitator. *Interdisciplinary journal of problem-based learning*, 1(1):4, 2006.
- [HSD<sup>+</sup>14] Polina Haefner, Julia Seessle, Jana Duecker, Matthias Zienthek, and Filip Szeliga. Interactive visualization of energy efficiency concepts using virtual reality. In *EuroVR 2014, Bremen, Germany*, pages 101–106, 2014.
- [HSG<sup>+</sup>13] Alexander Handfest, Michael Schröder, Philip Grefe, Pablo Carra, and Polina Häfner. Integration eines realen Fahrzeugs in eine Mixed-Reality-Fahrsimulation. In *Wirtschaft und Technologie im Dienst der Gesellschaft*, pages 49–58, Sofia, Bulgaria, 2013. FDIBA TU-Sofia.
- [HW97] Terry Hill and Roy Westbrook. SWOT analysis: it's time for a product recall. *Long range planning*, 30(1):46–52, 1997. Elsevier.
- [HW08] Mordechai Haklay and Patrick Weber. Openstreetmap: User-generated street maps. *IEEE Pervasive Computing*, 7(4):12–18, 2008. IEEE COMPUTER SOC.
- [Hä19] Victor Häfner. *PolyVR - A Virtual Reality Authoring Framework for Engineering Applications*. Dissertation, Karlsruher Institut für Technologie (KIT), 2019.
- [IEE99] IEEE. IEEE Standard for Application and Management of the Systems Engineering Process. *IEEE Std 1220-1998*, pages 1–84, 1999.
- [ILI20] ILIAS open source e-Learning e.V. ILIAS: The open source learning management system. <https://www.ilias.de/>, 2020. [Accessed: 25-06-2020].

- [Ilk18] Tuomi Ilkka. The impact of artificial intelligence on learning, teaching, and education. 2018. European Union, Brussels, Belgium.
- [Ims19] Imsimity. Der CYBER-CLASSROOM ist eine digitale Lernumgebung, die Unsichtbares sichtbar und erlebbar macht. <http://www.cyber-classroom.de/startseite.html>, 2019. [Accessed: 19-11-2019].
- [ind18] indeed. Gaming industry spotlight 2018: Augmented reality and esports on the rise. <http://blog.indeed.com/2018/03/29/video-gaming-spotlight>, 2018. [Accessed: 08-08-2018].
- [Ins11] Institute for Information Management in Engineering at KIT. MINT-BOX DRIVE Unterrichtsunterlagen. <https://www.imi.kit.edu/mint-intern/index.php>, 2011. [Accessed: 1-05-2020].
- [Ins17] Institute for Information Management in Engineering at KIT. DriveSim Project. [http://www.imi.kit.edu/english/46\\_3195.php](http://www.imi.kit.edu/english/46_3195.php), 2017. [Accessed: 30-08-2019].
- [Ins18] Institute for Information Management in Engineering at KIT. DriveSim Project Video. [https://www.youtube.com/watch?time\\_continue=1&v=1fbaqa03WkA](https://www.youtube.com/watch?time_continue=1&v=1fbaqa03WkA), 2018. [Accessed: 30-08-2019].
- [Ins20] Institute for Information Management in Engineering at KIT. Youtube Channel. <https://www.youtube.com/channel/UCjAWBnIghXloswxZvyoCQCQ>, 2020. [Accessed: 07-04-2020].
- [Iow19] Iowa Waste Reduction Center. Virtual paint. <https://iwrc.uni.edu/virtualpaint>, 2019. [Accessed: 10-05-2019].
- [JM94] Werner Jank and Hilbert Meyer. Didaktische Modelle. 3. Auflage, 1994. Cornelsen Verlag Scriptor GmbH & Co. KG, Berlin.
- [JP16] Alexandre Joyce and Raymond L Paquin. The triple layered business model canvas: A tool to design more sustainable business models. *Journal of cleaner production*, 135:1474–1486, 2016. Elsevier.
- [JV13] Bernhard Jung and Arnd Vitzthum. Virtuelle Welten. In *Virtual und Augmented Reality (VR/AR)*, pages 65–95. Springer Vieweg, Berlin, Heidelberg, 2013.
- [Kal18] Karlsruhe Institute of Technology. NEULAND Magazin. Lizenz zum Fahren. <https://kit-neuland.de/de/magazin/projekte/lizenz-zum-fahren/#site-contents-390>, 2018. [Accessed: 25-08-2020].

- [Kal18] Karlsruhe Institute of Technology. NEULAND. Lizenz zum Fahren. [https://kit-neuland.de/fileadmin/PDFs/WEB\\_NEULAND\\_2017-18.pdf](https://kit-neuland.de/fileadmin/PDFs/WEB_NEULAND_2017-18.pdf), 2017-18. [Accessed: 25-06-2020].
- [Kar20] Karlsruhe Institute of Technology. Berechnung des LQI. <https://www.sek.kit.edu/230.php>, 2020. [Accessed: 14-05-2020].
- [Kel12] James Kelly. The Peak Performance Center. Learning Theories. <http://thepeakperformancecenter.com/educational-learning/learning/theories/>, 2012. [Accessed: 22-11-2019].
- [Ker09] Michael Kerres. *Multimediale und telemediale Lernumgebungen: Konzeption und Entwicklung*. Walter de Gruyter, Berlin, 2009.
- [KH19] Andreas Kaplan and Michael Haenlein. Siri, Siri, in my hand: Who's the fairest in the land? on the interpretations, illustrations, and implications of artificial intelligence. *Business Horizons*, 62(1):15 – 25, 2019.
- [Khe04] Lachmi Khemlani. Autodesk Revit: implementation in practice. *White paper, Autodesk*, 2004. Arcwiz, Fremont, California, USA.
- [KHO15] Jurica Katicic, Polina Häfner, and Jivka Ovtcharova. Methodology for emotional assessment of product design by customers in virtual reality. *Presence: Teleoper. Virtual Environ.*, 24(1):62–73, February 2015. MIT Press, Cambridge.
- [Kim13] Tae-Young Kim. A situational training system for developmentally disabled people based on augmented reality. *IEICE TRANSACTIONS on Information and Systems*, 96(7):1561–1564, 2013. The Institute of Electronics, Information and Communication Engineers.
- [KP12] Michael Kerres and Annabell Preußler. 1. Mediendidaktik als Disziplin. 2012. Oldenbourg Wissenschaftsverlag, München.
- [Kru09] Kevin Kruse. Gagne's nine events of instruction: An introduction. <https://psu.pb.unizin.org/app/uploads/sites/88/2018/06/Gagne-Nine-Events-of-Instructoin.pdf>, 2009. [Accessed: 30-04-2020].
- [KSW00] Hannes Kaufmann, Dieter Schmalstieg, and Michael Wagner. Construct3D: a virtual reality application for mathematics and geometry education. *Education and information technologies*, 5(4):263–276, 2000. Springer.
- [Kum14] Greg Kumparak. A brief history of Oculus. <https://techcrunch.com/2014/03/26/a-brief-history-of-oculus/>, 2014. [Accessed: 12-11-2019].

- [Kun06] Sören Kunst. *Konzeption eines Modells zur Bewertung der Wirtschaftlichkeit von Virtual-Reality-Systemen in der Digitalen Fabrik*. Thesis at Hochschule Wismar, Institut für Elektrotechnik und Informatik, Printed at Diplomica GmbH, 2006.
- [Kun18] Sébastien Kuntz. MiddleVR for Unity | MiddleVR. <http://www.middlevr.com/middlevr-for-unity/>, 2018. [Accessed: 24-04-2018].
- [Kur15a] Serhat Kurt. Dick and carey instructional model. <https://educationaltechnology.net/the-addie-model-instructional-design/>, 2015. [Accessed 28-11-2019].
- [Kur15b] Serhat Kurt. Educational technology. instructional design models and theories. <https://educationaltechnology.net/instructional-design-models-and-theories/>, 2015. [Accessed 28-11-2019].
- [LC19] Ruding Lou and Jean-Rémy Chardonnet. Reducing cybersickness by geometry deformation. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, Osaka, pages 1058–1059. IEEE, 2019.
- [LD97] Matthew Lombard and Theresa Ditton. At the heart of it all: The concept of presence. *Journal of computer-mediated communication*, 3(2):JCMC321, 1997. Oxford University Press Oxford, UK.
- [LDC<sup>+</sup>10] Zdena Lustigova, Aude Dufresne, François Courtemanche, Josef Malach, and Martin Malcik. Acquiring physiological data for automated educational feedback in virtual learning environments. *New educational review*, 21(2):97–109, 2010.
- [Lin17] Lincoln Electric Companies. VRTEX virtual reality welding training simulators. <https://youtu.be/zRY1ERFsxVg>, 2017. [Accessed: 25-06-2020].
- [Lin18] Linde. Virtual reality training for operators by Linde. <https://www.youtube.com/watch?v=KYK6wuFaES8>, 2018. [Accessed: 20-05-2020].
- [LK16] Amber S Linde and Kevin Kunkler. The evolution of medical training simulation in the us military. In *MMVR*, pages 209–214, 2016. Stud Health Technol Inform.
- [LL13] Miriam B Larson and Barbara B Lockee. *Streamlined ID: A practical guide to instructional design*. Routledge, New York, 2013.
- [LNM19] Mohamed Lubani, Shahrul Azman Mohd Noah, and Rohana Mahmud. Ontology population: Approaches and design aspects. *Journal of Information Science*, 45(4):502–515, 2019. SAGE Publications Sage UK: London, England.

- [LSR<sup>+</sup>16] Mario Lorenz, Michael Spranger, Tino Riedel, Franziska Pürzel, Volker Wittstock, and Philipp Klimant. CAD to VR—a methodology for the automated conversion of kinematic CAD models to virtual reality. *Procedia Cirp*, 41:358–363, 2016. Elsevier.
- [Lut05] Bernd Lutz. *Konzepte für den Einsatz von Virtueller und Erweiterter Realität zur interaktiven Wissensvermittlung*. Dissertation, Technische Universität Darmstadt, 2005.
- [MAAAA17] F Mustafa, Ahmed Al-Ashaab, and H Al-Amili. A comparative study of product data exchange among cad systems. In *Proceedings of the 1st international conference on recent trends of engineering sciences and sustainability (IJRTSS)*, Baghdad- University of Baghdad, Iraq, 2017.
- [Mad12] Made in Germany. Das Wirtschaftsmagazin. Cyber-Classrooms - virtuelle Klassenzimmer als Exportschlager. <https://p.dw.com/p/16dsC>, 2012. [Accessed: 19-11-2019].
- [Mai96] Peter Herbert Maier. Spatial geometry and spatial ability—how to make solid geometry solid. In *Selected papers from the Annual Conference of Didactics of Mathematics, Regensburg*, pages 63–75, 1996.
- [Man01] Fabrizia Mantovani. VR Learning: Potential and Challenges for the Use of 3D Environments in Education and Training. In *Towards cyberpsychology: mind, cognition, and society in the Internet age*, volume 2, pages 207–225. IOS Press, Amsterdam, 2001.
- [Man18] ManpowerGroup. 2018 talent shortage survey. <https://go.manpowergroup.com/talent-shortage-2018#thereport>, 2018. [Accessed: 08-05-2020].
- [Mar10] Ann Christine Marr. *Serious Games für die Informations-und Wissensvermittlung-Bibliotheken auf neuen Wegen*, volume 28. Publisher: Dinges & Frick GmbH, Wiesbaden, 2010.
- [Mar18] François Marceau. Feasibility study of a haptic immersive learning environment for the training of manual production steps in the leathersgoods industry. Master thesis, Karlsruhe Institute of Technology, IMI, 2018.
- [May09] Richard E. Mayer. *Multimedia learning*. Cambridge University Press, Cambridge [u.a.], 2nd ed. edition, 2009.
- [MC05] David R. Michael and Sandra L. Chen. *Serious Games: Games That Educate, Train, and Inform*. Course Technology, Mason, USA, 2005.

- [McG20] Marianne Kolbasuk McGee. Virtual reality: Real privacy and security risks. <https://www.databreachtoday.com/interviews/virtual-reality-real-privacy-security-risks-i-3221>, 2020. [Accessed: 25-06-2020].
- [MDL<sup>+</sup>96] M. David Merrill, Leston Drake, Mark J. Lacy, Jean Pratt, and the ID<sub>2</sub> Research Group. Reclaiming instructional design. *Educational Technology*, 36(5):5–7, 1996. JSTOR, New York.
- [Mic18] Microsoft. Microsoft hololens | the leader in mixed reality technology. <https://www.microsoft.com/en-us/hololens>, 2018. [Accessed: 24-04-2018].
- [Mic19] Felix Michels. Realtime traffic simulation for a virtual driving simulator. Master thesis, Karlsruhe Institute of Technology, IMI, 2019.
- [Mic20] Microsoft. Microsoft hololens official webpage. <https://www.microsoft.com/en-us/hololens>, 2020. [Accessed: 20-04-2020].
- [Min15] Saloni Minocha. The state of virtual reality in education—shape of things to come. *International Journal of Engineering Research*, 4(11):596–598, 2015. Citeseer.
- [MLB<sup>+</sup>19] Andrew Munoz, Christopher Lewis, Nicholas Bolling, William Zandbergen, Connor Scully-Allison, Vinh Le, Sergiu Dascalu, and Benjamin Brown. Virtual reality physics lab. In Gordon Lee and Ying Jin, editors, *Proceedings of 34th International Conference on Computers and Their Applications, Honolulu, Hawaii, USA*, volume 58 of *EPiC Series in Computing*, pages 17–26. EasyChair, 2019.
- [MM02] Roxana Moreno and Richard E Mayer. Learning science in virtual reality multimedia environments: Role of methods and media. *Journal of educational psychology*, 94(3):598, 2002. American Psychological Association.
- [Moo18] Moodle. About moodle. [https://docs.moodle.org/38/en/About\\_Moodle](https://docs.moodle.org/38/en/About_Moodle), 2018. [Accessed 24-11-2019].
- [Mph20] Wallen Mphepo. Stereoscopy and autostereoscopy. In Branislav Sobota and Dragan Cvetković, editors, *Mixed Reality and Three-Dimensional Computer Graphics*, chapter 9. IntechOpen, Rijeka, 2020.
- [MSI96] Riichiro Mizoguchi, Katherine Sinitsa, and Mitsuru Ikeda. Task ontology design for intelligent educational/training systems. In *Proceedings of the Workshop "Architectures and Methods for Designing Cost-Effective and Reusable*

- ITSs''*. Position Paper for ITS'96 Workshop on Architectures and Methods for Designing Cost-Effective and Reusable ITSs, Montreal, 1996.
- [MTUK95] Paul Milgram, Haruo Takemura, Akira Utsumi, and Fumio Kishino. Augmented reality: A class of displays on the reality-virtuality continuum. In *Telem manipulator and telepresence technologies*, volume 2351, pages 282–292. International Society for Optics and Photonics, 1995. DOI 10.1117/12.197321.
- [MUH10] Kazunori Miyata, Katsuhiko Umemoto, and Takeo Higuchi. An educational framework for creating vr application through groupwork. *Computers & Graphics*, 34(6):811–819, 2010. Elsevier.
- [Mus15] Mark A. Musen. The Protégé Project: A Look Back and a Look Forward. *AI Matters*, 1(4):4–12, June 2015. NIH Public Access.
- [New19] Newegg. HTC VIVE Pro Virtual Reality Headset - Kit. <https://www.newegg.com/p/N82E16826918025>, 2019. [Accessed: 19-11-2019].
- [OHH<sup>+</sup>15] Jivka Ovtcharova, Polina Häfner, Victor Häfner, Jurica Katicic, and Christina Vinke. Innovation braucht resourceful humans, Aufbruch in eine neue Arbeitskultur durch virtual engineering. In *Zukunft der Arbeit in Industrie 4.0*, pages 111–124. Springer, Berlin, Heidelberg, 2015.
- [OJ20] Charles Owen-Jackson. Does virtual and augmented reality mean augmented cybercrime too? <https://www.kaspersky.com/blog/secure-futures-magazine/ar-vr-cybersecurity/31417/>, 2020. [Accessed: 25-06-2020].
- [OOJ14] Ifediora Christian Osita, Idoko Onyebuchi, and Nzekwe Justina. Organization's stability and productivity: the role of swot analysis an acronym for strength, weakness, opportunities and threat. *International Journal of Innovative and Applied Research*, 2(9):23–32, 2014.
- [Ope20] Open Cascade. Open source core technology. <https://www.opencascade.com/content/open-source-core-technology>, 2020. [Accessed: 20-05-2020].
- [oPitGEotsC07] Committee on Prospering in the Global Economy of the 21st Century. *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. National Academies Press Washington, DC, 2007.
- [Opt18] Optoma. Optoma EH320USTi. <https://www.optoma.com/us/product/eh320usti>, 2018. [Accessed: 20-06-0220].

- [oT20] Karlsruhe Institute of Technology. Informationen zur Lehrveranstaltungsevaluation. <https://www.sek.kit.edu/lehrveranstaltungsevaluation.php>, 2020. [Accessed: 14-05-2020].
- [Ovt15] Jivka Ovtcharova. Virtuelles Abbild - neue Ingenieurmethoden für Industrie 4.0. In *VAR<sup>2</sup> 2015, 3. Fachkonferenz zu VR/AR-Technologien in Anwendung und Forschung in Chemnitz*, pages 40–50, 2015.
- [Ovt20] Jivka Ovtcharova. Lectures on virtual engineering. *IMI, Karlsruhe Institute of Technology*, 2020.
- [Oxf19] Oxford. Lexico dictionary. [https://www.lexico.com/en/definition/artificial\\_intelligence](https://www.lexico.com/en/definition/artificial_intelligence), 2019. [Accessed: 08-11-2019].
- [PAD02] Dave Pape, Josephine Anstey, and Greg Dawe. Low-cost projection-based virtual reality display. In *Stereoscopic Displays and Virtual Reality Systems IX*, volume 4660, pages 483–491. International Society for Optics and Photonics, 2002.
- [Pal17] Tommy Palladino. Microsoft has figured out how to double field of view on hololens « hololens :: Next reality. <https://hololens.reality.news/news/microsoft-has-figured-out-double-field-view-hololens-0180659/>, 2017. [Accessed: 24-04-2018].
- [Pan95] Verônica S Pantelidis. Reasons to use virtual reality in education. *VR in the Schools*, 1(1):9, 1995. Virtual Reality and Education Laboratory (VREL), East Carolina University, Greenville, NC.
- [Pan96] Veronica S Pantelidis. Suggestions on when to use and when not to use virtual reality in education. *VR in the Schools*, 2(1):18, 1996. Virtual Reality and Education Laboratory (VREL), East Carolina University, Greenville, NC.
- [Pan10] Veronica S Pantelidis. Reasons to use virtual reality in education and training courses and a model to determine when to use virtual reality. *Themes in Science and Technology Education*, 2(1-2):59–70, 2010. Klidarithmos Computer Books.
- [PC17] Thibault Porssut and Jean-Rémy Chardonnet. Asymmetric telecollaboration in virtual reality. In *2017 IEEE Virtual Reality (VR), Los Angeles, California*, pages 289–290. IEEE, 2017.

- [PDSL17] George Papanastasiou, Athanasios Drigas, Charalabos Skianis, and Miltiadis D Lytras. Serious games in k-12 education: Benefits and impacts on students with attention, memory and developmental disabilities. *Program: electronic library and information systems*, 51(4):424–440, 2017. Emerald Publishing Limited, Bingley, United Kingdom.
- [PM02] Sarah Parsons and Peter Mitchell. The potential of virtual reality in social skills training for people with autistic spectrum disorders. *Journal of intellectual disability research : JIDR*, 46:430–43, 07 2002.
- [PP06] Narcís Parés and Roc Parés. Towards a model for a virtual reality experience: the virtual subjectiveness. *Presence: Teleoperators and Virtual Environments*, 15(5):524–538, 2006. MIT Press, Cambridge.
- [PPC92] Daniele Pralong, John R Phillips, and Simon Carlile. Acoustic validation of an “in ear” system for recording the head-related transfer functions (hrtfs) in the human. *The Journal of the Acoustical Society of America*, 92(4):2334–2334, 1992. ASA.
- [PPM<sup>+</sup>14] Emmanuel B. Vander Poorten, Jerome Perret, R. Muyle, D. Reynaerts, J. Vander Sloten, and L. Pintelon. To Feedback or not to Feedback - the Value of Haptics in Virtual Reality Surgical Training. In Jerome Perret, Valter Basso, Francesco Ferrise, Kaj Helin, Vincent Lepetit, James Ritchie, Christoph Runde, Mascha van der Voort, and Gabriel Zachmann, editors, *EuroVR 2014 - Conference and Exhibition of the European Association of Virtual and Augmented Reality*, volume vol. 2014, pages 157–161. The Eurographics Association, 2014.
- [PS04] Denis Charles Phillips and Jonas F Soltis. *Perspectives on learning*. Teachers College Press, Columbia University, New York, NY, 2004.
- [Pso95] Joseph Psotka. Immersive training systems: Virtual reality and education and training. *Instructional science*, 23(5-6):405–431, 1995. Kluwer Academic Publishers. Printed in the Netherlands.
- [Quo19] Quora. What is cognitive intelligence? <https://www.quora.com/What-is-cognitive-intelligence>, 2019. [Accessed: 08-11-2019].
- [QWCH16] Ane Qvortrup, Merete Wiberg, Gerd Christensen, and Mikala Hansbøl. *On the definition of learning*. University Press of Southern Denmark, Odense, 2016.
- [Red06] Redaktionsteam PELe. Didaktische Modelle. [https://www.e-teaching.org/didaktik/theorie/didaktik\\_allg/DidaktischeModelle.pdf](https://www.e-teaching.org/didaktik/theorie/didaktik_allg/DidaktischeModelle.pdf), 2006. [Accessed: 10-05-2019].

- [RGSM<sup>+</sup>08] P Robuffo Giordano, JL Souman, R Mattone, A De Luca, MO Ernst, and HH Bülthoff. The CyberWalk platform: human-machine interaction enabling unconstrained walking through vr. In *First workshop for young researchers on Human-friendly robotics, Napoli*, 2008.
- [Ric12] John W Rice. The gamification of learning and instruction: Game-based methods and strategies for training and education. *International Journal of Gaming and Computer-Mediated Simulations*, 4(4), 2012. IGI Global.
- [Rie11] Eric Ries. *The lean startup: How today's entrepreneurs use continuous innovation to create radically successful businesses*. Crown Publishing Group, New York, USA, 2011.
- [RK05] Albert Rizzo and Gerard Jounghyun Kim. A SWOT analysis of the field of virtual reality rehabilitation and therapy. *Presence: Teleoperators & Virtual Environments*, 14(2):119–146, 2005. MIT Press, Cambridge.
- [RN16] Stuart J Russell and Peter Norvig. *Artificial intelligence: a modern approach*. Pearson Education, Inc., Upper Saddle River, New Jersey, 2016.
- [Run14] Christoph Runde. Head Mounted Display & Datenbrillen. 2014. Whitepaper, "[https://www.vdc-fellbach.de/files/Whitepaper/2014\\_VDC-Whitepaper\\_Head\\_Mounted\\_Displays\\_&\\_Datenbrillen.pdf](https://www.vdc-fellbach.de/files/Whitepaper/2014_VDC-Whitepaper_Head_Mounted_Displays_&_Datenbrillen.pdf)" [Accessed: 03-01-2021].
- [Sam19] Samsung. Gear VR (SM-R323). <https://www.samsung.com/de/wearables/gear-vr-r323/>, 2019. [Accessed: 19-11-2019].
- [SC18] William R Sherman and Alan B Craig. *Understanding virtual reality: Interface, application, and design*. Morgan Kaufmann, Burlington, MA, USA, 2018.
- [Sch11] Daniel Schoenen. CAVE at Lifecycle Engineering Solution Center at KIT. Created for Karlsruhe City Marketing, 2011.
- [Sch14] Haiko Schlink. *Wirtschaftlichkeitsrechnung für Ingenieure*. Gabler Verlag Wiesbaden, 2014. eBook, DOI 10.1007/978-3-658-13950-6.
- [Sch17a] Adrien Schmidt. How AI impacts education. <https://www.forbes.com/sites/theyec/2017/12/27/how-ai-impacts-education/#50f0cfd6792e>, 2017. [Accessed: 20-05-2020].
- [Sch17b] Michael Schmiechen. Smart in 60 seconds! today: the target-actual comparison. <https://www.proadsoftware.com/en/blog/entries/2017/02/smart-in-60-seconds-part-13-target-actual-comparison.php>, 2017. [Accessed: 1-05-2020].

- [Sch18] Charline Schlatt. Entwicklung eines Modells zur Kosten- Nutzen-Analyse von Virtual Reality- Technologien in Lernumgebungen. Master thesis, Karlsruhe Institute of Technology, IMI, Karlsruhe, 3 2018.
- [Sch19] Ron Schmelzer. AI applications in education. <https://www.forbes.com/sites/cognitiveworld/2019/07/12/ai-applications-in-education/#690b059762a3>, 2019. [Accessed: 20-05-2020].
- [SD95] John R Savery and Thomas M Duffy. Problem based learning: An instructional model and its constructivist framework. *Educational technology*, 35(5):31–38, 1995.
- [SGHG14] Robert Sottolare, Arthur Grasser, Xiangen Hu, and Benjamin Goldberg. *Design Recommendations for Intelligent Tutoring Systems, Volume 2: Instructional Management*. Springer International Publishing, Cham, 06 2014.
- [SGR<sup>+</sup>02] Neal E Seymour, Anthony G Gallagher, Sanziana A Roman, Michael K O’Brien, Vipin K Bansal, Dana K Andersen, and Richard M Satava. Virtual reality training improves operating room performance: results of a randomized, double-blinded study. *Annals of surgery*, 236(4):458, 2002. Lippincott, Williams, and Wilkins.
- [She15] Kelly Sheridan. Microsoft HoloLens Vs. Google Glass: No Comparison - InformationWeek. <https://www.informationweek.com/mobile/microsoft-hololens-vs-google-glass-no-comparison/d/d-id/1318851?>, 2015. [Accessed: 24-04-2018].
- [Sim13] Dragos Simandan. Introduction: Learning as a geographical process. *The Professional Geographer*, 65(3):363–368, 2013. Taylor & Francis Online.
- [Sin13] Brendan Sinclair. GTA V dev costs over \$137 million, says analyst. <https://www.gamesindustry.biz/articles/2013-02-01-gta-v-dev-costs-over-USD137-million-says-analyst>, 2013. [Accessed: 20-05-2020].
- [SKD15] Vadim Shmelev, Maria Karpova, and Alexey Dukhanov. An approach of learning path sequencing based on revised Bloom’s taxonomy and domain ontologies with the use of genetic algorithms. *Procedia Computer Science*, 66:711–719, 2015. Elsevier.
- [SKH17] Amardeep Sathyanarayana, Nitish Krishnamurthy, and John Hansen. Driving distance based analysis of driving maneuvers: Dsp, human-to-vehicle interfaces, driver behavior, and safety. In *Vehicle Systems and Driver Modelling*, chapter 6, pages 1–12. Walter de Gruyter GmbH & Co KG, 01 2017.

- [Ski11] Burrhus Frederic Skinner. *About behaviorism*. Vintage, New York, 2011.
- [Sla14] Harald Slack. Semantic web technologies lectures. <https://youtu.be/i1tSsWdygS8>, 2014. [Accessed: 18-12-2019].
- [Sla18] Mel Slater. Immersion and the illusion of presence in virtual reality. *British Journal of Psychology*, 109(3):431–433, 2018.
- [Sol09] Robert W Solomon. Free and open source software for the manipulation of digital images. *American Journal of Roentgenology*, 192(6):W330–W334, 2009. American Roentgen Ray Society, Leesburg, VA.
- [SS97] Ian Sommerville and Pete Sawyer. *Requirements Engineering: A Good Practice Guide*. John Wiley & Sons, Inc., New York, USA, 1st. ed. edition, 1997.
- [SS06] Jaime Sánchez and Mauricio Sáenz. 3d sound interactive environments for blind children problem solving skills. *Behaviour & Information Technology*, 25(4):367–378, 2006. Taylor & Francis Online.
- [SSBD14] Shai Shalev-Shwartz and Shai Ben-David. *Understanding machine learning: From theory to algorithms*. Cambridge University Press, New York, USA, 2014.
- [SSV16] Mel Slater and Maria V Sanchez-Vives. Enhancing our lives with immersive virtual reality. *Frontiers in Robotics and AI*, 3:74, 2016. Frontiers.
- [Sta05] Sharon Stansfield. An introductory VR course for undergraduates incorporating foundation, experience and capstone. *SIGCSE Bull.*, 37(1):197–200, February 2005.
- [Sta17] Dr. Marija Stambolieva. HORIZONT ERWEITERN: Aktives Lernen mit Virtual/Augmented Reality. <https://hochschulforumdigitalisierung.de/de/blog/horizont-erweitern-aktives-lernen-virtual-augmented-reality>, 2017. [Accessed: 10-05-2019].
- [Sta18a] Statista. Entwicklung der Studienanfängerquote in Deutschland von 2000 bis 2017. <https://de.statista.com/statistik/daten/studie/72005/umfrage/entwicklung-der-studienanfaengerquote>, 2018. [Accessed: 25-08-2018].
- [Sta18b] Statista. Number of students in universities in germany during winter semesters from 2002/2003 to 2017/2018. <https://www.statista.com/statistics/584061/university-student-numbers-winter-semesters-germany>, 2018. [Accessed: 25-08-2018].

- [Ste92] Jonathan Steuer. Defining virtual reality: Dimensions determining telepresence. *Journal of communication*, 42(4):73–93, 1992. Wiley Online Library.
- [Stu15] Students of VRPC at KIT. Virtual reality practical course - winter term 2014/15 - energy efficiency game. [https://youtu.be/6rH5k\\_hG87U](https://youtu.be/6rH5k_hG87U), 2015. [Accessed: 20-05-2020].
- [Stu16] Students of VRPC at KIT. Virtual reality practical course - winter term 2015/16 - virtual twin of a milling machine. <https://youtu.be/MAIjNMaqFFE>, 2016. [Accessed: 20-05-2020].
- [Stu17] Students of VRPC at KIT. Virtual reality practical course - summer term 2017 - solar system. <https://www.youtube.com/watch?v=3oepYM1tgA8>, 2017. [Accessed: 20-05-2020].
- [Stu18a] Students of VRPC at KIT. Virtual reality practical course - summer term 2018 - solar system. <https://youtu.be/fWrH82Qz8hk>, 2018. [Accessed: 20-05-2020].
- [Stu18b] Students of VRPC at KIT. Virtual reality practical course - winter term 2017/18 - service prototyping for flexible workspaces. <https://youtu.be/a3C34b50FPs>, 2018. [Accessed: 20-05-2020].
- [Stu18c] Students of VRPC at KIT. Virtual reality practical course - winter term 2017/18 - solar system. <https://www.youtube.com/watch?v=GvvU1ZkYtMM>, 2018. [Accessed: 20-05-2020].
- [Stu19] Dirk Sturny. Lufthansa aviation training opens virtual reality hubs for cabin training. <https://www.lufthansa-aviation-training.com/en/about/media/lufthansa-aviation-training-opens-virtual-reality-hubs-for-cabin-training/>, 2019. [Accessed: 07-04-2020].
- [STVT<sup>+</sup>19] Ahm Shamsuzzoha, Rayko Toshev, Viet Vu Tuan, Timo Kankaanpaa, and Petri Helo. Digital factory–virtual reality environments for industrial training and maintenance. *Interactive Learning Environments*, 27:1–24, 2019. Taylor & Francis Online.
- [SU93] Mel Slater and Martin Usoh. An experimental exploration of presence in virtual environments. Technical Report 1, Department of Computer Science, QMW University of London, 1993. Tech report, [https://qmro.qmul.ac.uk/xmlui/bitstream/handle/123456789/4705/689\\_Slater&Usoh\\_1993.pdf](https://qmro.qmul.ac.uk/xmlui/bitstream/handle/123456789/4705/689_Slater&Usoh_1993.pdf).

- [Sup14] Superannuation. How much does it cost to make a big video game? <https://kotaku.com/how-much-does-it-cost-to-make-a-big-video-game-1501413649>, 2014. [Accessed: 20-05-2020].
- [TE20] China Association of Automobile Manufacturers Trading Economics. China total vehicle sales. <https://tradingeconomics.com/china/total-vehicle-sales>, 2020. [Accessed: 15-03-2020].
- [Tec19] TechViz. Techviz official web site. <https://www.techviz.net/>, 2019. [Accessed: 19-11-2019].
- [TFA02] Jorge Trindade, Carlos Fiolhais, and Leandro Almeida. Science learning in virtual environments: a descriptive study. *British Journal of Educational Technology*, 33(4):471–488, 2002. Wiley Online Library.
- [Top18] Toptal Company. How to hire a great virtual reality developer. <https://www.toptal.com/virtual-reality#hiring-guide>, 2018. [Accessed: 09-08-2018].
- [VH10] Rita Van Haren. Engaging learner diversity through learning by design. *E-learning and Digital Media*, 7(3):258–271, 2010. SAGE Publications Sage UK: London, England.
- [Vir17] Virtual Reality Society. Who coined the term “virtual reality”? <https://www.vrs.org.uk/virtual-reality/who-coined-the-term.html>, 2017. [Accessed: 25-06-2020].
- [Vir19] Virtualis Holdings Limited. A new era in engineering has begun now Visionary Render 2 is here. <https://www.virtualis.com/products/visionary-render/>, 2019. [Accessed: 19-11-2019].
- [Vir20] Virtuix. Virtuix omni. <https://www.virtuix.com/product/virtuix-omni/>, 2020. [Accessed: 24-06-2020].
- [VRW14] Peter Van Rosmalen and Wim Westera. Introducing serious games with wikis: empowering the teacher with simple technologies. *Interactive Learning Environments*, 22(5):564–577, 2014. Taylor & Francis Online.
- [vRZ17] Rob van Roy and Bieke Zaman. Why gamification fails in education and how to make it successful: introducing nine gamification heuristics based on self-determination theory. In *Serious Games and edutainment applications*, pages 485–509. Springer International Publishing, Cham, 2017.
- [WA09] Christopher D Wickens and Amy L Alexander. Attentional tunneling and task management in synthetic vision displays. *The International Journal of Aviation Psychology*, 19(2):182–199, 2009. Taylor & Francis Online.

- [WCM19] Yuyang Wang, Jean-Rémy Chardonnet, and Frédéric Merienne. VR sickness prediction for navigation in immersive virtual environments using a deep long short term memory model. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Osaka*, pages 1874–1881. IEEE, 2019.
- [Wer16] Thomas Wernbacher. European project proposal discover, 2016. Donau-Universität Krems, Zentrum für Angewandte Spieleforschung, unpublished.
- [Wil84] Gibson William. *Neuromancer*. Victor Gollancz, London, 1984.
- [Wil16] Leslie Owen Wilson. Anderson and Krathwohl–Bloom’s Taxonomy Revised: Understanding the New Version of Bloom’s Taxonomy. *Articel course handbook diakses pada hari selasa tanggal*, vol. 5, 2016. [https://quincycollege.edu/content/uploads/Anderson-and-Krathwohl\\_Revised-Blooms-Taxonomy.pdf](https://quincycollege.edu/content/uploads/Anderson-and-Krathwohl_Revised-Blooms-Taxonomy.pdf).
- [WOLB84] Larry Wos, Ross Overbeck, Ewing Lusk, and Jim Boyle. *Automated reasoning: introduction and applications*. Prentice Hall Inc., Old Tappan, NJ, 1984.
- [Woo10] Beverly Park Woolf. *Building intelligent interactive tutors: Student-centered strategies for revolutionizing e-learning*. Morgan Kaufmann, Burlington, MA, 2010.
- [Wor20] Workable Technology. Instructional designer job description. <https://resources.workable.com/instructional-designer-job-description>, 2020. [Accessed: 24-06-2018].
- [WW13] Michael G. Wagner and Thomas Wernbacher. Iterative didactic design of serious games. In Georgios N. Yannakakis, Espen Aarseth, Kristine Jørgensen, and James C. Lester, editors, *Proceedings of the 8th International Conference on the Foundations of Digital Games, FDG 2013, Chania, Crete, Greece, May 14-17, 2013*, pages 346–351. Society for the Advancement of the Science of Digital Games, 2013.
- [Xhi07] Wikipedia Xhienne. Swot analysis diagram in english language. [https://en.wikipedia.org/wiki/SWOT\\_analysis#/media/File:SWOT\\_en.svg](https://en.wikipedia.org/wiki/SWOT_analysis#/media/File:SWOT_en.svg), 2007. [Accessed: 07-04-2020].
- [YI18] Sze Yuan and Horace Ip. Using virtual reality to train emotional and social skills in children with autism spectrum disorder. *London Journal of Primary Care*, 10:1–3, 06 2018.

- 
- [YYJ11] Steve Chi-Yin Yuen, Gallayanee Yaoyuneyong, and Erik Johnson. Augmented reality: An overview and five directions for ar in education. *Journal of Educational Technology Development and Exchange (JETDE)*, 4(1):11, 2011.
- [Zar06] Jirí Zara. Virtual reality course—a natural enrichment of computer graphics classes. In *Computer Graphics Forum*, volume 25(1), pages 105–112. Wiley Online Library, 2006.
- [ZBB18] M Zardosht, SS Beauchemin, and MA Bauer. Identifying driver behavior in preturning maneuvers using in-vehicle canbus signals. *Journal of Advanced Transportation*, vol. 2018:1–10, 2018. Hindawi.
- [ZDB08] Feng Zhou, Henry Been-Lirn Duh, and Mark Billinghurst. Trends in augmented reality tracking, interaction and display: A review of ten years of ismar. In *2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality, NW Washington, DC*, pages 193–202. IEEE, 2008.
- [ZE01] Guy W Zimmerman and Dena E Eber. When worlds collide!: an interdisciplinary course in virtual-reality art. In *ACM SIGCSE Bulletin*, volume 33(1), pages 75–79. ACM, 2001.
- [Zha19] G. Zhang. Virtual simulation for history education. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Osaka*, pages 1646–1651, March 2019.



# A Appendix

## A.1 Methodology

### A.1.1 Roles and Teams

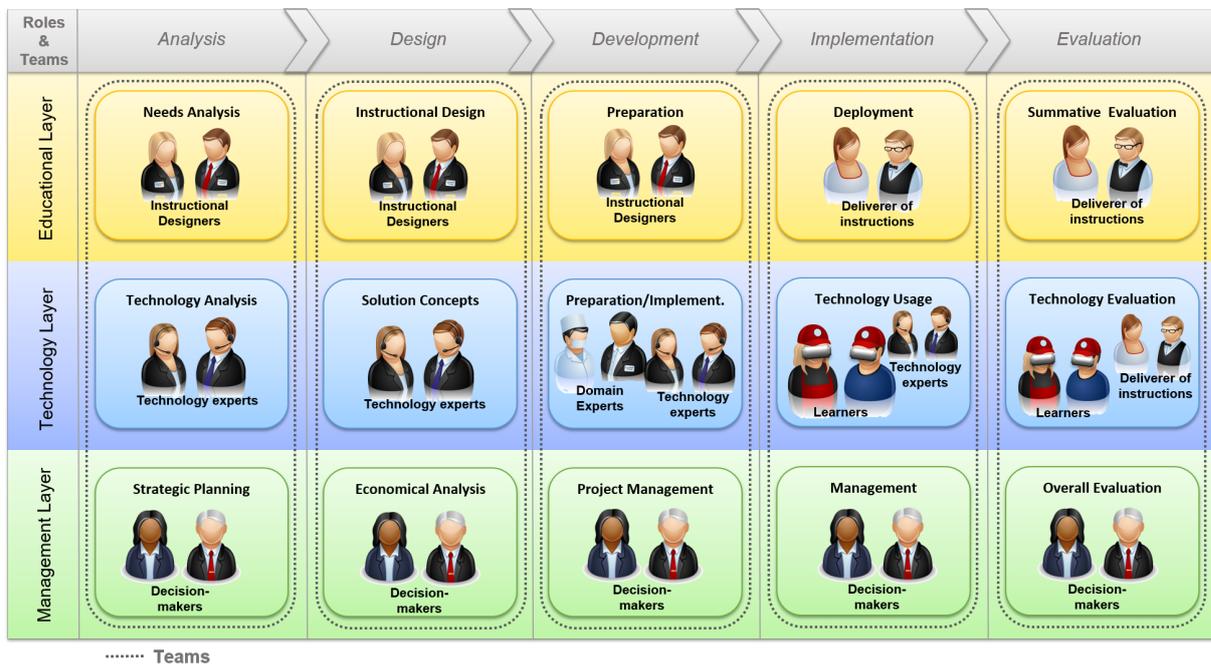


Fig. A.1: Roles and teams of the methodology

## A.2 Decision Support Method

### A.2.1 Benefit Analysis Questionnaire

There are 16 questions in this survey

#### **User perspective**

**Are you a course participant, a teacher or a member of the management? \***

Please choose **all** that apply:

- Course participant
- Teacher
- Management

#### **Framework**

**What is the content of the training course about? \***

Please choose **all** that apply:

- Practical skill
- Theoretical knowledge
- No statement possible

## Participant motivation

### To what extent do you agree with the following statements? \*

**Only answer this question if the following conditions are met:**

Answer was 'Course participant' at question '1 [Perspective1]' (Are you a course participant, a teacher or a member of the management?)

Please choose the appropriate response for each item:

	I fully disagree.	I rather disagree.	I partly agree.	I rather agree.	I fully agree.	No statement possible.
I am open-minded towards new technologies.	<input type="radio"/>					
I would like to try learning in a virtual reality learning environment.	<input type="radio"/>					
I could be motivated by the use of VR for training.	<input type="radio"/>					
I would rather learn through playful confrontation and active participation.	<input type="radio"/>					
I learn better through playful confrontation and active participation.	<input type="radio"/>					

### To what extent do you agree with the following statements? \*

**Only answer this question if the following conditions are met:**

Answer was 'Management' or 'Teacher' at question '1 [Perspective1]' (Are you a course participant, a teacher or a member of the management?)

Please choose the appropriate response for each item:

	I fully disagree.	I rather disagree.	I partly agree.	I rather agree.	I fully agree.	No statement possible.
The course participants are open-minded towards new technologies.	<input type="radio"/>					
Using a new technology can have a motivating effect on the course participants.	<input type="radio"/>					
An active participation and a playful confrontation with the learning matters is appropriate for the considered training.	<input type="radio"/>					

## Communication and evaluation

**To what extent do you agree with the following statements? All statements concern the recent learning environment without VR. \***

**Only answer this question if the following conditions are met:**

Answer was 'Teacher' or 'Course participant' or 'Management' at question '1 [Perspective1]' (Are you a course participant, a teacher or a member of the management?)

Please choose the appropriate response for each item:

	I fully disagree.	I rather disagree.	I partly agree.	I rather agree.	I fully agree.	No statement possible.
The learning matters can be explained well and easily.	<input type="radio"/>					
Details can be pointed out.	<input type="radio"/>					
Components of the learning environment can be analyzed separately.	<input type="radio"/>					
Processes can be slowed down or stopped for explanation.	<input type="radio"/>					
Within the training session language barriers can lead to communication difficulties.	<input type="radio"/>					
The performance of course participants can be evaluated objectively.	<input type="radio"/>					

## Better understanding

### To what extent do you agree with the following statements? \*

**Only answer this question if the following conditions are met:**

Answer was 'Teacher' or 'Course participant' or 'Management' at question '1 [Perspective1]' (Are you a course participant, a teacher or a member of the management?)

Please choose the appropriate response for each item:

	I fully disagree.	I rather disagree.	I partly agree.	I rather agree.	I fully agree.	No statement possible.
The understanding of the learning content could be improved by presenting it from additional perspectives.*	<input type="radio"/>					
The understanding of the learning content could be improved by presenting previously invisible (not exposed) components or processes.	<input type="radio"/>					
Better visualization of the dynamic behavior of the learning environment could improve understanding of the learning content. **	<input type="radio"/>					
The "trial and error" of different scenarios is important for understanding and so far time and/or resource consuming	<input type="radio"/>					
For a good understanding, it is necessary to repeat time-consuming or resource-intensive tasks more often.	<input type="radio"/>					

\* f.e.: inside view of a machine

\*\* f.e.: What's the consequence of a specific action?

### Are all relevant consequences of an action obvious?

\*

**Only answer this question if the following conditions are met:**

Answer was 'Practical skill' or 'No statement possible' at question '2 [Framework1]' (What is the content of the training course about?) and Answer was 'Teacher' or 'Management' at question '1 [Perspective1]' (Are you a course participant, a teacher or a member of the management?)

Please choose **only one** of the following:

- Yes.
- No.
- No statement possible.

## Consequences of a mistake

To that extent do you agree with the following statements?

**Possible consequences of a mistake made during the traditional training (without VR) are....**

\*

**Only answer this question if the following conditions are met:**

Answer was 'Teacher' or 'Course participant' or 'Management' at question '1 [Perspective1]' (Are you a course participant, a teacher or a member of the management?)

Please choose the appropriate response for each item:

	I fully disagree.	I rather disagree.	I partly agree.	I rather agree.	I fully agree.	No statement possible.
...high costs*	<input type="radio"/>					
...negative health effects (injuries, diseases, acid burns etc.)	<input type="radio"/>					
...safety risks (as far as life-threatening situations)	<input type="radio"/>					
...environmental pollution (air, water etc.)	<input type="radio"/>					

The degree of approval reflects the extent of the considered consequence.

\* Please also consider expenses caused by a wrong handling of a machine or similar means.

## Adaptability and flexibility

### To what extent do you agree with the following statements? \*

Only answer this question if the following conditions are met:

Answer was 'Teacher' or 'Management' at question '1 [Perspective1]' (Are you a course participant, a teacher or a member of the management?)

Please choose the appropriate response for each item:

	I fully disagree.	I rather disagree.	I partly agree.	I rather agree.	I fully agree.	No statement possible.
The course content is subject to frequent changes*.	<input type="radio"/>					
The course can easily be adapted to these changes.	<input type="radio"/>					

\* technical changes, new insights etc.

### To what extent do you agree with the following statements? \*

Please choose the appropriate response for each item:

	I fully disagree.	I rather disagree.	I partly agree.	I rather agree.	I fully agree.	No statement possible.
The group of course participants is very heterogenous*.	<input type="radio"/>					
It can be easily reacted to these different conditions of the participants.	<input type="radio"/>					

\* heterogenous in this case refers to the different conditions of the course participants: prior knowledge, physical constitution, learning style, cultural background etc.

### Cost & time

#### Should the traditional training be complemented or replaced by a virtual reality learning environment? \*

Only answer this question if the following conditions are met:

Answer was 'Teacher' or 'Management' at question '1 [Perspective1]' (Are you a course participant, a teacher or a member of the management?)

Please choose **only one** of the following:

- Replace
- Complement
- No statement possible

#### What are the average costs in the context of the training incurred by.... \*

Only answer this question if the following conditions are met:

Answer was 'Teacher' or 'Management' at question '1 [Perspective1]' (Are you a course participant, a teacher or a member of the management?)

Please choose the appropriate response for each item:

	Very low.	Low.	Medium.	High.	Very high.	No statement possible.
...material consumption?	<input type="radio"/>					
...machine and process downtime?	<input type="radio"/>					
...the employment of qualified teaching personnel?	<input type="radio"/>					
...mistakes made by course participants?	<input type="radio"/>					

#### How much time is spent during the training with... \*

Please choose the appropriate response for each item:

	Very few.	Few.	Medium.	Much.	Very much.	No statement possible.
... preparatory and follow-up work*? (see comment)	<input type="radio"/>					
... waiting time?	<input type="radio"/>					

\* f.e.: Covering the floor for painting, putting on protective clothing or tidying up afterwards.

#### Does the learning environment already exist? \*

Only answer this question if the following conditions are met:

Answer was 'No statement possible' or 'Practical skill' at question '2 [Framework1]' (What is the content of the training course about?) and Answer was 'Management' or 'Teacher' at question '1 [Perspective1]' (Are you a course participant, a teacher or a member of the management?)

Please choose **only one** of the following:

- Yes
- No
- Partially
- No statement possible

### Relevance of different use categories

**How important should the following aspects be for the investment decision on establishing a virtual reality learning environment in your opinion? \***

Please choose the appropriate response for each item:

	Very relevant.	Relevant.	Relevant as an aside.	Not relevant.	No statement possible.
Participant motivation	<input type="radio"/>				
Creation of a communication and evaluation basis	<input type="radio"/>				
Better understanding*	<input type="radio"/>				
Improvement of safety and health effects	<input type="radio"/>				
Adaptability and flexibility	<input type="radio"/>				
Consideration of environmental aspects	<input type="radio"/>				
Time savings	<input type="radio"/>				
Cost savings	<input type="radio"/>				
Acquisition costs	<input type="radio"/>				

\*The excellent visualizing options as well as the possibility to actively interact with the learning matters and make own experiences, can lead to a better understanding.

### Identification

For the evaluation it is necessary to know, for which training case the questionnaire has been answered.

**Please give a short hint on the training for which you answered this questionnaire. \***

Please write your answer here:

## A.3 DriveSim Project

### A.3.1 Current Situation Driving Lessons

#### *Theory Driving Lessons*

Different theory units cover all important areas of road traffic and driving. Here an example of the theory topics scope of a driving school [bus20]:

- Personal requirements, human risk factor (alcohol, illegal drugs and medicines, emotions);
- Legal framework (registration of vehicles, vehicle inspections, insurance);
- Traffic signs and traffic infrastructure;
- Road traffic system and its use (traffic routes, road markings);
- Right of way (right before left, roundabout) ;
- Traffic regulations / level crossings ( light signals, connections right of way / traffic regulations);
- Speed, distance and environmentally friendly driving (speed regulations, stopping distance, safety distances);
- Other participants in road traffic: characteristics and behaviour (public transport, cars, motorcycles, cyclists, children and others);
- Traffic behaviour during driving manoeuvres, traffic observation (entering, starting, overtaking, reversing);
- Stationary traffic (stopping and parking, no stopping);
- Behaviour in special situations (lighting, tunnel, traffic accident)
- Lifelong Learning / Consequences of violations of traffic regulations (driving behaviour in different age groups);
- Technical conditions / environmentally conscious handling of motor vehicles (operational safety, driving physics);
- Driving with solo motor vehicles and trains, passenger and freight transport (driving with trains, freight transport);

### ***Theoretical Examination***

For the preparation for the theoretical exam, usually high number of multiple-choice questions that cover all regulations are available. Each question can have a different number of error points and answer options. Many questions are self-explanatory. Driving students should often learn some questions by heart. For instance, in Germany, 30 of 1000 questions are asked on the test. A maximum of 10 points of failure in the exam are allowed. If the driving student ends up with more than ten error points or if he answers two questions with five error points wrong, he has failed. The driving student do the exam on a computer or tablet.

### ***Practical Driving Lessons***

When a driving student sits behind the steering wheel for the first time, there is a lot of fear and uncertainty during the first driving lesson. In Germany, the first driving class is on the road with all other traffic participants, which can be very frightening for beginners. While in China, there are exercises in exceptional training grounds before driving under real traffic and conditions. The driving lessons are usually two at once and last 90 minutes. The average number of driving lessons is about 20 hours, depending on the students' skills. The specific driving lessons consisting of intercity, motorway and night driving lessons are obligatory.

The training is gradual, from a basic level to the advanced level and then to the performance level. There are specific training drives such as motorway, country road, night diving, and at the end, the driving instructor prepares the trainee for the driving exam. Learning the basic driving tasks such as reversing and parking are also part of the training content.

### ***Practical Examination***

The driving instructor knows when the student is ready for the practical driving test. The examiner tells the student what to do during the test. For example, where to turn, where and how to park. The driving student passes the exam when he drives for 45 minutes without making any serious mistakes. The route consists of three basic driving tasks such as parking, emergency braking or a route within a town or village and one outside a town or village. If the student makes a grave error, then he fails the exam. A dangerous error can be, for example, running a red light, disregarding a stop sign or endangering other road users. If the driving instructor has to intervene, the student fails the practical exam.

### A.3.2 DriveSim Requirements

The main goals and requirements for the software and hardware infrastructure of the DriveSim project are listed below. Additional management, administrative or legal tasks of the project are not presented.

The goal of the project was to develop a novel driving simulator that is tailored to the needs of driving school students in China. The virtual environment should allow the driving student dealing with virtual traffic situations and training exercises and should enable a personalised learning curve.

The driving simulator should consist of a modular hardware solution, which can be customised according to requirements and budget. The hardware solution mainly should consist of two parts: the driving cockpit, which can be designed as realistic as possible by using a real car, and the immersive technology for visualising the virtual world.

One main requirement was to use a real vehicle as a cockpit for the driving simulation, which involves the connection and communication of a car with the software simulation. Modern vehicles are equipped with a CAN bus, which is an internal network for the connection of all sensors and actuators. By using this interface a regular vehicle can be modified for being used as a driving simulator without impairing its outer appearance. Furthermore the display devices in the cockpit can be controlled and driver input (pedals, steering, etc.) can be taped and sent to the vehicle dynamics.

To achieve some features the real car should be additionally be equipped with force feedback to increase the immersion of the system. In particular, there should be force feedback for the steering and for the suspension. By this means, unevenness of the road and vehicle acceleration can be reproduced.

The visualisation hardware should be configurable and should consist of different immersive visual outputs like stereoscopic projections, three dimensional monitors as well as tracking systems. A high-performance graphics workstation should control all output channels and ensure the real-time capability of the overall system.

The used authoring software should support the hardware configuration. On one side the software should have an interface to the real car and on the other side should support distributed visualisation, the use of tracking system and haptic devices to achieve an immersive system.

The virtual environment should be flexible in order users or service providers can adjust the world to their needs. This means that the system should provide rich variety of training roads as close as possible to the real road network and infrastructure.

Therefore the configuration logic to be developed contains the parameters for creating streets and its proximity, the traffic, road characteristics, as well as weather situation, specific traffic

situations like traffic accidents and vehicle defects. These modules have to be simulated consistently during the operation of the system. This especially includes all road users, like motorised and non-motorised vehicles, as well as the vehicle dynamics, which has to be as realistic as possible to reach the teaching aims and ensure the value added.

The driving simulation software should be extended with a tutoring system, which evaluates the driving behaviour and creates a profile of the user. This profile documents the users learning progress and is used as a basis for the generation of new tasks for the individual driving student. The generation of individual tasks should neither overwhelm the user nor demand too little from him in order to achieve a gradual learning progress. The complexity of the tasks can be customised by using traffic density, weather conditions and road configurations, as well as providing meta data and assistance to the learner.

The management of the driving simulator and software should be possible over the network. That means that a driving simulator hardware states should be monitored and controlled from distance. The software should also be configurable over internet and allow the interaction with the simulator and its database for the different users like simulator operators, driving instructors and driving students.

## A.4 Virtual Reality Practical Course - Educational Materials

### A.4.1 Introductory Questionnaire

VRPC Pre-Interview Questionnaire	
<b>Name</b>	
Please enter your name in the form last name, first name. Answer:	
<b>Course of studies</b>	
What is your course of studies? Please select an answer. <input type="checkbox"/> Computer Science <input type="checkbox"/> Mechanical Engineering <input type="checkbox"/> business engineering <input type="checkbox"/> Other	
<b>Semester</b>	
e.g.: 4th Bachelor / 2nd Master answer:	
<b>Matriculation number</b>	
Please enter your matriculation number here. Answer:	
<b>E-mail</b>	
Please enter your e-mail address, which will be checked regularly. Answer:	

<b>What are your preferences for the practical</b>			
Please enter what you would like to learn or practice during the internship			
	Learn from	Practic	I can do well enough :D
Programming			
CAD Design and Construction (CAD wie CATIA, ProE, NX)			
3D Modelling (e.g. Blender, 3dsMax)			
Teamwork			
Multidisciplinary work			
Time management			
Project management			
<b>Do you have any further motivation and interests in the practical</b>			
Answer:			
<b>Please describe your concrete experience with programming and programming</b>			
Answer:			
<b>Please describe your concrete experience with CAD construction</b>			
Answer:			
<b>Please describe your concrete experience with 3D modelling tool</b>			
Answer:			
<b>Please describe your concrete experience with hardware, mechatronics / electronics</b>			
Answer:			
<b>Please describe your participation in projects and/or the topic of your</b>			
Answer:			
<b>Please describe your experience with</b>			
Answer:			
<b>How did you find out about the practical</b>			
Answer:			
<b>Please describe other related experiences?</b>			
Answer:			

<b>Please rate the project areas and topics.</b>						
Here you rate the areas of the projects according to personal preference (where ++ = greatest interest). We will try to fulfill all wishes if possible						
<b>Scientific project:</b>	e.g. collaborative VR, VR Space					
<b>Engineering</b>	e.g. virtual twin, IoT, Value stream analysis					
<b>Artistic</b>	e.g. VR museum					
You can find more information in the ILIAS folder "Projects".						
	++	+	0	-	--	No preference
Scientific						
Engineering						
Artistic						

### A.4.2 Timetable

Virtual Reality Practical Course WS 2016/2017

Unit	Date	Activity	Room
1	19.10.2017	<b>Overall Introduction and Demonstrations in VR-Lab</b>	062, VR Lab
2	26.10.2017	<b>Homework Presentations</b> Tasks Assignment	062
02-09.11.2017		<b>Weeks with Labs on Blender and PolyVR</b>	272.2, 060.2
3	02.11.2017 02.11.2017	<b>Presentations Homework</b> <b>Presentation of Project Plans</b>	062
4	09.11.2017	Project work	272.2
5	16.11.2017	Project work	272.2
6	23.11.2017	Project work	272.2
7	30.11.2017	Project work	272.2
8	07.12.2017	Project Work	272.2
9	14.12.2017	<b>Midterm Project Presentations</b>	062
10	04.01.2018	Project work	272.2
11	11.01.2018	Project work	272.2
12	18.01.2018	Project work	272.2
13	25.01.2018	Project work	272.2
14	01.02.2018	Project work	272.2
15	08.02.2018	<b>Final Project Presentations</b> <b>Delivery of Documentation</b>	062

Legend:

- bold** Presence in class is required
- Theoretical Introduction
- Practical Introduction
- Project Work
- Formative and Summative Evaluation

Homework Evaluation

Evaluation of Project Work and Soft Skills

Fig. A.2: Virtual reality practical course timetable for the winter term 2017/2018

### A.4.3 Immersive Technology Topics for Students' Presentations

No	Topic	Student
1	Reality-Virtuality continuum (according Milgram), Mixed Reality, Definition and Examples;	
2	Augmented Reality: Definition, technology and devices	
3	Immersion and Presence in virtual environments: definition, important factors and problems i.e. motion sickness	
4	Visual Output: Stereoscopy definition - active, passive and auto stereo approaches	
5	Visual Output: Projection Systems for VR: CAVE, Powerwall	
6	Visual Output: Head Mounted Displays, VR headsets	
7	Acoustics In and Output: Hardware (Sound Systems, Headsets, Microphones), Software, Math behind	
8	Haptics: haptic devices for touch and force feedback	
9	Interaction, Tracking Systems, head tracking work principals	
10	Interaction: Devices, Controllers/Wands for navigation and manipulation in virtual environments: i.e. Flystick, data gloves	
11	Interaction: Devices for gesture control, i.e. Myo, Leap, Kinect	
12	Interaction: Devices for simulation of walking and running in virtual environments i.e. Treadmills, Cyberwalk	
13	Creation of 3D content for VR with CAD Software Tools:such as CATIA, NX, Creo	
14	Creation of 3D content for VR with 3D-Modelling Tools: such as Blender, 3DMax	
15	Interfaces between 3D/CAD modelling; Import/Export formats (i.e. VRML STEP)	
16	VR software: Interactive Computer Graphic, Rendering and Scene Graph for 3D applications	
17	Proprietary VR Software products: Unity, TechViz, Core features	
18	Open-Source VR Software: COVISE, Instant Reality, Core features	
19	VR applications in the area of marketing, industrial design and ergonomics	
20	VR applications for virtual factory, process simulations, planning	
21	VR applications for simulations/CAx, kinds of simulations (nBody, FEM, CFD, etc.) and example applications	
22	VR applications for learning and training	
23	VR applications for entertainment	
24	VR applications in medicine	
25	AR applications	

Tab. A.1: Homework - preparation of a presentation on an immersive technology topic

## A.4.4 Project Work Evaluation



### VRPC Evaluation Sheet „Project Work“

Project name \_\_\_\_\_

Name, Surname \_\_\_\_\_

Degree course \_\_\_\_\_

#### Individual criteria for the project work:

Nr.	Criterion	Max. Points	Score
1	Fulfilment of the tasks	10	
2	Functionality of the tasks	5	
3	Creativity in the fulfilment of tasks	3	
4	Dealing with interfaces to other team members	4	
5	Dealing with problems that have occurred	5	
6	Application of scientific methods and analysis State of the art	3	
7	Time management - timely completion and submission of tasks, and consideration of the time required for the practical course.	4	
8	Reflection on motivation, learning goals and success	3	
9	External form and presentation of the documentation	3	
10	Content specifications for documentation kept	5	
11	Social skills - motivation, teamwork, discipline, independence, communication	5	
	Total score (50P):	50	

## A.4.5 Evaluation of Presentation



### VRPC Evaluation sheet "Project Presentation"

#### Collective criteria for the small group

Project Name \_\_\_\_\_

Group Name \_\_\_\_\_

Group Members \_\_\_\_\_

Collective criteria for the small group	Max Points	Current	Total per Criterion
<b>1) Project presentation (final and intermediate)</b>	<b>15</b>		
1.1 Appearance and design of the presentation	5		
- Application graphical representations	1		
- Linguistic dexterity and creativity in the presentation	2		
- Answering questions after the presentation	2		
1.2 Content requirements are fulfilled	10		
- Project goals and tasks	2		
- allocation of tasks in the group and time schedule	2		
- Solution approaches and creativity	2		
- Group interfaces and integration of the solution	2		
- outlook	2		
<b>1) Demonstrations</b>	<b>9</b>		
2.1 Confident use of VR technology	3		
2.2 General presentation of the project and functionality	3		
2.3 Answering questions about the demo	3		
<b>2) Advertising materials - posters and flyers</b>	<b>3</b>		
<b>3) Distribution of tasks during the project work and presentation</b>	<b>2</b>		
<b>4) Time requirements</b>	<b>1</b>		
<b>Video (3 bonus points)</b>	<b>3</b>		
<b>Total score without bonus</b>	<b>30</b>		
<b>Total score with bonus</b>	<b>33</b>		

## A.4.6 Feedback Sheet



### Feedback questionnaire for "Virtual Reality Practical Course"

First name, surname (optional) \_\_\_\_\_

<b>About the organization:</b>	<i>is completely true</i>	<i>is not true at all</i>
<ul style="list-style-type: none"> <li>The goals of the entire practical course and the individual events were clear to me.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>The necessary resources for the successful completion of the internship were provided to me.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>The mixture between organisational guidelines and self-organisation was just right.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>The explanations of the procedure during the first event were sufficient.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>The three phases of the internship were coherent and well planned.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<b>About the methodology and didactics:</b>	<i>is completely true</i>	<i>is not true at all</i>
<ul style="list-style-type: none"> <li>I found the overall learning strategy to be correct and adequate.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>I found the alternation between presentations and practical activities beneficial to learning process.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>The group work helped me to get to know the way of thinking of other students and thus to get a more complete overall picture.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>I found the independent preparation and follow-up activities stimulating and useful.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>I was provided with sufficient learning materials.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<b>About the supervisors:</b>	<i>is completely true</i>	<i>is not true at all</i>
<ul style="list-style-type: none"> <li>The supervisors were sovereign.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>The feedback between the supervisors and me worked perfectly.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>The supervisors were professionally well prepared.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>The explanations of the supervisors were comprehensible and easy to understand.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> <li>My questions have been sufficiently addressed.</li> </ul>	<input type="checkbox"/>	<input type="checkbox"/>

<b>About the acquired competences:</b>	
<ul style="list-style-type: none"> <li>The practical course has completely fulfilled my expectations.</li> </ul>	<p><i>is completely true</i>    <i>is not true at all</i></p> <p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p>
<ul style="list-style-type: none"> <li>I feel more confident about working in interdisciplinary groups after the practical course.</li> </ul>	<p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p>
<ul style="list-style-type: none"> <li>During the practical course, I learned to manage my time better.</li> </ul>	<p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p>
<ul style="list-style-type: none"> <li>Through the practical course, I have acquired the practice-oriented application of engineering methods.</li> </ul>	<p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p>
<ul style="list-style-type: none"> <li>The practical course has given me profound knowledge in the field of virtual reality.</li> </ul>	<p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p>
<b>Comments and suggestions for improvement:</b>	
<hr/>	

## A.4.7 VRPC Project Examples



### Virtual Reality Space

Virtual Reality Practical Course in the Summer Semester 2017

Our Solar System is composed by four terrestrial planets, four giant planets, an asteroid belt, many dwarf planets, comets and satellites (natural or not), bounded by gravitation and obeying celestial mechanics. The Sun, our closest star, is about 109 times larger and 333000 times heavier than our planet and it is the main element of our Solar System. It produces a force that keeps the planets moving around it: our planet, the Earth, is the third closest to the Sun, but it is not the only interesting planet around us.



The **VR Space Project** is a VR model of our Solar System, based on a realistic description of the outer space and developed to be used within a cave automatic virtual environment. The project is an immersive tool that allows the user to learn and travel around the planets at the same time.

From here a journey to discover the outer space starts.

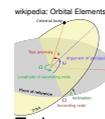
#### Planet Model

3D models, textures and some other elements' attributes are implemented, using information available from NASA and ESA and aiming for a realistic representation of the Solar System. VR Space has 9 planets, Earth's moon, the ISS, the Sun and Saturn's rings.



www.firstlearn.com/images/the-planets-and-the-solar-system.png

#### Kepler's Laws (the orbits)



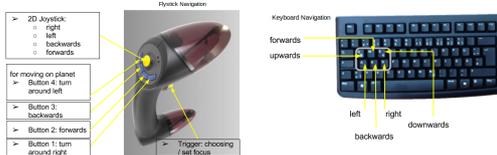
The celestial bodies are gravitational-bound to the Sun and they obey Kepler's laws. VR Space reproduces these physical laws from the planets orbiting around the Sun.

To keep a realistic feeling of the outer space, two scales were implemented: one for the distances between the planets and another for the sizes of planets. If the model scale was honest to the real space dimensions, the Earth would not be larger than a dot in the air.

#### Navigation System

##### Flystick or Keyboard

To navigate through VR Space a flystick or a keyboard is needed. It is possible to observe the objects from distance or to zoom onto them, without losing graphical details. VR space has 6 degrees of freedom (up, down, forward, backward, right or left view) available.



##### Navigation Bar and Scientific Facts

A navigation bar is presented to the user and it can be used to go from one planet to another. The user can return to an overview from all the planets and also start or stop the Solar System's animations. This menu also shows an information button, with interesting scientific facts about the observed object, allowing the user to learn more details while exploring.



#### The Team

- Navigation team: Reyhan Düzgün and Katja Benetschik
- Planets model team: Katharina Riesterer and Cornelia Schlagenhaut
- Orbits team: Celina Gödel and Genesis Perez

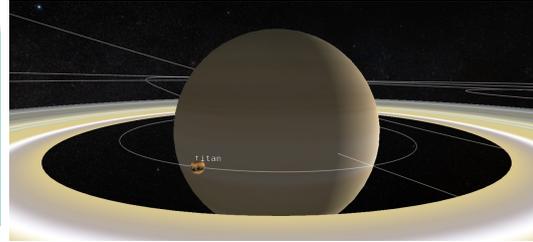


# VR Space - POI

## Virtual Reality practical course - winter term 2017/18

### Introduction

- ★ **Review:** The "VR Space" project began in the summer term 2017. A basic solar system virtual reality scene was built, including the sun, planets and their movements.
- ★ **POI: Points Of Interest** in the solar system have been chosen, along with 3D models of space objects and planets to enrich the scene.
- ★ **Goals:** Firstly, to improve upon last years project and enhance the usability with an intuitive navigation concept and better controls by removing any user interface. Secondly, to add more content and interactive features, to build a fun and immersive learning experience.



### Timeline

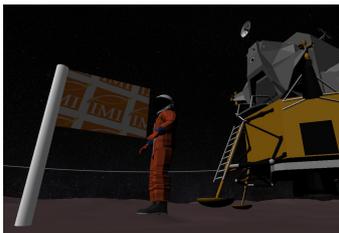
Add labels to space objects and make them "clickable"

Intuitive navigation and camera perspectives

Selecting interesting POIs and create their models

Finding information about POIs to implement the info boxes

Handle scaling issues of space

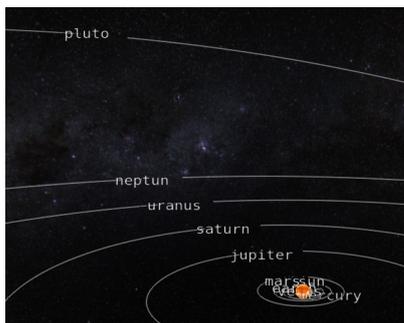


### Team Modeling and Research

- ★ **Research:** It consisted of finding interesting models and information about it, to make the user learn about the solar system while taking pleasure in it. To make it more immersive, sounds were also added to enlarge the user's experience.
- ★ **Modeling:** Models for the different points of interest have been found. Those models were taken from NASA's website and modified to make the geometry smaller in size, so they can be imported into PolyVR. A flag model was built by ourselves using Blender.

### Team Programming

The labels were modified to be easily "clickable", unifying the whole navigation concept. The planetary classes were improved upon to be more modular allowing easy future additions to the solar system and increasing maintainability and extensibility for future courses. Information boxes for the chosen POIs were implemented in HTML to add educational aspects. Custom animations and planetary configuration options were added. This allows to realistically perceive the solar system with the option to slow down planets to fully appreciate their beauty in slow motion. Finally, models were integrated into the PolyVR project.



### Summary and Outlook

- ▶ **Summary:** Users are able to navigate through the solar system and to the points of interest by clicking on labels displayed above objects. The additional content includes new 3D models but also comprehensive information boxes for the POIs. Adding sound support and customized animations for special scenes creates a truly immersive experience. The user can learn about the Solar system in an easy and fun way; an immersive learning tool was created.
- ▶ **Outlook:** Adding topography to the planet, not only using a "flat" sphere with a texture. Adding more interactivity such as animations will improve the user's experience and motivate the user to explore the solar system to find all hidden details.

### Team members

- ✓ **Programming :** David Weiß, Mark Weinreuter
- ✓ **Modeling and Research:** Hélène Cessey, Anne-Laure Gruhier, Hanfeng Zhang
- ✓ **Supervision:** Dipl.-Inf. Polina Häfner, Dipl.-Phys. Victor Häfner





# Virtual Reality Space

Virtual Reality Practical Course in Summer Term 2018

## Project Overview

The VR Space Project is a scientific model of the solar system, which includes our planets with their moons, satellites and further space objects. With the navigation system and interactive elements in the CAVE, an automatic virtual environment, a virtual space visit is to become commonplace.

Our project in the summer term of 2018 lasted 3 months. Based upon the work of the last terms, having set up the planets of our solar system including their movement, we improved the intuitive navigation, expanded the system with further space objects like moons and satellites and achieved our main goal by clearly visualizing the space debris.

This program promises to have you zooming around the cosmos as you look at the precise locations of planets, over 20 moons and hundreds of satellites in the solar system.



## Project Goal

- Simulation of the biggest moons and multiple satellites
- Implement new ISS model and Hubble telescope
- Visualize the space debris

## Project Task

- Research of data for space object simulation
- Coding and implementation of collected data
- Set up of color and textures from the Blender models



## Project Technical

- **Software**  
Blender : Create 3D models of the Hubble telescope, ISS and satellites  
PolyVR: Coding for simulation and implementation of the virtual environment
- **CAVE**  
Applicate and adjust the designed models and scenes to CAVE with 3D glasses and flystick

## Project Team

- Majors: Informatics, Industrial Engineering, Mechanical Engineering
- Team members: Guillaume Bernard, Jairo Arteta Chedrauy, Niko Benkler, Julian Marstaller, Qian Wang, Leonie Konzelmann
- Supervisor: Dipl.-Inf. Polina Häfner, Dipl.-Phys. Victor Häfner, Felix Longge Michels





# Flexible Workspaces

Virtual Reality Praktikum im Wintersemester 2017/2018

## Projektziel **„Welche Ziele haben wir uns im Rahmen des Praktikums gesteckt?“**



### Die Herausforderung

- Wir gestalten eine virtuelle Umgebung, um die Dienstleistung von Elabo sichtbar und greifbar zu machen.
- Der Mehrwert eines flexiblen Materialflusses soll auf Grundlage der „dimension“-Initiative visualisiert werden.



### Unsere Lernziele

- Interdisziplinäre Teamarbeit, in welcher einzelne Arbeitsstränge in einem Hauptresultat münden sollen.
- Kennenlernen einer Vielzahl von Methoden (z.B. Design Thinking Zyklus (siehe links)) und Tools (z.B. GitLab)



## Team Business **„Wir kümmern uns um eine runde Gestaltung der Dienstleistung.“**

### Prozesse

- Eine klare Definition des Prozesses vor und nach Implementierung der angebotenen Dienstleistung bildet die Grundlage für Verbesserungen und den Aufbau einer virtuellen Welt.



### Kosten

- Unter Berücksichtigung der vier Dimensionen (Akteure, Artefakte, Prozesse und Umgebung) werden Kosten der Situation vorher und nachher verglichen. Auf dieser Grundlage wird auch ein Preis vorgeschlagen.

Output 100 % ▲

### Risiko

- Die Implementierung des Risikomanagements vollzog sich kontinuierlich mithilfe von Issues, welche identifiziert, analysiert und zusammen im GitLab bewertet wurden.

Hauptrisiko **Markteinstieg**

## Team Modellierung **„Wir kümmern uns um eine detaillierte Darstellung der Gegenstände.“**

### Ausgangssituation

- Um die Situation vorher und nachher zu vergleichen, wird die Ausgangssituation definiert und die Raumaufteilung der Produktionsanlage dargestellt.
- Ein Produkt (Elektrischer Schaltschrank) wird ausgewählt und die Reihenfolge seines Produktionsprozesses definiert.



### Zustand mit Dienstleistung

- Modellierung neuer Objekte (mithilfe von Catia V6) und Vereinfachung einiger Dateien von Elabo (mit Blender).
- Neue Reihenfolge des Produktionsprozess in Richtung eines effizienten Materialflusses wird definiert.
- Platzierung der Gegenstände innerhalb der Raumaufteilung der Produktionsanlage, um die Koordinaten zu erzeugen.



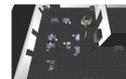
## Team Implementierung **„Wir bringen Leben in die modellierten Objekte.“**

### Umgebung

- Erzeugung einer Fabrikumgebung in PolyVR als Basis für die Dienstleistung.
- Visualisierung der Ausgangssituation eines beispielhaften Produktionsprozesses innerhalb der virtuellen Realität.
- Integration des Teams Modellierung

### Konzept

- Konzeption eines Screenplays für die drei Phasen „Ausgangssituation“, „Übergang“ und „Optimierter Prozess mit Dienstleistung“



### Implementierung

- Implementierung des Screenplays in PolyVR.
- Umsetzung der Nutzerinteraktion mittels diverser Kameras, Animationen und Steuerung durch Eingabegeräte
- Durchführung von Funktions- und Qualitätstests in der Cave.

## Das Team **„Wir sind Informatiker, Maschinenbauer und Wirtschaftsingenieure.“**

**Business** Anjela Mayer, Manuel Bauer, Pamela Lujan

**Modellierung** Benoit Samuel, Julian Knödler, Pamela Lujan

**Interaktion** Adis Heric, Anjela Mayer, Tim Schulze

**Projektleitung** Manuel Bauer

**Betreuung** Dipl.-Inf. Polina Häfner, Dipl.-Wi.-Ing. Matthes Elstermann



Quellangaben:  
- Design Thinking Zyklus: Hochschule St. Gallen  
- Logos: Webseite der Herausgeber  
- Fotos: Eigene Quelle

Alle weiteren Quellen sind am Institut für Informationsmngt. im Ingenieurwesen nachzuzufinden.



# DIE VIRTUELLE FABRIK

## AUSGANGSSITUATION

Im Rahmen des Virtual Reality Praktikums SoSe 2015 sollte eine Produktionsanlage aus einem Roboter und einer Fräse in der Virtuellen Realität abgebildet werden.

## VORGEHEN

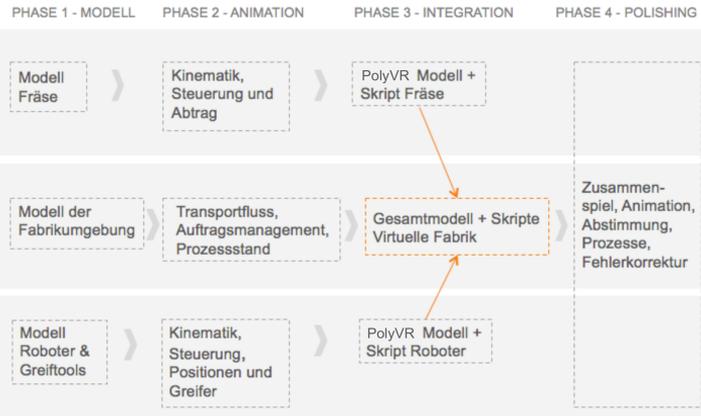
GRUPPE - FRÄSE



GRUPPE - LOGISTIK UND PROZESSE



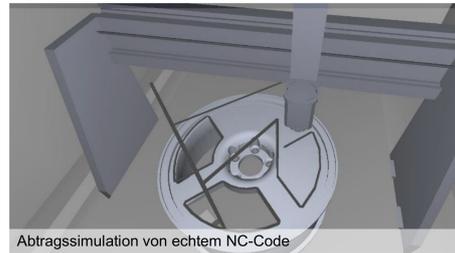
GRUPPE - ROBOTER



## ERGEBNISSE: ANLAGE AUS FRÄSE UND ROBOTER ZUR INTERAKTIVEN PRODUKTION VON ZWEI FELGENMODELLEN IN ECHTZEIT



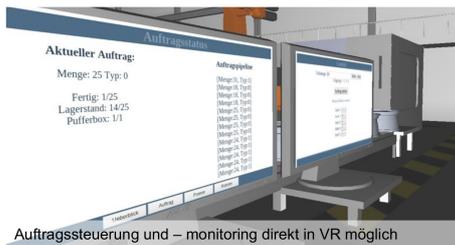
Vollautomatisierte Produktionszelle zum Fräsen von Felgen, Logistik- & Robotersimulation



Abtragsimulation von echtem NC-Code



Blick auf die gesamte virtuelle Produktionsanlage, echtzeitfähig



Auftragssteuerung und - monitoring direkt in VR möglich

### Koordination

Karlsruher Institut für Technologie (KIT)  
 Institut für Informationsmanagement im Ingenieurwesen (IMI)  
 Zirkel 2 – Geb. 20.20 (Rechenzentrum), 76131 Karlsruhe  
 Prof. Dr. Dr.-Ing. Dr. h. c. Jivka Ovtcharova

Mehr Informationen:  
[www.imi.kit.edu](http://www.imi.kit.edu)



# Virtuelle Inbetriebnahme einer Fräse

## Erstellung eines virtuellen Zwillings der Fräse Easy300mini

### DAS DRUM HERUM

#### DAS PROJEKT

##### REALE FRÄSE

- Die Fräse Easy300mini fräst eine Gravur nach vorgegebenem G-Code aus einem eingespannten Werkstück heraus
- Die Fräse sendet Metadaten in Echtzeit an die Datenschnittstelle, die daraufhin für die virtuelle Fräse aufbereitet werden und diese steuern



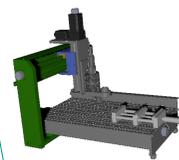
##### TABLET



- Der Nutzer kann per Tablet eine beliebige Gravur auf dem virtuellen Werkstück zeichnen
- Das Tablet sendet die Gravur an die virtuelle und die reale Fräse, um auf beiden den Fräsvorgang zu starten

##### VIRTUELLE FRÄSE

- Übertragung und Anpassung eines CAD-Fräsenmodells in *Blender*
- Übertragung der bearbeiteten Fräse in *PolyVR* (Implementierung der Kinematik und Vereinigung der Fräse mit konstruiertem Fräswerkzeug)
- Virtuelle Fräse führt realen Fräsvorgang in *PolyVR* aus



##### SCHNITTSTELLE

- Bidirektionaler Datenaustausch zwischen der realen und der virtuellen Welt

##### VISUALISIERUNG DER METADATEN

Echtzeit-Datenerfassung während des Fräsvorgangs

- Energieverbrauch
- Vorschubgeschwindigkeit
- Spindeldrehzahl
- und andere

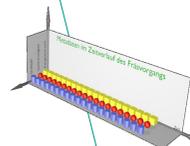
→ Visualisierung in Form von Tachometern und digitalen Anzeigen



Datenverlauf über die Dauer des gesamten Fräsvorgangs

- Veränderung des Energieverbrauchs
- Veränderung der Vorschubgeschwindigkeit
- Veränderung der Spindeldrehzahl
- und andere

→ Visualisierung in einem dreidimensionalen Koordinatensystem



- Spannende Projektarbeit in interdisziplinären Teams aus Maschinenbauern, Informatikern und Wirtschaftsingenieuren
- Bearbeitung einer interessanten, praxisbezogenen Projektaufgabe
- Eigenständige Projektorganisation und -koordination
- Und jede Menge Spaß



## A.5 MINT BOX Project

### A.5.1 Example of an assignment



Informationsmanagement  
im Ingenieurwesen



#### Reibung



#### 1. Vervollständigen des Skriptes

Mit Hilfe des Blocks „create quad patch“ (Zeichne eine rechteckige Fläche) wird die ganze Strecke generiert. Diesen Block wird benutzt um unsere eigenen Flächen zu bauen. Dieser Block hat als Eingabeparameter ein Material und die Ecken der gewünschten Fläche.

Die neu generierten Flächen müssen in die Physik eingebunden werden und beim Resetsignal zuerst entkoppelt und dann wieder in der Physik Engine eingebunden werden. Als einstellbarer Parameter bei Physik ist die Reibung.

Im Skript muss man eine neue Position und Orientierung des Autos („CAR\_start\_position\_frame“ als Target) einstellen, genau da, wo wir die neuen Flächen erstellt haben.

Damit die Motorleistung einstellbar ist, muss der Block eingebunden werden.

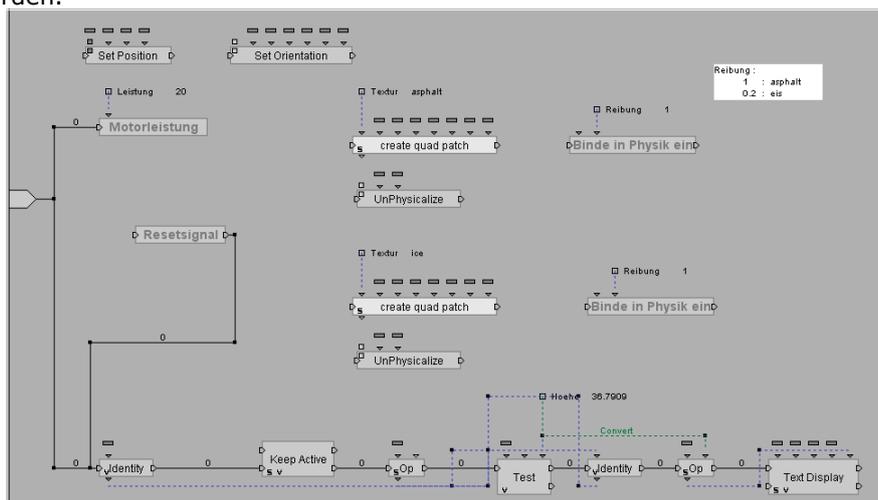


Bild1:Ausgangsskript