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Challenge the Experts: A Game-Based Knowledge Sprint in System Generation Engineering for Rapid Design Knowledge Build Up

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Abstract

In development projects, particularly those that are lengthy and complex, valuable knowledge is often lost, for example, due to staff turnover. As a result, a large share of components is carried over, yet without a clear understanding of the project context or underlying interrelations. This paper addresses rapid, early-stage knowledge build-up in a live, problem-based learning environment: the Generational Sheet-Metal Development (GSD) course, situated within Systems Generation Engineering (SGE). With five prior reference generations in place, GSD provides a rich basis for reference-system analysis and a realistic setting for method development and evaluation. Guided by Design Research Methodology and the human-centered, iterative process (ISO 9241-210), expert interviews were conducted with instructors, tutors, and students to identify 15 learning objectives (e.g., robust handle concepts, cleanability, bending stiffness). These objectives were translated into a physical, game-based knowledge sprint—Challenge the Expert—that bundles multiple hands-on challenges under one coherent game frame. Students compete as a team against domain experts who possess strong topic knowledge but are unaware of the specific challenges, creating a demanding, authentic benchmark. Each challenge operationalizes one learning objective with clear rules and scoring; for example, a bending-stiffness rig makes geometric effects directly experienceable. Objectives remain implicit during play and are assessed afterwards. The intervention was iterated in two runs: an internal rapid-prototyping trial and a course kick-off deployment. Evaluation combined a post-workshop survey with a compact, moderated retrospective. Results indicate high perceived effectiveness versus lecture-style input, strong reported transfer to subsequent design work, improved understanding of issues in earlier generations, and positive team experience. The retrospective disseminated insights across participants and surfaced additional learning content (e.g., surface structuring affecting cleanability). The paper contributes (DS1) a transferable method for developing and conducting physical, game-based learning environments for reference-system knowledge, (PS) a concrete operationalization pathway from learning objectives to challenges within an overarching game design, and (DS2) empirical evidence that such a format supports rapid knowledge build-up, intergenerational design continuity, and team cohesion in SGE contexts.

Keywords: System Generation Engineering; Gamification; Knowledge Transfer; Design Education; Sheet-Metal Design

1. Introduction

Engineering education has long been challenged by the question of how to combine rigorous technical content with formats that foster motivation, collaboration, and profound learning. Traditional lecture-based formats often fall short in conveying the dynamics of real product development processes, where time pressure, competition, and teamwork shape the outcome. In recent years, gamification has emerged as a promising approach to bridge this gap by translating abstract concepts into tangible experiences [1].

The format presented in this article adopts a game-based teaching approach, creating a high-paced learning environment where students compete directly against highly knowledgeable experts. This enables them to acquire knowledge in a condensed format playfully and enjoyably. The form of knowledge transfer aimed for here is therefore not only intended to package and convey teaching content playfully, but also to maintain the fun of teaching and create a shared positive experience for the students.

Beyond the classroom, effective knowledge transfer is also a key challenge in industrial practice. Companies frequently struggle to preserve and communicate design decisions,

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especially in iterative development cycles where reference systems serve as starting points for new generations. Lost or poorly transferred knowledge can result in inefficiencies, redundant work, or missed opportunities for innovation [2].

Against this backdrop, the paper presents "Challenge the Experts", a game-based knowledge sprint designed for the context of System Generation Engineering (SGE). The format seeks to condense the exploration of reference systems into an interactive, team-based competition, enabling students to build a deep understanding of design knowledge rapidly. By structuring the learning process into challenges, rules, and clear victory conditions, the approach not only facilitates knowledge transfer in academia but also highlights principles relevant to industrial contexts, where rapid and reliable knowledge build-up is equally critical.

2. Theoretical Background

2.1. Gamification & Serious Games

The terms 'gamification' and 'serious games' refer to concepts that are closely related, yet systematically distinct. Both of these concepts aim to utilize game principles for non-playful objectives [3,4]. It is important to note that serious games do not necessarily have to be digital; physical formats are also suitable as learning environments, and indeed represent the environments in which they originated [5]. The pursuit of knowledge and the development of skills represent the fundamental objective of serious games, which is distinct from the primary goal of entertainment [6]. Gamification, in contrast, denotes the application of game elements, principles, and models from game design to non-gaming contexts [4]. Whereas the creation of serious games generally results in the development of a distinct gaming environment, gamification involves the transformation of real-world processes into 'playable' activities through the implementation of targeted design elements. The conventional distinction between reality and play is purposefully obscured [7].

2.2. Iterative development based on the human-centered design process

The human-centered design process, as delineated by ISO 9241-210, [8] employs a consistently iterative approach, whereby design solutions are iteratively refined on the basis of user-centered evaluations.

The core principles underpinning this approach are as follows: firstly, there is an explicit understanding of users and the context of use; secondly, there is continuous involvement of users in the development process; thirdly, user-centered evaluation is a driving force; and fourthly, there is an iterative approach throughout the entire development process. [9] The following essay will provide a comprehensive overview of the relevant literature on the subject.

The human-centered design process integrates context understanding, usage requirements, design, and evaluation into an iterative process throughout the entire life cycle, thereby enabling a high degree of user centricity.

2.3. Knowledge management

Knowledge management can be defined as a complex organizational task that aims to systematically capture, store, share, and reuse knowledge. The objective is to ensure the preservation of the knowledge that has been generated and to make it available for future projects. The following essay will provide a comprehensive overview of the relevant literature on the subject. [10]

The difficulty of managing knowledge in product generation development arises from extensive component reuse combined with limited visibility into past projects, particularly within large organizations. [2]

2.4. System Generation Engineering

References have a significant impact on products and the product development process. In the concept of System Generation Engineering (SGE), the development process for new technical products, systems, or subsystems is based on reference products or systems that serve as the foundational structure. A reference system element, as part of a reference system, can be defined as a predecessor or competitor product, or a comparable source of direct inspiration on which a system generation in the SGE model is based. This approach leverages the established design and functional elements of the reference system to guide and enhance the development of new system generations. [11] Reference system elements in the model of SGE can be varied by three types of variation that are applied in the development of the system of objectives: Carryover Variation (CV), Attribute Variation (AV), and Principal Variation (PV). [12]

2.5. Live-Lab Generational Sheet-Metal Development (GSD)

The Live-Lab GSD is based on the model of SGE. Students get the CAD models and physical prototypes of the predecessors and develop their generation based on chosen reference system elements. As a master's course in Mechanical Engineering at Hamburg University of Technology, the students work in small groups designing a top heat grill out of sheet-metal parts. Before they begin their design, the students analyze the predecessors and define their reference systems elements they want to use in their design. The GSD Live-Lab serves as a research environment that allows the investigation of product engineering methods and processes in a development process that is as close to reality as possible. So the Live-Lab GSD thus combines the didactic elements of a university course with the requirements of everyday industrial development in sheet-metal design. [13]

3. Research Objectives and Design

In development projects, particularly those that are lengthy and complex, valuable knowledge is often lost, for example, due to staff turnover [10]. As a result, a large share of components is carried over, yet without a clear understanding of the project context or underlying interrelations [2]. This knowledge gap in product development must be addressed. Gamification and Serious Games have shown significantly positive effects on cognitive, motivational, and behavioral learning outcomes, making them a promising avenue for knowledge transfer [14,15]. However, there is still a lack of an established standard for the development of Serious Games [9]. This paper seeks to contribute to such a foundation by designing and evaluating a concept within the university setting of Problem-based Learning, specifically in the course "Generational Sheet-Metal Development" (GSD).

The objective of this work is to develop a physical-playful learning environment that provides participants with condensed knowledge about reference system elements from both user and developer perspectives, enabling them to build a deep system understanding in a short period of time.

To address the research objective, the following research questions are formulated according to the Design Research Methodology (DRM) [16]:

1. Research Question – Descriptive Study 1 (DS1):

What requirements exist for a physical-playful learning environment in Problem-based Learning to provide participants with condensed knowledge about reference system elements from both user and developer perspectives?

2. Research Question – Prescriptive Study (PS):

What should a method for designing and implementing a physical-playful learning environment for knowledge transfer in Problem-based Learning look like?

3. Research Question – Descriptive Study 2 (DS2):

To what extent does a physical-playful learning environment generate measurable knowledge gains for students in the context of Problem-based Learning?

The DS1 is implemented through a literature review as well as five stakeholder interviews to define requirements for the learning environment and to derive the relevant teaching content. In the PS, the requirements and learning objectives are iteratively translated into a method for designing the physical-playful learning environment, which is tested in two runs. Each run concludes with a retrospective, which also serves as the evaluation basis for the learning environment in DS2.

The course GSD serves as the research environment, following the principles of Problem-based Learning and creating a realistic development setting for student teams [13,17]. With five previous product generations available, a broad set of potential reference system elements exists from which suitable elements must be selected for the current development task.

4. Requirements for a Physical-Playful Learning Environment for Knowledge Transfer in Teaching

The analysis and compilation of requirements for a physical-playful learning environment are based on a combination of literature review, accumulated practical experience, expert interviews, and the observation of missing analyses of reference system elements in earlier iterations of the course GSD. The objective is to develop a physical-playful learning environment, called Challenge the Expert, that provides participants with condensed knowledge about reference system elements and thereby fosters a deep system understanding.

4.1. Literature-Based Requirements

The most important requirements for a physical-playful learning environment are derived from approaches in Game-Based Learning and Gamification. For the design, requirements from both areas are combined to ensure not only the didactic effectiveness of the game elements but also the motivation of the participants.

The human-centered design process, according to ISO 9241-210 [8], provides the methodological framework. Accordingly, the usage context of a physical-playful learning environment must be explicitly understood. Moreover, participants should be embedded in a continuous, iterative development process with feedback and evaluation. Essential elements of this process include rapid prototyping and early testing of the physical-playful learning environment, as well as consideration of the overall learning experience.

Gamification follows didactic principles centered on motivation and autonomy. Incorporating the *four freedoms of play* (freedom to fail, experiment, assume roles, and effort) [18], a total of 12 requirements were derived to ensure the environment fosters profound learning through self-directed effort.

4.2. Practice-Based Requirements and Learning Objectives from Expert Interviews

In addition to the literature, expert interviews were conducted with lecturers, tutors, and students of the course Generational Sheet-Metal Development (GSD). These interviews yielded 15 learning objectives with varying degrees of relevance for design. Examples include the carrying concept with suitable handle positioning and sufficient stiffness for safe and ergonomic transport of the top heat grill, cleaning friendliness through easily accessible and simple-to-clean surfaces, as well as the influence of geometry on the bending stiffness of sheet metal, for instance, through flanges.

Furthermore, the relevant reference system elements of previous system generations were identified and classified into the categories "bug" or "feature", indicating whether they should be considered disruptive or beneficial for subsequent system generations.

From the practical testing of the physical-playful learning environment, clear requirements for effective implementation emerged. These include the introduction of retrospectives for reflection and knowledge sharing, a strong team orientation to foster group cohesion and collaboration, and time limitations to maintain attention and performance levels.

Finally, the reduction from 15 to 7 learning objectives resulted from a selection process driven by high design relevance and time constraints. Only learning objectives that could be successfully operationalized into tangible, short-duration challenges were retained to ensure maximum impact within the limited workshop time. Examples include the design of robust and ergonomic handles as part of a well-considered carrying concept for the top heat grill, user-centered cleaning friendliness, and hands-on experience of sheet metal bending stiffness.

4.3. Conclusion

The requirements for a physical-playful learning environment are diverse and combine methodological, didactic, and practice-oriented aspects. These were derived from literature, expert knowledge, and practical insights, and they form the starting point and guideline for the subsequent development and implementation of a physical-playful learning environment for knowledge transfer about reference system elements in the context of Problem-based Learning.

The identified learning objectives reflect the relevant requirements and constitute the foundation for both the design and evaluation of the learning environment.

5. Method and Implementation of a Physical-Playful Learning Environment for Knowledge Transfer on Reference Systems

The development method for the physical-playful learning environment Challenge the Expert is based on an iterative, user-centered approach in which implementation itself is embedded as an experimental step within the development cycle.

To create a physical-playful learning environment for GSD, a method is required that consistently prioritizes learning objectives and involves students in such a way that they, as the primary target group, both rapidly acquire a deep understanding of reference system elements and, as an evaluative instance, significantly shape the iterative refinement of the environment through their feedback. Inspired by the human-centered design process according to ISO 9241-210, the method is structured into seven steps.

The methodological framework (Figure 1) highlights the interlinked dual structure of development method and process design. The method is fundamentally iterative to ensure a high degree of user-centeredness and to address the dual role of students as learners and evaluators. The aim is to foster a profound understanding of reference system elements from both a user and a developer perspective. To this end, learning objectives derived from the interviews are transformed into clearly defined, gamified challenges. The overarching game concept integrates all challenges into a coherent format, *Challenge the Expert*, which establishes a transparent point system and defines explicit win conditions between students and experts.

Experts are highly knowledgeable individuals with extensive expertise in the addressed subject matter. They are not familiar with the specific challenge or the exact wording of the learning objective, thereby creating a demanding and realistic counterpart for the students. In addition, a motivating, team-oriented setting is established.

The actual implementation of the format follows the process model shown in figure 1. After a short introduction, the individual challenges are presented and volunteers selected. Students then compete together as a team against the expert team. Each challenge awards points, which are tracked throughout the game. At the end of each session, a moderated retrospective takes place to reflect upon experiences and insights. A questionnaire measures individual learning outcomes and provides input for improvements.

An exemplary challenge in *Challenge the Expert* involves estimating the correct bending stiffness of different handle geometries: a flat sheet, a right-angled bend, and a flanged variant. In this way, the relationship between geometry and bending stiffness is conveyed through play. Figure 2 illustrates the transition from conceptual design to realized prototype to actual use in the learning environment.

A clear game mechanic governs implementation: Teams alternately place weights to reach a target deflection, determined by a buzzer race. Winning two out of three rounds secures the challenge. This combines a clear target with immediate feedback, translating theoretical bending stiffness knowledge directly into a tangible experience. The exemplary challenge illustrates the transformation of a learning objective into a gamified task and underscores the tight coupling between development method and implementation.

The developed method was tested in two runs with 18 and 5 participants, respectively. Implementation represents an integral part of the iterative cycle, as observations and reflections are reintegrated into the refinement of the game concept and the fine-tuning of individual challenges.

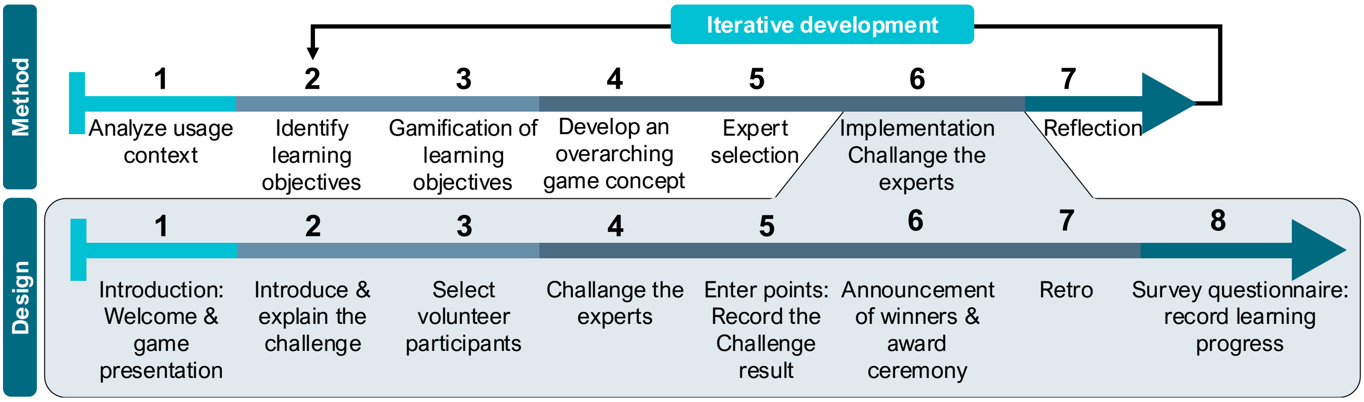

Figure 1: Preparation method and implementation

This chapter presents a transferable process model that systematically translates learning objectives into playable tasks, consistently engages students, and firmly embeds reflection and evaluation into the sequence. Figure 1 consolidates the core steps and demonstrates the link between the method and concrete implementation.

Figure 2: Transition from design to prototype and application. (Top: model of test bench, left: CAD, right: 3D print; bottom: implementation).

6. Effectiveness of a Physical-Playful Learning Environment for Understanding Reference Systems in Higher Education

This chapter examines to what extent *Challenge the Expert* fosters deep system understanding. Evaluation is based on a moderated retrospective and a post-session questionnaire completed by students immediately after the session to assess specific learning objectives.

During the reflection, active and observing participants exchange their experiences and perceptions using the format *What – So What – Now What*. Insights are consolidated and prioritized, recorded on Post-its, and then used as a basis for discussion. In addition, participants reflect on their personal takeaways and engage in open dialogue.

The learning objectives, which are deliberately addressed implicitly during the session, are systematically assessed in the subsequent questionnaire. The questionnaire measures the participants perceived knowledge gain regarding reference system elements from both developer and user perspectives. It also captures the overall impression of the event.

Figure 3 presents the aggregated responses to the following statements:

- S1: Learned more than a lecture
- S2: Understood legacy design issues
- S3: Transfer to future design decisions
- S4: Overall workshop experience
- S5: Handle position and build influence load behavior
- S6: Handle geometry affects bending stiffness
- S7: Cleanability matters for user experience
- S8: Grease-tray mounting affects user experience
- S9: Locate heat spots and their material effects
- S10: 3-point vs. rail guidance understood

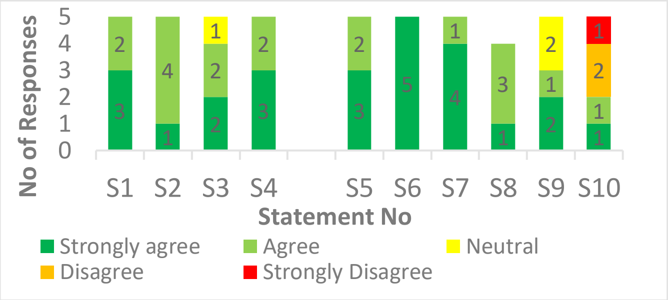

Figure 3: Survey results from second run
([S1-S4]: overall impression, [S5-S10]: learning objectives)

While Figure 3 evaluates the six explicit technical learning objectives, the seventh objective aimed at reducing hesitation to interact with reference artifacts was validated through direct observation. Since physical handling of the components was a prerequisite for participating in the challenges, this objective was achieved implicitly through the game mechanics itself. Respondents reported learning more than in a purely lecture-based format, perceiving a clear practical relevance, and experiencing teamwork as beneficial. The influence of handle geometry on bending stiffness, for example, was unanimously reported as well understood. Other aspects, such as handle positioning and construction contributing to load-bearing behavior, or cleaning friendliness, were also well comprehended. Only the understanding of three-point guidance vs. rail guidance of the grillage showed potential for improvement, because advantages and disadvantages were hard to differentiate so they focused more on overall handling.

In the free-text responses, participants expressed a concrete wish for an extended quiz phase, justified by the high level of enjoyment experienced during the interactive sequence.

7. Discussion

7.1. Insights from the Retrospective

The retrospective enables both active and observing participants to consolidate knowledge, ensuring a comparable learning level regardless of involvement. By exchanging direct experiences with external observations, the format effectively bridges the gap between different roles. It also surfaced previously overlooked learning objectives, such as the negative impact of hexagonal structures on surface cleanability, which emerged only through joint reflection. The applied *What–So What–Now What* format proved effective for prioritizing insights with minimal time investment, while simultaneously fostering team cohesion.

7.2. Insights from the Questionnaire

The survey results (Fig. 3) confirm the successful translation of learning objectives into challenges. High approval ratings regarding technical understanding and workshop experience validate the effectiveness of gamification compared to classical theoretical input. Free-text responses reinforced this positive reception, with a specific wish for an extended quiz phase, indicating high motivation for deeper engagement within the gamified framework.

8. Conclusion and Outlook

This paper presented the development and evaluation of a physical-playful learning environment, embedded in the *Challenge the Expert* format, to foster deep understanding of reference system elements. By combining gamified challenges within an overarching competitive framework, the approach successfully linked knowledge transfer with knowledge generation. Evidence from retrospective reflection and survey data confirmed not only measurable knowledge gains compared to traditional teaching formats but also strong motivational effects, enhanced collaboration, and sustained learner engagement. Specifically, the study answers the research questions as follows:

The Descriptive Study 1 identified that a physical-playful learning environment requires user-centered design balancing didactics with motivation. Key requirements include a strict structural framework and a moderated retrospective to consolidate individual experiences into shared group knowledge.

The Prescriptive Study yielded a seven-step method tightly coupling development and execution to translate learning objectives into the competitive 'Challenge the Expert' format. This iterative approach ensures that execution insights directly inform continuous refinement.

The Descriptive Study 2 confirmed substantial knowledge gains regarding reference system elements. Consequently, students rated the format's effectiveness significantly superior to traditional lecture-based teaching.

The results underline the potential of a physical-playful learning environment beyond engineering education. In industrial product development, similar formats can accelerate onboarding and support the transfer of implicit knowledge across product generations. By systematically translating design knowledge into challenges, the approach bridges gaps between users and developers in real-world projects. Future work should therefore investigate scalability, digital integration, and long-term knowledge retention. Ultimately, adapting the format to industrial practice demonstrates that physical-playful learning environments are not peripheral but can become core instruments in shaping how knowledge is created and sustained in engineering.

From an engineering design research perspective, the contribution lies in a transferable methodology that enables developer teams to rapidly adopt the user perspective, facilitating the acquisition of deep system understanding from multiple viewpoints within a compressed timeframe. By physically experiencing product behaviours and functional limitations, engineers achieve a depth of comprehension that surpasses theoretical study, directly linking design decisions to user experience. Future investigations will focus on quantifying the specific time savings of this approach compared to traditional onboarding to validate its efficiency for the industry. Additionally, research should extend to the broader engineering design curriculum to evaluate whether such physical-playful learning environments sustainably enhance overall learning quality and design competence.

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