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# Personalized and Demand-Based Education Concept: Practical Tools for Control Engineers ⋆

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**Abstract:** This paper presents a personalized lecture concept using *educational blocks* and its demonstrative application in a new university lecture. Higher education faces daily challenges: deep and specialized knowledge is available from everywhere and accessible to almost everyone. University lecturers of specialized master courses confront the problem that their lectures are either too boring or too complex for the attending students. Additionally, curricula are changing more rapidly than they have in the past 10–30 years. The German education system comprises different educational forms, with universities providing less practical content. Consequently, many university students do not obtain the practical skills they should ideally gain through university lectures. Therefore, in this work, a new lecture concept is proposed based on the extension of the just-in-time teaching paradigm: Personalized and Demand-Based Education. This concept includes: 1) an initial assessment of students' backgrounds, 2) selecting the appropriate educational blocks, and 3) collecting ongoing feedback during the semester. The feedback was gathered via Pingo, ensuring anonymity for the students. Our concept was exemplarily tested in the new lecture "Practical Tools for Control Engineers" at the Karlsruhe Institute of Technology. The initial results indicate that our proposed concept could be beneficial in addressing the current challenges in higher education.



*Keywords:* Higher Education, Changing Society, Graduate Students, Control Engineering, Model Predictive Control

## 1. INTRODUCTION

Higher education plays an important role in shaping the skills and competencies of future professionals, driving innovation, and advancing our society. However, it is confronted by many challenges that can undermine its impact and relevance: see Oprean et al. (2011) or Gürdür Broo et al. (2022). The vast availability of specialized knowledge is among these challenges, which (while democratizing information access) leads to information overload and heightened competition among institutions to provide distinctive and impactful education. In the age of generative artificial intelligence, lecturers and university professors are confronted with the task of not only delivering content but also ensuring that their teaching remains relevant and engaging in an environment where information is readily accessible to everyone.

In addition to technological advancements, there is a growing concern regarding the attention spans of young students Bunce et al. (2010); Bradbury (2016). Maintaining student engagement is increasingly difficult, as distractions are plentiful, and students often prefer interactive and multimedia content over traditional lecture formats Schwerdt and Wuppermann (2011). Consequently, university lectures must add significant value compared to online tutorials or prerecorded lecture videos to justify students' time and effort in attending them. Furthermore, monotonous lectures can easily lose students' attention, while overly difficult content lowers motivation. Academic programs now evolve rapidly to keep pace with technology, industry demands, and emerging fields. Consequently, flexible, innovative teaching methods are crucial for meeting changing educational needs and student expectations, see Rossiter et al. (2023).

Within the German education system, the diversity of educational formats[1] offers a range of pedagogical approaches. Universities often prioritize theoretical teaching

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[1] These include *Universitäten, Hochschulen und Duale Hochschulen*, which can be translated as research universities, Universities of Applied Sciences, and Dual Universities of Cooperative Education. For more information, the reader is referred to German Higher Education (2024)


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content at the expense of practical training. This prioritization can lead to master's and doctoral students frequently having difficulties transitioning from the academic world to working in industry. This is due to university curricula often focusing on theoretical problems, which results in graduates who – despite possessing deep theoretical understanding – lack the hands-on experience necessary to apply their knowledge effectively to real-world problems.

Addressing these challenges requires a paradigm shift in lecture design and delivery, which is also the goal of the Technical Committees of the IFAC and IEEE societies; see Rossiter et al. (2019, 2023); Visioli (2023). Therefore, this paper proposes a personalized lecture concept that uses *educational blocks* to tailor content to individual student needs. Based on the Just-in-Time Teaching (JiTT) paradigm, our proposed Personalized and Demand-Based Education (PDBE) concept aims to enhance lecture engagement and efficacy by customizing content delivery based on graduate students' backgrounds and ongoing feedback, focusing on practical topics relevant for industry applications.

Our PDBE concept comprises three key components: (1) an initial evaluation of students' backgrounds to understand their prior knowledge, (2) the selection of appropriate educational blocks that align with both curricular objectives and individual student profiles, and (3) the continuous collection of feedback throughout the semester to adjust and refine the teaching approach dynamically. To facilitate anonymous feedback, we use the Pingo platform hosted by Karlsruhe Institute of Technology (KIT), which ensures student anonymity and encourages candid responses. We implemented our novel PDBE concept in the *Practical Tools for Control Engineers* [2] course at the KIT. This application served as an exemplary case to test the efficacy of our framework in a real-world educational setting.

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature on JiTT paradigms and personalized education concepts. Section 3 details the methodology of our study, including the implementation of the proposed concept. Section 4 presents the results of our preliminary findings, while Section 5 discusses the implications and limitations of these results. Finally, Section 6 concludes the paper and outlines directions for future research.

## 2. THEORETICAL BACKGROUND

Due to recent challenges, many engineering educators struggle to keep pace with industry demands and interdisciplinary competencies (Oprean et al. (2011); Gürdür Broo et al. (2022)). Therefore, recent research focuses on improving teaching methodologies in higher education, particularly in engineering and technology domains. This section gathers the most applicable work for this paper into two groups, providing a concise literature overview.

### 2.1 Just-in-Time Teaching Concepts

One such innovative approach is the JiTT, a pedagogical strategy that synchronizes pre-class preparation with in-class activities (Cheng and Xu (2020); Fox and Doherty (2021)). Students complete brief assignments online before coming to class, allowing instructors to adapt the upcoming session based on the submitted work. This method fosters active learning by addressing misconceptions and knowledge gaps immediately (Jonsson (2015); Perez-Poch and Lopez (2017); Fukuda et al. (2024)). It also encourages students to stay engaged, as they see that their contributions shape the class activities. By shifting part of the content delivery and assessment outside the classroom, JiTT opens up valuable face-to-face time for deeper exploration (Tucker and Griffin (2017); Gupta and Lee (2021)). Effective JiTT implementation can improve student motivation and performance, as demonstrated in computer science fundamentals (Perez-Poch and Lopez (2017)). The literature suggests that JiTT helps maintain students' attention and motivation, especially when used alongside interactive classroom strategies like group work or live simulations.

### 2.2 Personalized, Practical and Competence-based Teaching Concepts

In parallel, personalized or demand-based education concepts highlight that students enter courses with varying backgrounds, skills, and learning styles Smith et al. (2019); Peter and De Vries (2018). The theoretical foundation of personalized education suggests instructional blocks and content sequencing should adapt to each student's prior knowledge, emphasizing differentiated instruction and scaffolding where necessary. Research indicates that combining personalized lecture content with regular students' feedback better aligns curricular goals, enhancing comprehension and retention of core concepts Claros and Duart (2021); Chang et al. (2022). Personalized and Practical approaches are particularly valuable in fast-evolving fields such as control engineering, where technologies and methodologies develop rapidly (Orr et al. (2022)).

A consistent finding across studies emphasizes the critical role of practical, hands-on experiences for developing problem-solving skills alongside theoretical understanding (Alonso et al. (2019); Bogunovic and Theis (2022)). Project-based learning, simulation labs, and real-world case studies are frequently cited as effective methods to bridge theory-practice gaps. These approaches gain additional potential when they are coupled with adaptive feedback systems that helps instructors to analyze student performance in virtual labs or mini-projects Umezawa et al. (2018); Makransky and Petersen (2019), subsequently adjusting content delivery, scheduling correction, or providing alternative resources. For broader perspectives, see comprehensive reviews in Rossiter et al. (2018, 2023).

The "community roadmap" Rossiter et al. (2023) outlines how evolving societal priorities—including sustainability, infrastructure development, and digital transformation—necessitate broadening research agendas, training programs, and flexible course architectures. It further advocates for novel learning formats (e.g., modular content, micro-courses) to address complex societal challenges.

Building on this literature review, this paper proposes an adapted implementation of the JiTT framework for graduate control engineering education at a German uni-

[2] The lecture website is available at `https://www.irs.kit.edu/english/Lectures_4827.php`.

versity, designed to prepare students for real-world engineering problem-solving including software engineering components. The proposed concept uses education blocks similar to the learner-centric design principles Claros and Duart (2021).

## 3. THE PERSONALIZED DEMAND-BASED EDUCATION CONCEPT

This section introduces the personalized sets of education blocks for our proposed PDBE concept, which are divided into two main categories: *Software Tools* and *Control Tools*. The exemplary components for the first implementation during the semester are given in Fig. 1. The students' feedbacks guide the selection of these educational blocks, ensuring that most of the students receive content tailored to their background. The usage of these two main blocks are justified by the literature indicating the benefit of the competence-based teaching concepts. Thus, through this concept, control engineering students can gain a foundational set of tools to effectively solve industry-relevant control and systems engineering problems.

### *3.1 Demand Identification and Implementation*

Central to our approach is a demand identification using Pingo Questions at the lectures, which is feedback procedure that tailors lecture content.

1 **Preliminary Student Assessment:** At the beginning of the course, students participate in a needs assessment through a questionnaire focused on their prior experience with software tools and control theory. This initial assessment affects our instructional approach, allowing us to provide targeted support and ensure that the course content is both accessible and engaging for all students.
2 **Identification of Knowledge Gaps:** Using the questionnaire results, the instructor has to determine which software or control topics are most relevant for students. Some of them may need extra time on coding basics, while others might benefit from more advanced control material.
3 **Selection of Education Blocks:** A customized selection of software and control blocks happens based on the identified students knowledge gap. This ensures lectures remain engaging for most students despite of the varying backgrounds.
4 **Continuous Semester Feedback:** After each block, students submit anonymous feedback on the lecture. The instructor uses this information to clarify confusing points or add examples in subsequent sessions. Future content is adjusted to address their needs, making the learning process flexible and responsive.

In the upcoming subsection, the necessary tools are presented.

### *3.2 First Educational Block: Software Tools*

Students first explore essential software and programming topics central to modern control engineering. The focus lies on writing clean, maintainable code, using version control to manage collaborative work, and understanding how to apply different programming languages or development

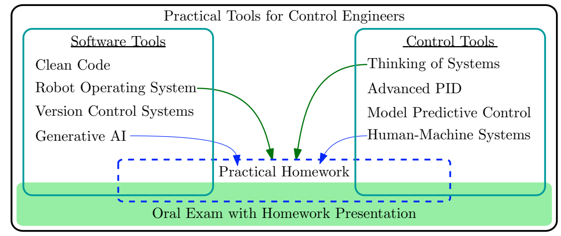



Fig. 1. The educational blocks of the lecture *Practical Tools for Control Engineers* as the current implementation of our PDBE concept

environments. For instance, Python is emphasized for its readability and extensive library support, while C/C++ or MATLAB may be chosen for performance-critical tasks or advanced mathematical modeling.

Students additionally learn simulation and design techniques that enable them to verify control strategies and optimize system parameters before real-world deployment. Through practical mini-examples – such as simulation of robotic applications and simple industrial processes – students discover how these tools integrate with real-world control engineering tasks. The goal is to establish reliable software foundations, empowering learners to confidently select and apply appropriate technologies in diverse scenarios.

### *3.3 Second Educational Block: Control Tools*

Once students acquire the necessary software skills, they continue with practical control topics covering advanced Proportional Integral Derivative (PID) controller and Model Predictive Control (MPC).

Since PID controller is still relevant for most of the industrial applications, its extensions were presented (Anti Wind-Up, Smith Predictor, MIMO PID). Model Predictive Control (MPC) is introduced in simplified linear form, demonstrating how stability concepts and constraint handling operate through simulation examples. Students also examine human-robot interaction systems where control strategies must ensure safety and efficiency.

### *3.4 Implementation of the Proposed Concepts in the Practical Tools for Control Engineers Lecture*

The software and control tools discussed in the previous subsections belong to competence-based teaching methods. By using student feedback for personalization, we managed to increase student engagement during lectures. Furthermore, we used the interactive Pingo tool to provide an additional value to our work, which are presented in the following subsections.

*Engagement and Motivation Tools*
The Pingo system was utilized to conduct short, in-class quizzes throughout the course. These quizzes provided students with opportunities to test their understanding of newly learned concepts. Similar to the JiTT approach, by providing immediate feedback on knowledge gaps, we could address misconceptions and areas of confusion promptly. This real-time feedback enabled identification of topics requiring further clarification, allowing subsequent lecture adjustments. To increase engagement of these activities, extra credit for the exam could be collected. To

| Range (Lines of Code) | Occurrences |
|---|---|
| 0–100 | 4 |
| 101–1000 | 4 |
| 1001+ | 5 |

Table 1. Answers for the question *How long was your longest project?*

ensure anonymity, all in the Pingo test participating students received these bonus points if 66% of them answered 66% of the questions correctly.

*Additional Implementation Considerations*
In addition to quick quizzes, we included presentations of practical research projects, see e.g. Varga et al. (2023a). These sessions showcased our institute's research initiatives, emphasizing the practical relevance of lecture content. Specifically, projects focused on developing advanced human-machine interaction systems demonstrated real-world applications of theoretical concepts, see Kille et al. (2024).

*Considerations for the Homework*
Students were required to complete a comprehensive homework assignment as a prerequisite for the oral exam. To simulate real-world experiences, they faced challenges typical of open-source projects, including software installation difficulties[3]. For this task, the students developed model predictive controllers suitable for modeling human-machine interactions using the framework presented in Varga et al. (2023b).

## 4. RESULTS

For the first time, the course "Practical Tools for Control Engineers" was offered in the winter term 2024/25 at KIT. It was attended regularly by 18–22 students throughout the semester, which consisted of 15 weeks of 1.5-hour lectures. The course was organized into three parts: a 6-week software tools block, a 7-week control tools block, and a 2-week block dedicated to preparing for homework and the exam. The following presents the questions raised during the first lecture along with the students' answers.

Q1 How long was your longest project? (lines of code)
A1 Table. 1
Q2 Which Programming Languages do you know?
A2
- · Python (12)
- · Matlab (9)
- · C (7)
- · C++ (5)
- · C# (2)

Q3 In what kind of applications have you used your programming knowledge?
A3 Table 2
Q4 With how many peers have you worked together (number of project members, open-source vs. private projects)?
A4 Fig. 2

Students' background identification showed that they have some relevant experience working in a team and handling larger code bases. On the other hand, some of them have never worked in a team and have only a little coding experience. This heterogeneous background had to be taken into account during the fine-tuning of the lecture content.

[3] While tools like ROS2, Python, and CasADi are well-documented, students encountered common issues such as dependency conflicts and platform-specific configurations.

| Group | Count |
|---|---|
| Web-development | 4 |
| Microcontroller | 7 |
| Control tasks | 10 |
| Simulation | 2 |
| Autonomous driving | 1 |
| AI-Tooling/Database | 10 |
| Robotics | 2 |

Table 2. Student Background on applications

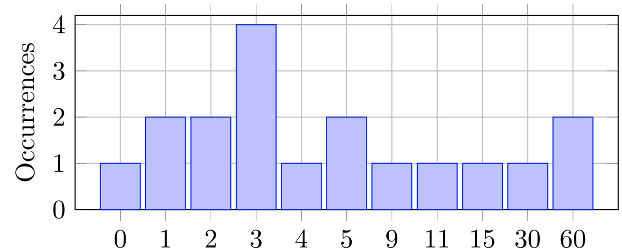



Fig. 2. Background Information: Answers for *With how many peers have you worked together (number of project members, open-source vs. private projects)?*

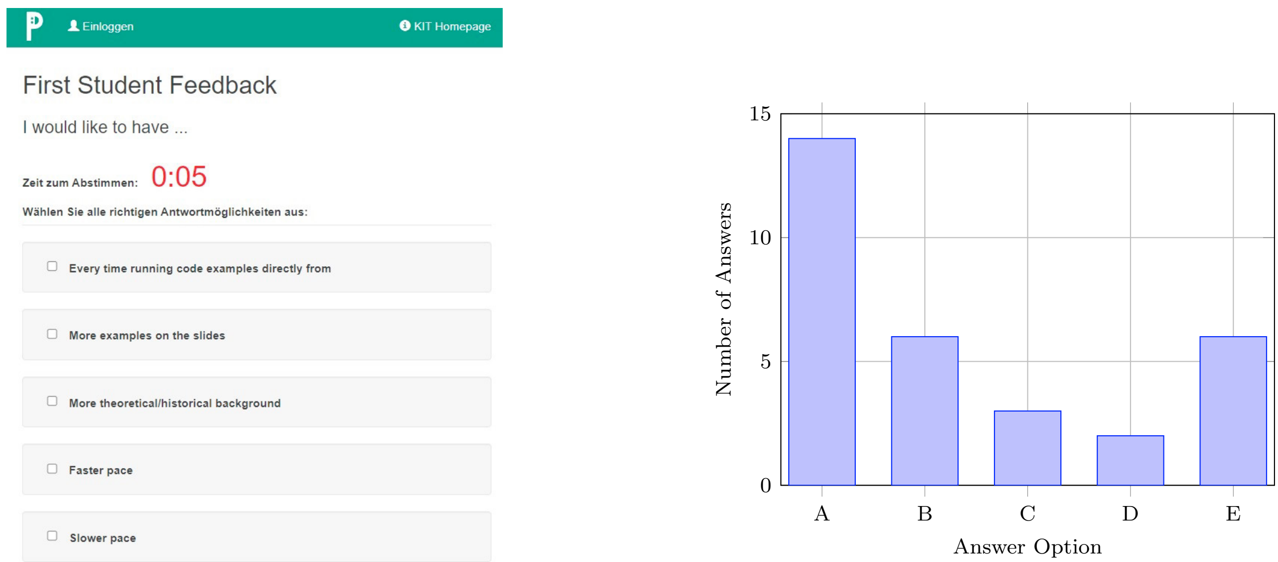
Fig. 3 shows the students' Pingo results and the outcome of a feedback question. It turned out that they preferred to carry out the example codes together during the lecture instead of doing them as after-class assignments. This feedback was taken into account during the semester, and dedicated time slots were planned for carrying out the lecture examples and demonstrating the working principles of the code examples.

During the semester, seven in-class mini quizzes were conducted. Only the students who engaged in lecture-to-lecture learning during the semester could answer them. Only once, 66% of the questions were answered correctly by 66% of the participating students, indicating that most students did not prepare for the lectures.

Evaluation Office of the Quality Management Department at KIT offers a central teaching evaluation, which provides a standardized feedback system for lecturers. "The teaching evaluation at KIT enables students to anonymously provide feedback on courses. Each evaluation questionnaire includes six mandatory questions, which are used to calculate the Teaching Quality Index for a course. The questions include

- the evaluation of the content of the course,
- the evaluation of the teaching quality of the full-time and part-time lecturers,
- the assessment of the organization and supervision of the course
- the assessment of student commitment in connection with the course,
- the assessment of the infrastructure,
- the overall assessment of the course.

The lecture achieved above-average results, which indicate the relevance and the suitability of the applied PDBE concept.




(a) Student Feedback Question Round Using Pingo Hosted by KIT

(b) Feedback results: *"I would like to have..."*
A: Code execution every time B: More slide examples
C: More theory/history D: Faster pace E: Slower pace

Fig. 3. Pingo view of the student questionnaire (left side) and the results (right side) indicating that the presentation of the code examples in the previous lectures was not sufficient

## 5. DISCUSSION

The main limitation of our concept was the limited resources during the preparation of the lecture. Since the education blocks were not prepared for all possible scenarios, they had to be extended during the semester to respond in accordance with the students' feedback. Furthermore, there is no baseline for our results. Comparing different lectures does not provide a sufficient benchmark for rigorous evaluation. Consequently, additional structured studies are needed to identify best practices and consolidate consistent data.

We also did not fully address the question of scaling the concept to larger classes. Our current findings are confined to smaller groups, and significant adjustments in resources and infrastructure would be required to confirm its feasibility and effectiveness on a larger scale.

We are planning to address these limitations. Furthermore, the question of how the practical implementation of more advanced mathematical concepts, like Varga et al. (2021); Varga (2024), could be integrated into a seminar-like extension of our current lecture will be answered.

## 6. CONCLUSION

This paper presents the application of a novel educational concept, Personalized and Demand-Based Practical Education, utilizing educational blocks to enhance lecture engagement and effectiveness. Furthermore, we apply the concept to the new lecture Practical Tools for Control Engineers at the KIT. The preliminary results showed that the concept is applicable to a lecture at a university and is accepted by the students.

In our future work, a) we aim to adapt the concept for seminar-based courses, which can emphasize more interactive and discussion-oriented learning over traditional lectures. Furthermore, we are planning to include additional transportation research topics, like e.g. platooning HasanzadeZonuzy et al. (2018) or automotive sensor fusion algorithms Lindenmaier et al. (2022). Seminars and additional research topics can better prepare students for practical laboratory work at our institute by developing essential skills like problem-solving and collaboration.

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