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BUILDING AGILE PRODUCT DESIGN COMPETENCES IN STUDENT PROJECTS

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ABSTRACT

The increasing complexity of technical solutions caused by constantly changing requirements and competitive situations, has led to the introduction of agile development processes in various domains in order to be able to react faster and more efficient to changes. This paper explores the integration of agile aspects into engineering education to prepare students for the corporate world. Two approaches, a single-stage and a two-stage approach, were implemented and evaluated in student projects at Technische Hochschule Ulm and Technische Universität Ilmenau. The findings reveal that both approaches effectively enhance students' competencies in agile product development. The observations highlight the value of iterative sprints, design thinking, peer learning, focused work, stakeholder involvement and the application of digital tools. Students exhibited increased confidence, independence, and creativity in their development projects. The integration of agile approaches in teaching methodologies proves beneficial in addressing the challenges posed by complex technical solutions and evolving requirements.

Index Terms – Teaching, Agile, Product Development, Competences

1. MOTIVATION

Constantly increasing requirements from different stakeholders and intensifying competitive situations lead to the development of more and more complex technical solutions, encompassing keywords such as digitization, connectivity, sustainability, automation, autonomation, user-centricity, time-to-market, collaboration and innovation, etc. The growing complexity also implies that stakeholders are unable to fully specify precise requirements and boundary conditions at the beginning of the development process. Additionally, there are numerous uncertainties during development, including technical implementation and ensuring the required product properties. Dealing with uncertainties is becoming increasingly important. In light of these challenges, agile development processes, which allow flexible responses to changes, are gaining importance in the industry. In this context, SCRUM [1] in particular plays an important role as a very frequently used framework for team collaboration and organization. Originally utilized in software development [2], agile approaches are now increasingly applied in other domains [3–5]. Agile development occurs in iterative cycles commonly referred to as "sprints". Within each sprint, only pre-selected requirements and boundary conditions, which depend on predefined development goals and may also be subject to uncertainty, are addressed by the development team. At the end of each sprint, a significant improvement in the maturity of the solution respectively a potentially releasable increment should have been achieved, which can be evaluated, for example, by using prototypes. The current state of the solution is then in the frame of a sprint review discussed with various stakeholders as part of a sprint review in order to incorporate their experiences and views as a basis for subsequent sprints. In this way,

the increment or development progress can be monitored and the development backlog can be reassessed. Potential users can thus provide early feedback (expectation comparison/matching), and knowledge about the current solution can be gradually refined and expanded. The aforementioned approach can also be accompanied by a sprint retrospective, which enables adjustments or improvements for upcoming sprints based on self-reflection.
In the context of engineering education, method-based systematic product development already plays a crucial role in preparing students for the increasingly complex corporate world. Given the growing importance of agile development, the aim is to integrate agile aspects as immanent components of consecutive teaching. Currently, training on development methodologies often focuses on the main process steps (task specification, concept synthesis, design, etc.). However, students often misunderstand the required sub-steps and their intermediate results as a strict chronological task list. This misunderstanding can be addressed through targeted adaptations in teaching towards agile development.

2. OBJECTIVE OF THE PROJECT AND THE CONTRIBUTION

Given the aforementioned requirements, it is necessary to explore approaches for developing competencies in agile product development in engineering education. Agile product development is a current research topic, and there are currently no established approaches that can be directly applied to teaching. This is especially true in the field of systems engineering. Many agile approaches originate from software development and must be adapted and, if necessary, expanded for interdisciplinary product development. Furthermore, the more method- and tool-oriented competence development must be expanded to include framework conditions, restrictions and procedures for agile product development. This requires targeted integration into the curricula, taking into account the specific conditions of the respective university.
Against this background, various approaches to competence development in agile product development were applied and evaluated in student projects conducted in collaboration between Technische Hochschule Ulm (THU) and Technische Universität Ilmenau (TUIL). During the application and evaluation process, the focus was on two research questions:

- What approaches to developing competences in agile product development are suitable for extending teaching in the context of development methodology?
- What are the benefits and challenges of adapting teaching methods?

Based on the findings from these studies, conclusions and measures for teaching are discussed.

3. BASICS OF AGILE DEVELOPMENT

From the author`s point of view, agile product development represents an extended way of thinking that complements conventional product development processes, as described in [6] or [7] in a target-oriented manner. It revolves around two key aspects: stakeholders and their needs, and collaboration within the development team.

- Agile development focuses on measurable progress, increasing maturity, etc. through iterative "sprints" that eventually lead to one or more advanced and evaluable prototypes (minimum viable products). The goal is to gradually create value for users through measurable reduction of development/product backlog, uncertainties, etc.
- An essential element of the agile development process is development teams that are self-organized as much as possible. Agile teams emphasize efficient and effective interaction through practices like development/product retrospectives, and, in addition to the development process, constantly strive for continuous improvement of teamwork, e.g., through self-reflection methods. Core values include a shared focus, respect, mutual support, commitment to collaboration and openness to change. Clear guidelines

with explanations of the necessary "rules of the game" and other necessities are important here to ensure the core values.
- By closely, highly focused collaboration with stakeholders and seeking frequent feedback, agile development aims, similar to “Design Thinking” approach, aims to better capture, understand, and implement stakeholder requirements to maximize stakeholder benefits.
- Continuous assessment of requirements and the environment, coupled with flexible adaptation of the development process, enables rapid responses to changes and ongoing product improvement.

However, agile working also leads to challenges (e. g. problem-specific composition of the teams, adherence to agreements, focus on the relevant backlog items, etc.), which can also be seen in the evaluation of the approaches in this paper.

4. APPROACH

The development of competences in the context of development/design methodology (methods, tools, guidelines, etc.) is a major challenge for students to master first, because agile product development requires methodological competence. For this reason, courses on this focus were started first at THU and TUIL (in sum up to 15 lectures), labeled “Teaching Basics” in Figures 1 and 2.

In order to expand competences in the field of agile product development of agile development based on the teaching basics, specific approaches are needed that enable students to train them effectively. The learning success in the application of agile approaches and ways of thinking depends primarily on practical exercises on predefined development tasks and the experience gained from them. Against this background, the authors of the paper have developed two approaches (see also section 2), which were implemented in parallel and evaluated within of the curriculum:

- Single-stage approach at the THU (see Figure 1):
  - Ongoing development task during the semester in small project teams (max. 5 students) using the agile approach, some of which may have an international scope, supported by coaching in agile methods. At the end of the semester, the results are presented in a colloquium.
- Two-stage approach at the TUIL (see Figure 2):
  - Stage 1: Teaching the agile approach for a small development task in weekly seminars and in small project teams (max. 4 students), accompanied by coaching in agile methods
  - Stage 2: Application of the acquired knowledge by students in an ongoing semester project, without additional method coaching, but with subject-specific guidance on content-related questions. Here, too, as mentioned in approach 1, a presentation of the achieved results is required at the end of the semester in the context of a colloquium. A special feature is that all groups must also present a critical self-reflection on group work (sprint planning, review, retrospective, group dynamic processes, communication and documentation problems, etc.) and their impact on the product development task. This self-reflection also includes the submission of suggestions for improvement. The goal here is to confront students with their own activities, approaches, etc. so that they can offer ideas and solutions to avoid problems in the future.

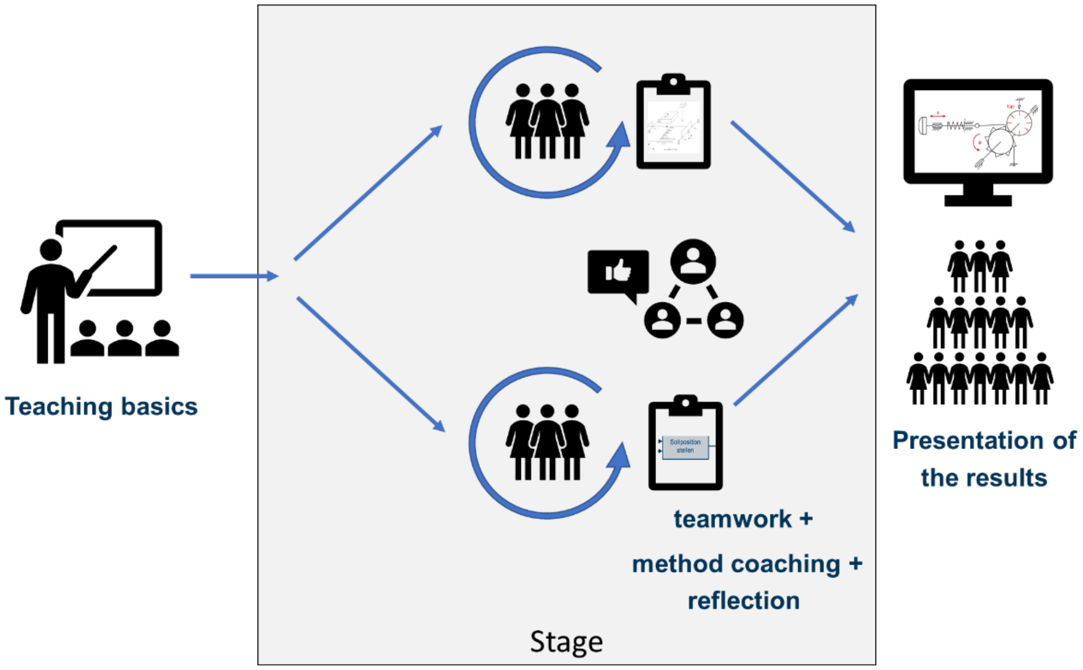

Figure 1 Overview of the procedure for the single-stage approach

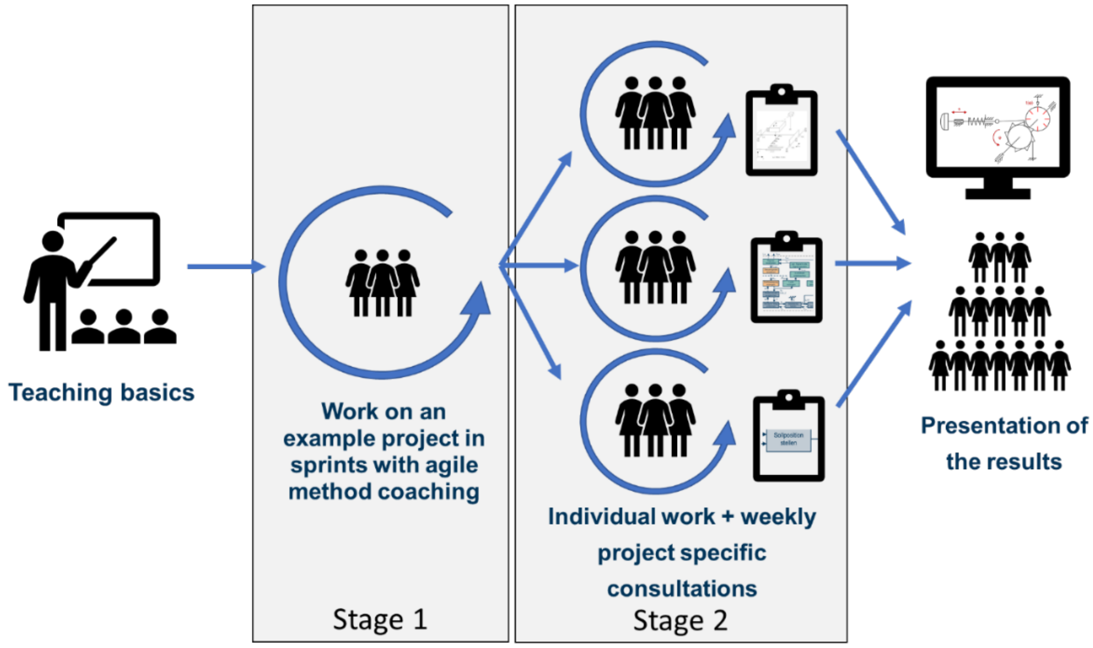

Figure 2 Overview of the procedure for the two-stage approach

In preparation for both approaches, the students were taught the basics of systematic product development, as already indicated above. This included, among other things, the use of methods and tools for the systematic elaboration development goals, the recognition of challenges in problem-solving processes, the consideration of different stakeholders in connection with requirements elicitation from a stakeholder perspective. Furthermore, business models as well as synthesis and analysis approaches were presented. Moreover, well-known agile approaches were discussed, whose basic principles are already contained in TOTE (Test-Operate-Test-Exit) [7] cycles and are further specified by agile frameworks such as SCRUM [1].

4.1 Details to the single-stage procedure at THU

At THU, the single-stage approach was implemented in the education of a total of 100 students in the 6th semester of “Mechanical Engineering” degree program with a specialization in “Product Design” over a period of 4 semesters. The course "Product Innovation" builds on the introductory course "Development Methodology" (in the 4th semester, including project exercises) and expands the methodological approach by including agile methods and more advanced content. For the students, this represents their second methodological development project. In terms of structure:

- Initially, SCRUM is introduced as an agile framework and applied in the course of the semester in a development project, which may also include cooperation with internationally distributed teams from other universities.
- Digital tools such as cloud-based Miro (collaborative online whiteboard platform, see miro.com) or Jira (tracker to capture and organize tasks for teams, see www.atlassian.com) are introduced for project work and documentation, which offer alternatives to local text documentation.
- Agile methods such as “Design Thinking” and tools like the “Product Backlog” are introduced and applied in teamwork, as are feedback, retrospective, and conflict management.
- Lectures on topics such as prototyping, patent law, product safety and industrial design are integrated into the project and applied.
- A presentation in the middle of the semester serves to coordinate across groups.
- Weekly meetings provide coaching and guidance for the projects.

The semester task is introduced at the beginning of the semester. After the introductory lecture on agile methods, the first task is the distribution of tasks and roles as well as communication, coordination, and organization/leadership planning within the teams for project implementation. The teams consist of 4-5 students. One team worked over two semesters with a partner team from another university (which partly did not use agile methods) on an internationally distributed project. These two teams divided the tasks independently and developed, for example, an electric scooter and the corresponding charging station.
In two semesters, all teams were uniformly tasked with the developing an assembly device for neodymium magnets in a Halbach arrangement (see Figure 3).

Figure 3 Stack of neodymium magnets

This device had to be developed in individual sprints. The starting point was manual operation/arranging. Further developments then concerned partial automation with larger magnets.

4.2 Details two the two-stage procedure at the TUIL

At TUIL, the focus was on the two-stage approach. The competence building in agile development was carried out for engineering students of mechanical engineering incl. automotive engineering, mechatronics and production engineering as well as industrial engineering in the fourth or fifth semester as part of the course "Development Methodology". Approximately 140 students participated. The course sequence to date is shown in Figure 4.

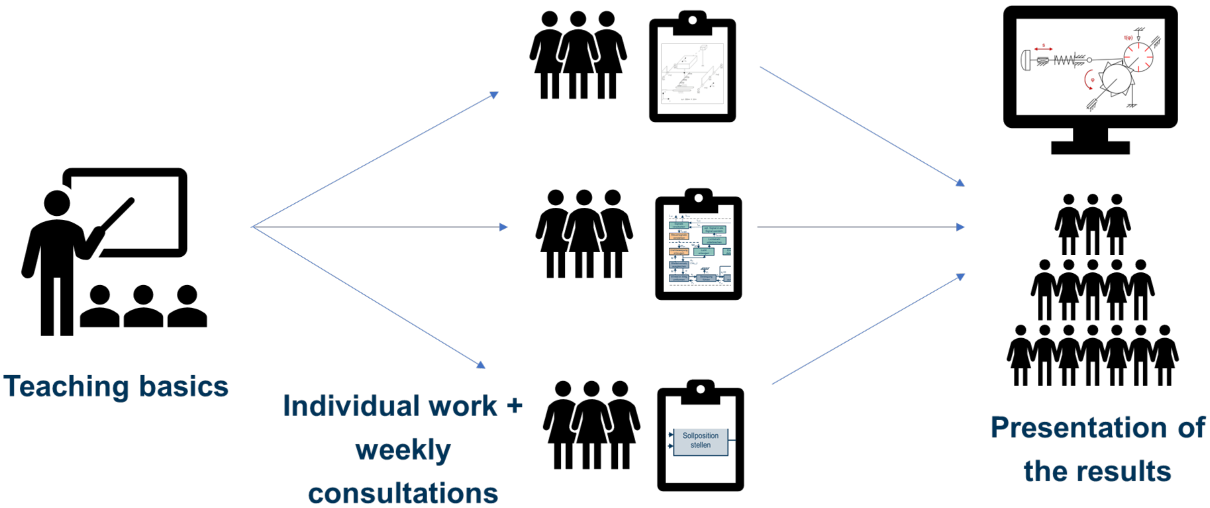

Figure 4 Previous approach in the course

The extended course is structured as follows:

- 15 lectures on problem-solving processes, development approaches, design guidelines and methods in the development context (2 lectures per week in the first weeks to ensure sufficient technical, especially methodical background for the projects).
- 4 agile workshops using the two-step approach with presentation and discussion of the next sprint goals, presentation/review of results and ideas for the next sprint, and sprint retrospective to refine the results (max. 120 minutes).
- Subsequent weekly consultations of the project (partial) results and open questions and team coaching. The is based on group-specific findings and the observations of the teachers.

In the lectures before the workshops, the basics of agile development are explained. The students form teams of four, which are ideally interdisciplinary. On average, five teams take part in each workshop. In the workshops, the development task or sprint goal is first explained and, in accordance to agile development principles, the respective goals of the sprints are presented corresponding to the backlog items (part of sprint planning). Each workshop will last in minimum 90 minutes (up to 120 minutes possible). Between the workshops, students have the opportunity to revise or finalize their results (a kind of sprint review resp. evaluation of the product development increment). The workshops themselves are also divided into two parts. First, the students have about 45 minutes to work on the backlog items. Afterwards, the five teams per Workshop present their progress to each other and to the teachers. The remaining time of the workshop is used to review the sprint results.

The development task for the workshops was to design an automatic page turner for books for physically disabled people. The workshops take place in the Ilmenau “Lernwelt”[1] (see Figure 5). The “Lernwelt”, located in the university library, is a multifunctional teaching and learning space. It enables a wide range of activities, from concentrated individual work and learning in small groups to interactive, project-oriented teaching and learning formats with dynamically composed groups.

[1] “Lernwelt”, https://www.tu-ilmenau.de/universitaet/quicklinks/universitaetsbibliothek/lernen-arbeiten/arbeitsraeume/lernwelt

In the “Lernwelt”, students can document their results on whiteboards, pinboard, flipcharts, etc., or utilize digital devices (realized in the context of the project "examING - Digitization of Competence-Oriented Testing for Bachelor's Degree Courses in Engineering[2]" funded by the “Stiftung Innovation in der Hochschullehre”) for presentations. Some good results of the students from the workshops can be seen in Figure 6.

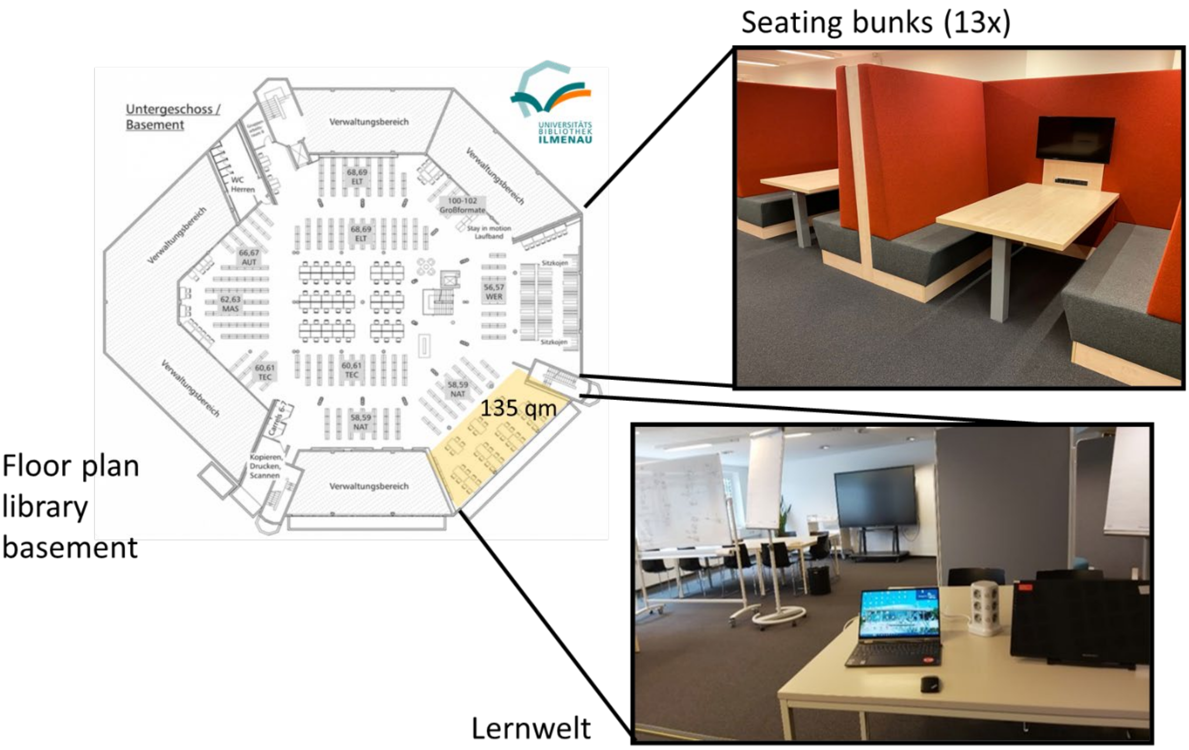

Figure 5 Lernwelt (pictures: TU Ilmenau)

Figure 6 Small selection of the students' results from the workshops

[2] www.tu-ilmenau.de/examing

5. RESULTS

Both approaches were tested with over 200 students. Teachers accompanied the students as method coaches, scrum masters, etc., while documenting the students' experiences and impressions. The lessons learned can be categorized as follows:

1. Findings from observations during active guidance by the teachers
2. Findings from the students' independent work (only in the two-stage approach)
3. Findings from the documentation of the approach and the project results

5.1 Findings from observations during the active guidance by the teachers

Projects using development methods, guidelines, tools are usually associated with many uncertainties for the students if the methods have not yet been applied or not consciously applied at the beginning of the project and the technical task is complex.

This was particularly evident in Ilmenau (two-stage approach) against the background mentioned above:

- Learning from peer teams: Through the presentation and discussion of the first sprint results between the teams, an intensive exchange of knowledge took place. This not only concerned the technical ideas and approaches to the task, but also to the visual presentation of the ideas on the whiteboards, pinboards, flipcharts, etc. Uncertainties about information content, design of presentations could thus quickly cleared up..
- Focused work in sprints: The goals defined in the specific workshops enabled the teams to work on the backlog items in focused sprints, which led to quick results in a short time.
- Recognizing the value of development methods: The application of development methods in the sprints, along with the accompanying coaching, quickly demonstrated the added value of using such methods.

Informal surveys of the students revealed that the sprints and the mutual presentations including the discussions and the preparation time for the next sprint were particularly helpful in reducing uncertainties.

Similar observations were made at THU, confirming these findings. In the one-stage approach, where the methods of product development and project approach were applied for the second time by the students, the groups quickly familiarized themselves with the project task, resulting in greater overall confidence and independence in their work. The observations in this context were as follows:

- Unusually smooth role allocation and implementation in the SCRUM model.
- Face-to-face meetings with teams from partner universities proved advantageous for detailed coordination of the project task. The agile approach of involving stakeholders early on was particularly helpful in providing the THU teams with a clearer understanding of the task at hand during sprint planning.
- The agile methodology worked well even when teams were distributed or when only one team used it.
- The students displayed great creativity in utilizing digital tools for work and documentation, finding them highly beneficial.
- Notably, there was a high proportion of constructive questions and suggestions among the teams during the interim presentation.
- The incorporation of group dynamics, including self-reflection results and sprint retrospectives, was initially unfamiliar to the students but ultimately proved to be very helpful, according to their feedback.

Overall, active instruction and implementation in agile methods resulted in improved communication, effective collaboration, and a positive learning experience for students, which ultimately reduced uncertainty and fostered greater confidence in their development projects.

5.2 Findings from the students' independent work

In the two-stage approach, it was observed that during the workshops, the students worked diligently towards the sprint goals and applied the development methodology. However, it should be noted that during their independent work without coaching, some students reverted back to their old habits.

In contrast, in the one-stage approach, the students displayed a high level of autonomy throughout the project, and there was no "falling back into old habits." The students' previous experience with systematic approaches was clearly evident, especially in their selection of suitable methods.

5.3 Insights from the documentation of the procedure and the project results

The documentation in the one-stage approach was consistently comprehensive and well-structured. Approximately 80% of the groups chose to use digital tools for documentation, primarily Miro, which resulted in easily traceable outcomes. The construction of prototypes indicated that the students had thoroughly engaged with the task's constraints, leading to overall functional solutions. The improved results compared to projects in the fourth semester suggest that repeated application of the systematic approach is beneficial. However, it requires further observations in detail to assess whether the agile approach produces superior outcomes.

In the two-stage approach, after the workshops, the students were assigned the task of independently working on and documenting another project. Most groups were able to achieve good project results. Several students reported that they focused on the aspects of concentrated work during the process, enabling them to achieve targeted and relevant outcomes. However, when directly comparing the results with student teams from previous years who followed conventional working methods, there was no significant improvement.

6. CONCLUSION

The following conclusions can be drawn from the authors' experience with the development of competencies among students in the context of agile product development:

- Single-stage approach: The single-stage approach, where students continuously work with agile methods in one semester, yields positive results. Students develop greater confidence and independence in project work and can apply the methods quickly and smoothly.
- Two-stage approach: The two-stage approach, which includes workshops on agile development, benefits students through intensive collaboration and learning from each other. By presenting and discussing sprint results among teams, uncertainties are reduced, and there is an exchange of technical ideas and approaches. Focused work in sprints allows students to achieve results in a short period.
- Interdisciplinary teams: Forming interdisciplinary teams proves advantageous. With diverse academic backgrounds and perspectives within the team, creative solutions can be developed.
- Stakeholder involvement: Early involvement of stakeholders, both within the university and externally, is helpful in defining and aligning project tasks. The agile approach enables continuous communication and coordination with stakeholders.
- The application of analogue and digital tools: The targeted application of analogue, such as whiteboards, and digital tools, such as Miro or Jira, for the interactive work and

documentation of the projects proved to be helpful. The students found these tools supportive and effective.
- Group dynamics and feedback: Incorporating group dynamics through feedback and retrospectives promotes learning and continuous improvement. Students benefit from the constructive questions and suggestions of the other teams, which improve their own project results and the way they proceed during a sprint.
- Realistic project tasks: Engaging in realistic project tasks allows students to apply learned methods during the “Teaching Basics” in a real-world context (see Figure 1 and 2). This enables them to directly apply and deepen their acquired knowledge and skills.

Overall, the use of agile methods in student training leads to positive results in the development of methodological competencies in the environment of concrete teaching tasks. Continuous consideration or inclusion of stakeholders, teamwork and the use of digital tools support the learning process and enable students to achieve relevant, usable project results. It is important to encourage students' independence and ensure that they can independently apply the methods they have learned in an agile environment.

In order to further elaborate on the knowledge gained and to gain additional insights, the following approaches could be considered:
- Long-term evaluation: A long-term evaluation could provide insights into the effectiveness of the developed methodological competences in later projects or professional experiences of the students. It would be conceivable to track their progress and performance over a longer period of time, including after graduation in companies with different approaches, in order to determine the long-term impact of the acquired skills.
- Comparative studies: Comparing outcomes and experiences of students who have gone through the agile development approach with those who have followed a conventional approach could help to identify the specific benefits and advantages of agile methods in terms of project outcomes, student satisfaction and competence development.
- Collaboration with industry: Collaboration with industry partners and integration of real projects and scenarios into the curriculum would provide students with hands-on experience and opportunities to apply agile methods in collaboration with collaborators from an authentic environment. Industry partners can also provide insights and feedback on the effectiveness of the students' approach and contribute to the overall assessment. Further training for employees from industrial companies in combination with student projects could also provide interesting insights.
- Cross-institutional studies: The comparison between TUIL and THU suggests integrating other institutions of higher education that have implemented similar approaches in order to compare and validate the results. This may include sharing best practices, exchanging experiences and conducting joint development or even research projects to gain a broader perspective on the effectiveness and generalizability of the agile development approach.
- Follow-up surveys and interviews: Follow-up surveys or interviews with graduates could provide their perspectives on the long-term impact of the acquired methodological skills. It would be interesting to see how these skills have affected their professional development, problem-solving skills and adaptability in the workplace.
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Thus, overall, further insights and knowledge could be gathered that would be valuable for the continuous refinement and implementation of agile development methods in engineering education.

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