Requirements for utilizing student projects as validation environment for design methods and collecting research data

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Abstract

Student projects represent a middle ground between lab and industry studies, with both controlled conditions and realistic development scenarios. The problem is that there is no comprehensive list of requirements to develope specific guidelines for using student projects as a validation environment for design methods. Additionally, structuring and data collection in student projects are associated with challenges. This study employs a mixed-methods approach, including a systematic literature review and expert interviews, to identify key requirements for effective method validation and data collection in student projects. The resulting requirements list can serve as a basis for developing guidelines to optimize student project conditions, enhancing their effectiveness in method validation.

Keywords

student project, validation environment, data acquisition, method validation, design methods

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1. Motivation

For successful product development, the implementation of systematic methods is essential [1], [2]. Despite extensive evidence supporting the positive impact of design methods on product quality, their adoption within the industry remains limited [3], [4]. To improve the uptake, method validation is crucial to demonstrate the practical utility of a design method and to support their integration into industrial practice [5]. In the method validation, an important decision is choosing effective validation environments for investigating design methods, as different environments offer varying degrees of internal and external validity [6]. Internal validity, on the one hand, is defined as the extent to which a researcher can justify that observed correlations are indicative of a causal relationship. External validity, on the other hand, is defined as the capacity to extrapolate the relationships identified in a study to broader populations, different time periods, and various settings. Researchers need to take the trade-off in validity between industry studies with a high external validity and laboratory studies with a high internal validity into account [6]. Additionally, in laboratory studies they have to decide whether experts or students should be used as test subjects. The more realistic conditions of industry or field studies, using real design processes in companies, allow for good transferability to other persons and situations, which leads to a higher external validity, whereas with the more controllable conditions of laboratory studies the ability to establish a causality of the observed correlations yields a higher internal validity.

In this trade-off in validity, student projects offer significant research potential in the areas of understanding of design, the need for methods, method development and method validation [7]. As a result, student projects can be seen as a relaxation of the validity trade-off of laboratory and industry studies, as they provide a reasonable degree of both internal and external validity. However, the development of student projects is also associated with various challenges, such as time-consuming preparation and supervision or the fluctuating motivation of students [8]. Nevertheless, with the right organization, their advantages predominate. They can be carried out on a larger scale and the conditions can be controlled more closely than industrial studies, while still representing the character of a real development process [9]. At the same time, they can only approximate real-world scenarios to a limited extent. They simplify complex realities, making them less accurate reflections of professional environments. Additionally, students lack the depth of expertise and problem-solving abilities that experienced engineers have acquired from handling real-world challenges directly. Compared to laboratory studies with students, student projects allow a more detailed examination of the topic over a longer period of time, which enables a more realistic development process to be reproduced [10]. However, the longer observation period also has disadvantages. For example, external influences cannot be excluded or controlled, which means that various interference factors must be taken into account. As another advantage of student projects, the annual repeatability makes it possible to conduct research across years, which provides data for several generations of product development. This allows research on product generation engineering as well as the analysis of the applicability and effectiveness of different design methods or different versions of the same design method under reproducible conditions. In conclusion, student projects offer a balanced compromise between the controlled conditions of laboratory studies and the realistic settings of industrial studies, offering potential in method validation and advancing the understanding and application of design methods.

1.1. Design Methods and Method Validation

A design method is defined by Gerricke et al. [11] as a structured approach or a detailed plan for achieving specific results. This includes defining how information should be presented, the type of input data required, the tools to be utilized, the actions to be performed and their sequence, and the decomposition of tasks.

According to the design research methodology (DRM) by Blessing and Chakrabarti [3], method validation proceeds through stages reflecting the maturity of the method: Support, Application, and Success. During the *Support stage*, the method's applicability and usability are assessed. The *Application stage* examines the method's impact on its specific objectives, while the *Success stage* involves analyzing the method's influence on key success factors.

Eisenmann et al. adapted the concept of *levels of evidence* from the medical field, providing a hierarchy to categorize study designs based on the reliability of results concerning the relationship between the method and its outcomes [12]. Higher levels of evidence are characterized in rising order by empirical data, control groups, hypothesis testing of the method's desired effects, and, at the highest level, repeated hypothesis testing to enable meta-analysis.

1.2. Research Problem and Aim

Despite the stated advantages, student projects have not been used to their full potential as an environment for the validation of design methods. To address this, guidelines are needed to optimize student project conditions, enhancing their effectiveness in method validation. Existing research in other engineering disciplines provides a solid foundation to refer back to; however, it is essential to complement this work with the specific requirements of mechanical engineering. Carver et al. [13] developed a checklist intended for researchers using students as participants in studies. The authors emphasize broad considerations as well as specific issues pertinent to the field of software engineering. Bursac et al. [10] initiated the compilation of a short list of requirements for the organization of student projects in the field of sheet metal development. The problem is that there is no comprehensive list of requirements to develope specific guidelines for using student projects as a validation environment for design methods in the field of mechanical engineering, taking into account the unique challenges in this context. In addition, the structuring of and data collection in student projects is still associated with numerous challenges and there is a lack of support to address them. This leads to the following research question:

What requirements exist with regard to the use of student projects as a validation environment for design methods and the collection of research data from student projects?

2. Methods

A mixed-methods approach was used to answer the research question. This comprised a literature review to evaluate publications on student projects and requirements for a validation environment on the one hand and, on the other, supplementing these findings with more than 10 years of experience in carrying out student projects at the authors' chair, extracted through expert interviews.

2.1. Literature Review

To identify fitting literature, a systematic literature review was performed following the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) statement [14]. The detailed procedure is illustrated in Figure 1. Searches were conducted using Scopus and IEEE, focusing on English-language publications. The following search string was used: *(TITLE-ABS-KEY("student project") OR TITLE-ABS-KEY("Live lab") OR TITLE-ABS-KEY("project work")) AND (TITLE-ABS-KEY("product development") OR TITLE-ABS-KEY("mechanical engineering") OR TITLE-ABS-KEY("engineering design") OR TITLE-ABS-KEY("design method") OR TITLE-ABS-KEY("method validation")).* This string targeted literature on student projects being used as a research environment in the context of mechanical engineering.

The search yielded 768 results (see Figure 1). In a first step, publications older than ten years were excluded as well as papers that were not in the context of mechanical engineering. In the same step, conference papers were excluded to set the focus on high quality research published in journals. With these criteria, 719 papers were excluded. After checking for duplicates, the titles and abstracts of 49 papers were initially screened to remove irrelevant records using exclusion criteria: 1) lack of student projects as a validation environment, 2) not mentioning data acquisition in student projects, 3) lack of advice for the implementation of student projects. Full-text eligibility was then assessed for 22 papers. Consequently, 13 records were excluded using the same exclusion criteria. Ultimately, 9 studies were deemed significant for addressing the research question and included in this review. From these, requirements were extracted regarding the use of student projects as a validation environment for design methods and the collection of research data from student projects.

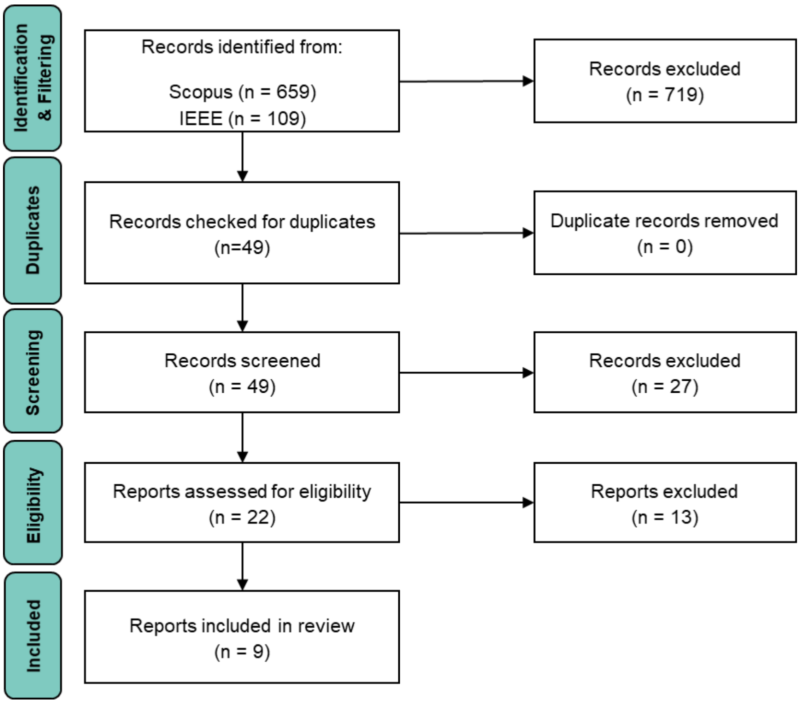

Figure 1: PRISMA flowchart describing the procedure of the paper selection and stating the number of papers for each step

2.2. Expert Interviews

The aim of the expert interviews was to extract and synthesize experiential knowledge from previous years of organizing project works to facilitate the identification of effective methodologies, lessons learned, and potential pitfalls based on firsthand accounts. The qualitative data obtained from these interviews enriched the evidence base of the literature review, informing future decision-making and research directions with a comprehensive understanding of past experiences. The interviews were conducted based on the results of the literature review as shown in Table 1. These discussions focused on contextualizing and understanding the findings of the literature review. This dialog allowed for a deeper exploration of the literature findings and their implications for ongoing and future research efforts in the field. The findings from the interviews were utilized to contextualize the results of the literature review in the discussion part of this work.

Experts were selected based on their extensive experience and involvement in organizing student projects over the past years. Criteria for selection were the involvement in and the organization of at least two years of project work. The experience of the experts interviewed is based on years of teaching the Mechatronic Systems and Products course, which consists of student projects and an accompanying lecture as described by Krebs et al. [15]. This project is designed for 5th-semester students enrolled in the Mechatronics degree program at the Karlsruhe Institute of Technology. The primary focus is on the strategic utilization of synergies in the development of new systems. Students engage in an industry-oriented development process, learning that the integration of different mechatronic sub-areas leads to superior solutions compared to optimizing individual sub-areas in isolation. This methodology is aligned with the practices of interdisciplinary development teams in the industry.

The key aspects of the student projects are presented in Figure 2. The objective of the project is to design a complete mechatronical system capable of collecting cubes and assembling them into a tower on a specified playing field. The project is structured with an initial setup of one group leader and the division of the team into two sub-groups, each comprising five students. Each sub-group is responsible for developing an independent subsystem. Successful task completion requires collaboration between these subsystems. The milestone plan provides a framework for project planning and serves as a control mechanism for workshop supervisors. These milestones also assist students in concentrating their efforts on intermediate goals. Upon completion of the project, students engage in a self-reflection exercise, linking their practical experiences to the scientific principles discussed in their lectures, thereby reinforcing their theoretical understanding through practical application.

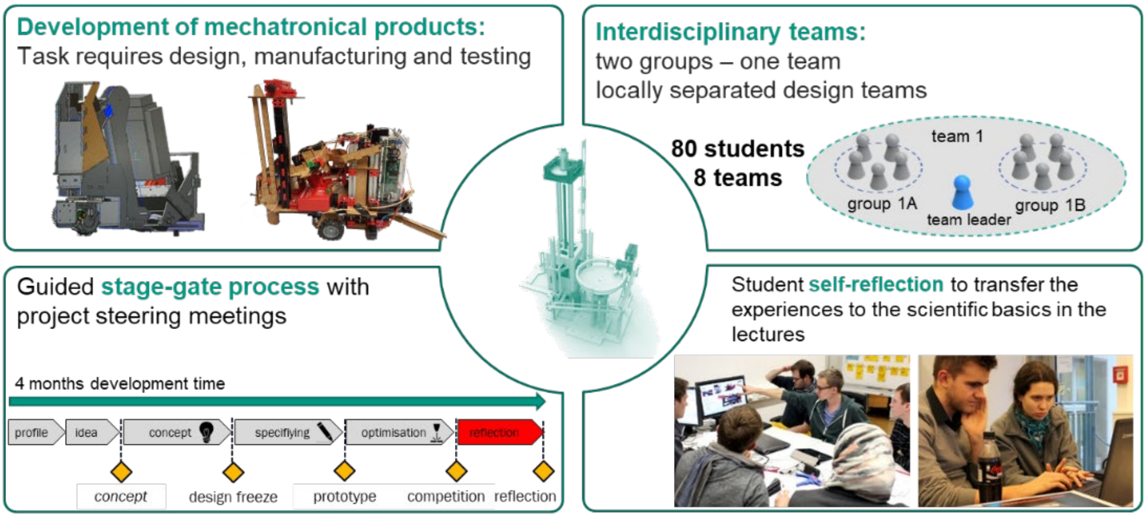

Figure 2: Structure of the student project, which serves as the basis for the revision concepts

3. Results

Among the nine reviewed journals, only three concentrated primarily on method validation. These studies specifically evaluated the DRM's Support stage through applicability and the refinement of methods [16], [17]. Furthermore, only one journal concentrated on assessing the method's Application stage by evaluating its effectiveness in achieving defined objectives [18]. The remaining literature focused on educational research and the validation of new teaching approaches [19], [20], [21], [22], [23], [24]. Although these studies do not align precisely with the primary research aim, they provide valuable insights into student projects, data collection methodologies, and validation techniques within educational contexts, from which requirements can be derived, so the papers are included in the research.

The extracted requirements of the analysis of the papers are divided into three categories. Based on the research question, the first two categories involve requirements on the collection of various data types used in the literature for validation purposes and listing the tools and methods employed for validation. The third category highlights additional requirements as critical points and recommendations by the authors, essential for advancing student projects. The whole list is stated in Table 1. In the following, the most frequently mentioned requirements are addressed.

Table 1: List of requirements collected from the literature review

Category	Requirements	References
Data types collected	Presentations of (interim) results	[16], [20], [21], [23], [24]
	Grades / Evaluation of results by teachers	[16], [17], [20], [21], [22]
	Reports	[16], [21], [23], [24]
	Prototypes	[16], [22], [24]
	Drawings	[16], [21], [22]
	Personality tests, Team roles	[18], [19], [22]
	CAD data	[16], [21]
	Online platform for tracking the progress of the project	[18], [22]
	Interviews with teachers	[22]
	Market analyses, Cost analyses	[20]
	Self-assessment of skills	[18]
Validation tools used	Questionnaires, Surveys	[18], [19], [20], [21], [22], [23], [24]
	Control group without method / with other approach	[21], [22]
	Evaluation of the method based on the grades / evaluations of the student projects	[17], [21]
	Focus group interviews	[22]
	Tests	[22]
	Successful prototype creation	[18]
Critical points noted	Questionnaire after grades have been determined so that students do not have to worry about their answers influencing their grades	[16], [18], [22], [23]
	Motivation of students not always given, different standards of quality	[16], [20], [22]
	Declaration of consent	[16], [19]
	Data protection	[16], [19]
	Resource-intensive	[22]
	External intervention through project management meetings	[16]
	Generalizability of the results only for the same task	[16]
	Higher motivation with self-selected topic	[20]
	Copyright issues	[16]
	Group size not too large (~5 optimal)	[20]
	Industry standards cannot be mapped	[16]
	Observation of project meetings to track project progress	[18]
	Success of the method as an aid for students greater than for experts, results could be distorted	[18]
	Subjectivity tests of the teachers' assessments	[16]

There are numerous data collection methods, with presentations and reports being commonly utilized, alongside outputs from the development process such as CAD data, drawings, and prototypes. Project assessments by educators also provide valuable data.

Validation tools in student projects predominantly include questionnaires and surveys, as these tools offer a direct way of collecting feedback from participants and quantifying their experiences and assessments. However, control groups and assessments based on project grades or ratings are also used. Less commonly used tools are quizzes to assess students' knowledge about a topic or the used method.

When using student projects as a research environment, key considerations include clarifying data privacy and consent requirements with the relevant institutional authorities. External interventions, such as project management meetings and feedback during the project, must be accounted for as potential confounding factors. Another point mentioned is, that student motivation and the quality of results can vary significantly. It is also brought up that when employing them, questionnaires should be administered after grades are finalized to mitigate bias, ensuring students do not fear their responses will influence their evaluations.

4. Discussion

The literature review identified various requirements for structuring project work, types of data that can be collected, and diverse validation tools for assessing design methodologies. Expert insights were used to contextualize these points and highlight additional considerations.

4.1. Data Collection

Collecting different types of data is crucial in order to draw a variety of conclusions and provide a comprehensive understanding of the student projects. Presentations and reports provide insight into the students' thoughts and intentions. These documents provide a qualitative perspective on the student's thought process and methodology [21]. Outputs of the development process, such as CAD data, drawings, and prototypes, provide quantitative and objective evidence of students' progress and technical skills [16]. Evaluations of the results, both by teachers and by students' self-assessments, complement this data and enable reflection on the goals achieved and the quality of the work [18].

Design methods often aim to analyze and improve the function of a system [25]. In order to validate the Application stage of these methods, the functionality of the developed systems is therefore required [3]. This data type is still missing in the compiled list. Functional evaluations of systems are crucial for gaining insights, but as mentioned by the experts, they can often only be carried out late in the development process, making it difficult to attribute success to specific methods. To be able to use student projects as a validation environment not only for the Support stage, but also for the Application stage, they should be designed in such a way that early functional tests are possible. This can be achieved through iterative development cycles and early prototyping and testing.

In the field of design research, the integration and connection of various data types is of high importance for deriving comprehensive insights into design knowledge. By linking qualitative and quantitative data from diverse sources, researchers can construct a more holistic view of the underlying design principles and processes [22]. According to expert opinion, it is crucial to consider the temporal mapping of different data types during the planning of a project work to maximize the potential for future research. This means ensuring that data collected at various stages can be precisely synchronized over time. Proper planning and implementation of this temporal data synchronization will enable researchers to track changes, assess the progression of design iterations, and effectively compare outcomes across different stages of the design process.

4.2. Method Validation

The validation tools used in student projects depend on the objective of the validation of the method. Questionnaires, tests, and focus group interviews are often employed in the literature and can be used to evaluate the Support stage of the method [3]. These instruments provide direct feedback from the participants and enable a detailed analysis of the methodological support [22]. Control groups, project success and grades can serve as benchmarks for evaluating the Application stage [18]. The analysis of the project results even allows an evaluation of the Success stage of the methods used. However, if project evaluations serve as the validation basis, the subjectivity of assessments must be accounted for, as highlighted by Petrakis [16].

The suitability of project work as a validation environment greatly depends on the evaluation purpose. The literature indicates that project work is frequently utilized and particularly effective for Support stage evaluation due to its extended duration and coverage of the entire development process [16], [17]. However, its use in Application and Success stage evaluation is less common [18]. This was discussed with the experts and different approaches to facilitate these evaluations were mentioned. As previously noted, one approach to facilitating Application stage evaluation is by testing the functionality of the developed system. For Success stage evaluation, the designed systems can be assessed by analyzing reductions in cost, weight, or emitted CO_2 compared to a predecessor system, as these are frequently key success factors in industrial development processes. Given the need to account for numerous confounding factors in these evaluations [18], it is essential to devise and implement strategies to mitigate their impact.

To enhance the level of evidence in validation, the before mentioned key success factors can also be employed for hypothesis testing of design methods [12]. Incorporating control groups, as done in some instances in the literature [21], [22], should also be planned to further strengthen the level of evidence. Additionally, a meta-analysis, achieved by annually employing design methods in student projects, can provide the highest level of evidence. In this context, ensuring the comparability of projects across different years must be integrated into the long-term planning of student projects.

4.3. Confounding Factors

Several factors can influence the reliability of data collection and the validity of the results [16]. It was stated in the expert interviews, that the reliability of data recording by the students often varies greatly and only works if someone is consistently responsible for it, or if the data is naturally generated during the development process. Especially in later phases of the project when time pressure increases, documentation tends to be neglected, necessitating careful planning and appropriate measures to ensure effective data collection.

It was also mentioned in the literature and by the experts, that student convenience can contaminate data quality [20]. For example, students may present a simple system as a critical system in a presentation in order to make their work appear more positive. Reports can only reflect reality to a limited extent due to the subjectivity of the students. More objective data can be obtained through test reports that can be filled out directly in the development process and that record the motives of the test subjects at the time of completion.

By using control groups and repeating studies over several semesters under comparable conditions, student projects can provide a high level of evidence for method validation [12]. However, contact between groups and with students from previous years is difficult to control, making it difficult to maintain a true control group throughout the semester. These factors need to be carefully considered when planning and implementing student projects in order to achieve valid and reliable results.

5. Conclusion and Outlook

This study aimed to highlight the gap in the literature regarding the known requirements for the use of student projects as a validation environment for design methods in mechanical engineering. Student projects are mostly employed as a validation environment in the Support stage, but offer the potential to evaluate the Application and Success stage of methods as well with a high level of evidence through a suitable design. Especially for the evaluation of the Success stage of methods, Eisenmann [12] points out that the transition from laboratory studies to field studies is a significant challenge. Student projects can facilitate this transition and act as an important intermediate step. By conducting a systematic literature review and expert interviews, we identified key requirements and challenges associated with structuring student projects for method validation and collecting research data. To enhance the effectiveness of student projects in method validation, it is crucial to establish comprehensive guidelines that incorporate these identified requirements and address the associated challenges. The guidelines should include clear protocols for data collection, measures to ensure data accuracy, and strategies to mitigate the impact of confounding factors. The compiled list of requirements and their contextualization through expert knowledge can serve as a basis for the development of these guidelines. This structured approach and detailed planning recommended to be developed can help ensure that student projects provide reliable and valid data, strengthening the evidence base for methodological approaches, and contributing to the broader goal of integrating systematic design methods into industrial practice.

Future research should focus on combining and enriching the list of requirements specific for mechanical engineering with research results from other areas, for example by Thomas [26] or Bello et al. [27], to be able to develop a more comprehensive and holistic set of guidelines. The search string employed in the literature review as well as the focus on journal articles must be considered a confounding factor, potentially affecting the comprehensiveness of the results obtained. Utilizing a broader search string might yield additional results. Results from conference papers in mechanical engineering should also be taken into account in a next step, as important requirements on this topic are also listed here, for example from Üreten et al. [28]. With a comprensive requirements list, the subsequent objective should be the development and testing of these comprehensive guidelines for using student projects as a validation environment for design methods. In addition to the aforementioned standardized protocols for data collection and analysis, this also includes research into innovative approaches to increasing student motivation and engagement. Additionally, further studies are needed to assess the long-term impact of these guidelines on the quality and reliability of research data obtained from student projects. Moreover, the potential of student projects to facilitate meta-analyses and longitudinal studies on design methods should be explored. By ensuring the comparability of projects across different years, researchers can generate a high level of evidence for the effectiveness of design methods, contributing to the continuous improvement of engineering practices. Collaborations with industry partners can also provide valuable insights and resources, enhancing the realism and applicability of student projects.

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