STUDENT PARTICIPANTS IN EMPIRICAL STUDIES IN ENGINEERING DESIGN - A COLLECTION OF REFLECTIONS TO IMPROVE YOUR STUDY QUALITY

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ABSTRACT

Engineering design has a broad variety of approaches, methods and methodologies to conduct, evaluate and validate research. This contribution focuses on empirical studies and divides existing approaches and classifies them according to a scheme with criteria and boundary conditions, such as participants (students, researchers), the length of the study, the incorporation of the study into the curriculum etc. There are certain ideas, challenges and recommended practices associated with each environment and scenario. Knowing them will help design method developers in engineering design who want to conduct empirical studies but have little or no experience with student participants. Therefore, conducted studies from the research institute are mapped onto the classification scheme and synthesized challenges and recommended practices associated with laboratory conditions and student participants will be presented.

Keywords: Design methodology, Human behaviour in design, Design education, Empirical studies, Engineering design

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1 INTRODUCTION

Engineering design research has a broad variety of approaches, methods and methodologies to conduct, evaluate and validate research. This contribution focuses on empirical studies and divides existing approaches into *academical and industry validation environments* and makes a distinction with further criteria, such as the participants of such studies, being *students, researchers or practitioners in industry*. A simplified classification scheme of validation environments evolves from these criteria. There are certain ideas, challenges and recommended practices associated with each environment and scenario. The focus in this paper lies on academical validation environments in engineering design with student participants in empirical studies, especially experiments, to validate, and thus test the goodness of, design methods in product development. Empirical research work conducted at the research institute of the authors of this contribution form the set of studies and will be described. For the purpose of transparency, the procedure of analysis of this set of experiences will be presented as well. Experiences made in this context based on various studies in the research institute will then be mapped onto the simplified validation environments scheme, an exemplary study will be presented more detailed to demonstrate the validation scheme and how challenges as well as recommended practices based on the systematic analysis of these studies were developed. This paper targets researchers with little or no experience in empirical studies in the area of product development in engineering design. Specifically, we want to provide the design method developer with summarised literature and a pool of experiences of studies, synthesised challenges as well as recommended practices such that the planning, conduction and analysis of their own empirical research study is facilitated and the quality of their research is improved. The design method developer will also be made aware of further questions that go beyond the scope of this paper. Though our focus lies heavily on empirical studies in the area of engineering design, we strongly believe that the presented core ideas here are also useful to and transferrable to be applied by beginners in empirical sciences in other fields, such as social sciences.

2 STATE OF THE ART

There are various approaches referring to the conduction, evaluation as well as validation of design methods in engineering design. These include, but are not limited to, the Experimental Design Research by Cash et al. (2016), the Design Research Methodology by Blessing and Chakrabarti (2009), the Validation Square by Seepersad et al. (2006) and the Spiral Eight Fold Model by Eckert et al. (2003). Cantamessa (2003) has a classification scheme with empirical research, experimental research, development of new tools and methods, implementation studies and other. Barth et al. (2011) have showed that there exist validation types, these are application, comparison, focus groups, questionnaire, simulation, statistical analysis, none, n/a. Empirical experimental validation studies in real contexts in industry are associated with challenges (Carver et al. 2006) such as the length of data collection until sufficiently data has been collected (Vermaas 2016), real design projects being not only too contextual but also too open-ended (Vermaas 2016 with reference to Frey and Dym 2006, Reich 2010) and "practically impossible to carry out" (Vermaas 2016). It is not always possible to find an adequate project or context to validate in industry. Therefore, the research institute has focused on developing a support for design method developers to validate their design method in laboratory conditions in academia (Üreten et al. 2020b, Üreten et al. 2019). In this contribution, we refer to empirical studies from social sciences being qualitative and involving human participants, such as focus groups, expert interviews, observations and experiments focused on qualitative data collection and analysis techniques for instance. These are also applied in the area of product development and can be adapted to the specific conditions. Many studies considered refer to design method experiments, where control of variables plays an important role. These have been part of the research in the research institute of the authors and therefore direct access to data and experience was possible and these will be shared in a structured way in this contribution with a broader audience.

Empirical studies with student participants in academical context can be found in various literature, e.g. Jansson and Smith 1991, Razzaghi et al. 2009, Fu et al. 2015, Ruckpaul et al. 2015. They usually include control and test groups with different stimuli and students are asked to solve a task in an educational context. Moreover, literature on a higher strategic level about the laboratory experiments with student participants and their implications exists. There are two perspectives with regards to this. One refers to

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the concerns with external validity. The other refers to its benefits and why as well as under which boundary conditions student participants are acceptable (Svahnberg et al. 2008).
External validity is discussed in terms of whether the findings from the study with student participants are applicable or generalizable to real world industry environments (Carver et al. 2006). In educational settings, experimental studies with students also bear the task to be of pedagogical value for students and not only research value for the respective research (team). It is mentioned that some interests of the respective stakeholders (e.g. students, researchers) are complementary, and others may be competing, such as the student who wants to learn something from the participation and the researchers focusing on the quality of the research (Carver et al. 2006). Students are assumed to have less experience than professionals (Carver et al. 2006). In software engineering, certain studies on the validity have been conducted and found out that there are relevant factors for the generalisability of the results from student laboratory environments to professional environments. These include the subjects, the incentives and their experience. Also, another study found out that there are little differences between graduate students and professionals. (Carver et al.2006)
Guidance on these issues already exists in software engineering for instance (Carver et al. 2010, Ko et al. 2015).
The relevance of student participants and experiments in laboratory conditions in academia comes with the lacking standardisation of conduction of experiments in the industrial context and their above mentioned challenges. It is possible to incorporate laboratory experiments in academic courses with certain preparation, however, in industry, getting the resources and having standardised procedures to cope with is highly difficult due to the high number of factors that actually do effect efficient design method use.

3 METHODOLOGY

The following methodological steps were conducted. Empirical studies conducted at the research institute of the authors were collected with regards to their contribution to new insights in academic study context and student participants. Some of the work is already published (Üreten et al. 2020a; Üreten et al. 2020b, Üreten and Krause 2018; Üreten and Krause 2017; Üreten et al. 2017) and will be presented shortly to give an overview and impression of the study contexts. For more details and results of these studies it is recommended to look at the sources respectively. The procedure of how they were analysed will be outlined. The analysis happens on a meta-level as reflection. These studies were then mapped onto a simplified scheme of types of empirical studies to test design methods in product development and provide the base for the abstracted synthesis of challenges and recommended practices (see section on results). They include the experiences of the authors but also inspiration from exchanges with colleagues and students. The experiences made by the authors refer to various phases of empirical studies, including the acquisition, planning and conduction as well as analysis of the studies. As the challenges and recommended practices are related to certain criteria and boundary conditions, the studies are described and classified according to these criteria in Figure 1 with an example. Grey areas in Figure 1 are for what is covered in experiments at the research institute, other possibilities are available but have not been covered so far in this analysis. All chosen studies were conducted in laboratory conditions in an academic field. However, they differ in certain criteria. The set of differences found is exemplary and neither systematic nor exhaustive. They are based on literature as well as own studies. These categories can also guide the design method developer in decision-making about their study.

Descriptions of the studies conducted at the research institute - set of empirical studies

In the following, the set of studies will be summarised. The summary of the set of studies includes the above mentioned published as well as further studies conducted in the research institute.
The studies that were conducted are from the research institute in an academical context. Their focus can differ in accordance with main contribution to research or teaching. Participants were students and the recruitment differed from one study to another. There are differences in how the potential participants are recruited depending on whether the study takes place during a regular lecture for instance, where students' time is usually planned ahead, and studies that take place in additional workshops beyond the regular course. Generally, in all the studies, participants were acquired through different channels and means. The motivation and benefits to participate in the study differ. The methods applied in the

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empirical studies differ, e.g. interviews took place, experiments as well as observations. Also, the tasks are different from one study to another requiring different skill sets and pre-knowledge from participants.
The contribution from Üreten et al. 2020a is about current challenges and solution approaches in empirical engineering design research. A workshop with researchers from different academic institutions took place to share experiences with empirical studies. When it comes to participants of such studies, the following challenges and recommendations were documented. The number of required participants and the qualifications of these participants is a challenge. Checking for the number of required participants according to the concepts of statistical reliability is one recommendation the team in the workshop came up with. Checking for pre-knowledge of participants prior to the experiments is recommended, especially if homogeneous participants are required for the study. The choice between student participants or participants from industry can be answered by looking at the hypothesis for instance.
Also, because it is difficult to conduct large-scale statistical studies which require a great deal of time and other resources, it is possible to develop small-scale design studies (Cash et al. 2012).

Procedure of analysis for the set of empirical studies
The procedure of analysis of these studies can be summarised into two main phases. In the first phase, the authors and respectively main study coordinators have documented their impressions, experiences and reflections about each of the study separately and then formulated a synthesis. Guiding questions for the documentation were

- How did I proceed?
- What worked out well? What was helpful during problem-solving?
- What were the challenges I experienced?
- What can be improved?

These questions are similar to questions that are tested in a study before by Üreten and Krause in 2018 (described in the following text as well). For each study, a reflection was accomplished by the researchers individually but afterwards also as a team. These reflections are key for the development of the following ideas. This documentation was used as a basis to share own experiences with other main study coordinators of different studies of comparable type. Comparable type refers to the comparable study environment in academia with student participants using empirical sciences methods for conducting studies. The authors did not only share their experiences and exchange ideas, they also had discussions with other experts such as colleagues, to find synergies and develop solution approaches in the second phase.
One example will be given in more detail to demonstrate the analysis. In the study from Üreten and Krause 2018 the goal was to find out factors that are crucial to design method acceptance amongst students and how questions in focus group interviews for design method validation experiments can be developed. The main context of the study was doctoral research in design method validation, and findings would also be useful to improve education. The focus group interviews were separate to the engineering design class, in which students had to methodically follow a procedure to pass the project. Participants were bachelor students who had accomplished this project in the same year. The study was conducted with two cohorts in two years and sessions were of different length ranging approximately one hour. The number of sessions for each study was one, and their task was to answer questions, describe and discuss their procedure. Students had to describe their procedure followed to solve the task in their project about engineering design methodology systematically. The questions directed to the study participants were the following:

- How did you proceed?
- What worked out well? What was helpful during problem-solving?
- What were the challenges you experienced?
- What can be improved?
- How did you evaluate your solutions to the individual methodical steps? What made you feel confident about your solutions?
- How did you decide you were finished with the partial solutions to the task?
- Any other comments?

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The studies were conducted with each team individually, however, the participants were the same participants of one team that accomplished the project together. There was no intervention from researchers during project completion. The documentation of the interviews happened by the researcher, the interviewer, but was backed with audio recordings.
The analysis of the focus group interviews revealed that there are several factors that influence design method acceptance amongst students. These have been categorised as follows, *provided material to the students within the course context*, *additional, own research initiative of students* and *team inspiration, decisions and organisational conditions*.

Figure 1. Simplified classification scheme of academical experiments with human participants

Criteria/ Boundary Conditions	**Possible Values**				
Study goal in context of research	Test hypothesis				
Study goal in context of design/ design method	Analysis: Gathering new information	Synthesis: Creating new systems/ ideas/ methods	Evaluation: Testing existing systems/ ideas/ methods		
Context of study	Research	Education			
Curricular integration	Separate	Included			
Participants level	Undergraduate/ bachelor students	Graduate/ master students, doctoral students			
Expertise of participants	Specific/ previous knowledge from lectures, additional material or similar, certain practical skills	No specific expertise			
Length of study	Short term: 1 day – 1 week	Medium term: weeks - months	Long term: > ½ year		
Length of each session	< 1 hr	1 hr – ½ day	> ½ day		
Number of sessions	One	Multiple			
Number of tasks	One	Multiple			
Type of tasks	Interview	Discussion	Reading	Sketching	Other
Group/ individual	Group	Individual			
Support	Guided workshop/ support given when necessary	No intervention			
Documentation	By researcher	By tutors/ trained personnel	By participants		

Possible in Theory Own Experiences

In the following, the experiences and reflections are bundled into categories and presented such that other study conductors can benefit from the experiences made and consider them ahead of time to manage their studies accordingly. Especially, the quality of the study should be improved by considering challenges well ahead of time.

4 RESULTS

Synthesised results yield the following challenges and recommended practices as follows.
Acquisition approach from researchers - motivate to participate. Finding the right number of participants to reliably develop results and sufficient people as well as participants with required qualifications is a challenge (Üreten et al. 2020a) and includes various aspects. This part has a lot of operational value for design method developers who want to get some ideas on how to approach students practically and with an understanding of how bias can be caused and mitigated for data analysis later on. The elements that will be presented here have a theoretical value referring to the

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choice of adequate participants. There are certain **benefits associated with students as participants** in testing design methods in empirical studies. Students have the academic background that is required to work with design methods. Depending on their level in their studies and what is required from the researchers perspective, a match can be found. Knowledge amongst students can thus be assumed to be comparable if studies are attached to a certain course. Due to the formal structures in academical contexts, reaching out to students to acquire them as study participants is facilitated. They are the target group and thus represent valuable resources. In comparison to an industrial environment, the academic environment offers an acceptable and good enough laboratory environment where variables can be better controlled. Moreover, current students are future design method developers. Therefore, a study participation may contribute to their methodological skill set that is applied in industry later and thus foster consistent design method application.

In the context of homogeneous knowledge amongst students, calibration is an important consideration.

Calibration of participants. It is important to "calibrate" participants prior to collecting data in validation studies so as to make reliable findings. Specifically, they should be comparable to each other with the variables that are not going to be tested in the experiment. For instance, if students' solution approaches should be tested to a specific design step in a new design method, all other variables should be similar or comparable amongst the students, such that causal relationships can be identified. From the experiences made, calibration is especially important with regards to the skills that are required to solve the problem given in the experiment. This can refer to technical understandings or students' methodical skill set. If one student solves the problem at hand better than another and has non-comparable skills to the other, it remains questionnable if the goodness of the design method is because of the design method adaption or the individual, advanced skill set of the student.

We have made the experiences that in empirical studies attached to a course, it can be assumed that the students are comparable as they usually require some fundamental knowledge to access a course. In the study of Üreten and Krause 2017, all course participants had finished their fundamental engineering courses. Another option is to include an input session for balancing the knowledge between participants. Moreover, knowledge tests or self-evaluation of certain skills can be collected prior to the experiment to ensure – to the best of knowledge – homogeneous conditions. It is important to balance inhomogeneity or to detect and document inhomogenity for better data analysis with regards to the goodness of the design method.

From operational perspective, the participants acquistion elements are the *channels to approach potential participants* (students), the *person who approaches potential participants* (students), the *information given to potential participants* (students) and *study participation incentives*.

Channels, ways to communicate and formats. **There are various channels on how to reach out to students,** either in person or digitally. These include, but are not limited to, the following platforms of the university or academical entity: learning and teaching platform, website of university, homepage of research institute, newsletters, electronic mail, flyer, banners, posters and placards. Besides these written announcements, oral announcements through personal contact on exhibition stands, social- or research-focused events can be made. Here, for further inspiration, we encourage researchers to get more insight through communications, media and marketing literature. The strategies there can be adapted and transferred to the process of acquiring adequate and enough study participants.

Study acquirer and context. We also made the experience that it makes a difference who is acquiring the students. The higher their trust in the person that actually does the acquisition, the higher the willingness to participate. And trust is a phenomenon itself, here we refer to the fact of natural authority and personality as well as rank in academical standing. We had studies with more formalised approaches to acquire students, say the professor of a course presenting the study with the respective researchers or undergraduate and graduate students asking for students to participate. Peers can be from same semester, higher or lower semester. Also, the goal is important. It does make a difference, according to our experience, if a professor for instance is formally inviting students for participation in a study or a graduate student is asking for support for data collection and thus a workshop participation. Also, in the student-student acquisition level, there are differences identified. It makes a difference if a tutor whom students know since a semester through regular exercises recommends a workshop or a one-time-only appear students does so. Other contexts that can be used are student union (meet-ups), exercises, lectures, project-based-learning sessions and workshops. It is not always the case that a person is doing the study acquisition from face-to-face directly. Written announcements

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from the respective research team can be on physical or digital pinboards of the university or the research institute or on online data bases. Indeed, it is worth a try to see if an existing data base offers the participants you require.

Content. Independent of which format you use, certain information should be passed on to potential participants such that they have a good basis to decide if they want to participate or not. Besides the requirements for an aesthetically appealing format of information transportation, for example eye-catching flyers. The following information should thus be included when the design method developer reaches out to potential participants (most important aspects in bold): **study inclusion criteria**, examples include participants studying mechanical engineering in graduate degree holding a bachelor in mechatronics; **location of the study**, such as university campus or digital platform; **duration of the study**, timing, or available time slots, such as the experiment takes 30 minutes, mondays from 4pm-6pm hrs or on personal availability; if preparation is required and if yes, how?; **how to register** for the study and rules for de-registering (latter can be part of another step) including deadlines; how the study relates to other projects, lectures, exercises of the university or the target groups context; their contribution to teaching and science, such as improving engineering design education for upcoming bachelor students; research team or contact; depending on how much information can be given to potential participants, information about the general topic, goal of the study and task or procedure can be given; mention if there are special risks or exclusion of certain criteria, like light sensitivity if you are planning an empirical study with light; funding institution or project (logos) and **benefits (incentives).** Each acquisition requires adaption, extension or a thoughtful combination of these possibilities. However, from one study to another, weighting of importance may change.

Incentives. The researchers planning the studies should consider an incentive for potential participants to participate in the study. The important part to consider is that participation is voluntary. There are indeed various motivators in form of incentives to foster participation. The incentives are categorised into "Expertise development", "Course-related advantages and extra-curricular opportunities" and "Financial and material reward". "Expertise development" includes all aspects that relate to a gain of knowledge, skills or change in attitudes that help to develop the participants' personal expertise in product development. One example is that students will gain experience in ideation methods, e.g. brainstorming, through their participation. Another would be that they gain experience in a real engineering task and experience team dynamics. "Course-related advantages and extra-curricular opportunities" refer to benefits that give the participant an advantage in a course they (will) attend and opportunities. These include that they can make up for one missed class in a compulsory course setting through their participation for instance or collect bonus points for an examination. "Financial and material rewards" is the monetary renumeration that is given to participants for participation but also includes vouchers for food, books or small give-aways like pens, post-its. The value of the monetary benefits of participation should be adequate, this means not too much and not too little and in compliance with ethical considerations, it can be based on hours of participation. It is recommended to consider case-specific adaptions and combinations tailored to the study goal, resources and other boundary conditions related to each empirical study.

Besides increasing motivational factors for students, elimination or reducing barriers to participation is important. We have thus analysed the studies mentioned with regards to this aspect in more detail and have synthesised the cumulated results as follows.

Reducing barriers for participation. Participation may be hindered because of organisational aspects or fear for being evaluated and graded in a course related to the examination. Organisational issues hindering may be to clashes in curricula with compulsory classes, social events or similar events (such as other complementary empirical studies or competing seminars). Furthermore, it should be transparent if and in how far their participation would – in case of attachment to a course – be part of an assessment of that greater course. Another barrier would be to expect the participant to do effortful preparation or use gadgets that are not available or accessible for the participant. It is recommended to keep these barriers as low as possible. One way to manage time issues would be to check students curriculum and schedule experiments in long free time in between two compulsory curricular activities or implement the study in a course setting. At this point, it needs to be said that registering for participation and actually participating are two totally different issues. That's why it makes sense to have optional plans for having enough data collected.

Study personnel and their interaction with students. Study personnel can already influence students, especially if the empirical study takes place within a course. Besides the personnel responsible for the

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research, any personnel acting during the empirical study may influence the validity of the data collected. There can be bias already in the researcher and the instructor behaviour. Often, these two roles are executed by the same person (Carver et al. 2006). For example, observers that are not trained well enough may start interfering with students during the experiment. Additionally, the socio-cultural experiences and educational background of the study observers can well influence their observations. Although there are standards in how to train and prepare study participants, it is still a challenge. Study observers in the above mentioned studies were students or researchers from the institute. Students were either student assistants or course participants who had organisational roles due to the course structure or student researchers completing their thesis.

There are several effects that can appear in research studies based on the study observer and study participants. These include social desirability, referring to participants who think that certain reactions are expected or even desired. Thus, their answers are influenced and they tend to give answers that are social accepted. Another example are people who want to improve their self-image in front of the experimenter (Hussy et al. 2013). These can impact the reliability of the results. Therefore, strategies to mitigate these risks or identify them and document them is of utmost importance.

Expectations from participants. Our experience is that in empirical studies attached to a course, students may participate with expectations to get support from the researchers, to progress in their task through external support provided during the experiment or get an evaluation of their deliverables in a course that will need to be handed out later. An example for the latter are the focus group interviews in Üreten et al. 2018. The final documents for course evaluation were handed in and the focus group interviews were around that topic where sometimes uncertainties in students answers were expressed and an answer towards their performance in the methodological engineering design project was expected because evaluation of the deliverables was still pending and one of the supervisors of that course was the same as the interviewer. Our suggestion is to remind students that there is no wrong or correct and their opinion will not have any influence on their grading. Additionally, the researcher may offer to answer their questions after the interview. Also, it is a possibility that students will be disappointed by the experiment and may thus be coloured in their future with regards to the design method tested in the experiment. This needs careful framing and consideration.

5 DISCUSSION

This contribution extends already existing body of knowledge by specifically analysing empirical studies in the area of engineering design focusing on testing design methods with student participants in academical context. There is a thin line between voluntary and expected participation in course-attached studies. This needs to be considered in studies with regards to the effects this may bring along as participation is voluntary. Depending on the academic institution, ethic committees are involved in assessing clearance prior to approaching potential participants to a study. There is a high and written as well as unwritten expectation in certain studies that the study conducted in laboratory fields has to or will be transferable to industry settings. There are three main points we developed based on our experiences. Instead of absolute conclusions and assumptions for generalisation, a more relativistic and case-specific approach is recommended. Also, there is a long history and it is still current practice to work with student participants in many fields of science due to various reasons, such as the goal of the study that requires students to test better educational improvements for instance, or simply the accessibility of these valuable resources with comparable background knowledge increasing the validity of the findings. It is also possible to use the laboratory setting for a pre-study that will prepare for a study in industry. This may help to check for inconsistencies in the experimental procedure and organisation and give tendencies or some first hints about the research question to be answered as well. It is important to have a transparent communication and documentation to be able to analyse more detailed the data collected.

Strenghts of this study include that the studies analysed and which form the basis of this research are comparable and in similar classifications. This set of homogeneous studies allows comparability and enables a broader and deeper insight into academical studies with students. The advantage of using studies from the own pool of experiences is that the authors themselves were involved in the steps and have access to the details, challenges and mitigation strategies used. No other party where information can be misunderstood or lost was involved.

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Limitations of this work exist. The fact that all empirical studies taken here as a basis are from the same research institute can convey ideas limited to these boundary conditions and generalisability is not necessarily given. A different university culture such as having frequently studies and students being used to it and having seldom studies with little familiarity of potential participants are different organisational boundary conditions. Cultural boundary conditions can influence the interaction between researcher-participant. Extending these views with other researchers experiences can add to detail and new perspectives. Furthermore, it needs to be mentioned that conventions evolve over time and researchers develop their own standards, such as ways to analyse and discuss data. There could be a bias that can be mitigated through incorporating other researchers unfamiliar to the institutes' conventions.

These challenges and recommended practices are also considered to extend the elements of the concept map (Üreten et al. 2019), such as "participants" and are included in the design method validation system (Üreten et al. 2020b). They are especially relevant for the planning phase of the experiment. Considering the aspects mentioned above ahead of time can support to reduce or eliminate risks to the validity of the validation study. The aspects mentioned here can support and give initial inspiration to inexperienced researchers in many other fields, such as social sciences, to become aware of the intricacies and extend their horizon by specific studies, challenges and recommended practices in engineering design as well.

6 CONCLUSION

The summary of this work is that working with students as participants for design method experiments in product development in laboratory conditions in academical context brings the advantage that comparable background knowledge of students can be assumed, less variables such as disturbing factors to the experiment or more controllable variables are involved in comparison to industry experiments and accessibility is facilitated through incorporating experiments in course-curricula or classes. At this point, efforts need to be made for keeping participation voluntary without causing bias or fear about grading due to their participation and performance in the experiment. This way, valuable resources, namely the future design method developers, will be actively incorporated in research and education. This collection of challenges and recommendations based on own experiences provides inexperienced design method developers who want to conduct an empirical study with a set of studies and support, that can facilitate their study planning and contribute to a higher research quality. One idea that can help foster the quality of the studies is that metrics can be defined for the recommended practices identified in this contribution to determine their merit and value. Later on, they need to be checked if these can become best practices for certain boundary conditions. These findings can benefit other branches of science, such as psychology, too.

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REFERENCES

Barth, A.; Caillaud, E.; Rose, B. (2011), "How to validate research in engineering design?" International Conference on Engineering Design, ICED11, Denmark.

Blessing, L. T. M.; Chakrabarti, A. (2009), *DRM, a* Design *Research Methodology*, Springer, London.

Cantamessa, M. (2003), "An empirical perspective upon design research", *Journal of Engineering Design*, Vol. 14, No. 1, pp. 1-15, Taylor& Francis. https://doi.org/10.1080/0954482031000078126

Carver, J.; Jaccheri, L.; Morasca.; S.; Shull, F. (2006), "Issues in Empirical Studies with Students", Technical Report MSU-060714.

Carver, J.C.; Jaccheri, L.; Morasca, S.; Shull, F. (2010), "A checklist for integrating student empirical studies with research and teaching goals", *Empirical Software Engineering*, Vol. 15, pp. 35–59, https://doi.org/10.1007/s10664-009-9109-9

Cash, P.; Elias, E.; Dekoninck, E.; Culley, S.J. (2012), Methodological insights from a rigorous small scale design experiment, In: *Design Studies*, Volume 33, Issue 2, pp. 208-235. https://doi.org/10.1016/j.destud.2011.07.008

Cash, P.; Stanković, T. and Štorga, M. (Eds.) (2016), *Experimental Design Research. Approaches, Perspectives, Applications*, Springer, Cham. https://doi.org/10.1007/978-3-319-33781-4_1
Jansson, D. G.; Smith, S. M. (1991): "Design fixation", *Design Studies*, Vol. 12, Issue 1, pp. 3-11, https://doi.org/10.1016/0142-694X(91)90003-F.
Eckert, C. M.; Clarkson, P. J.; Stacey, M. K. (2003), "The spiral of applied research: A methodological view on integrated design research", *Proceedings of the 14th International Conference on Engineering Design (ICED'03)*, Stockholm, Sweden.
Frey, D. D. & Dym, C. L. (2006), "Validation of design methods: lessons from medicine", *Research in Engineering Design* 17, 45–57.
Fu, K., Murphy, J., Yang, M., Otto, K.; Jensen, D.; Wood, K. (2015), "Design-by-analogy: experimental evaluation of a functional analogy search methodology for concept generation improvement", *Research in Engineering Design*, 26, pp. 77–95. https://doi.org/10.1007/s00163-014-0186-4
Hussy, W.; Schreier, M.; Echterhoff, G. (2013), "Forschungsmethoden in Psychologie und Sozialwissenschaften für Bachelor", 2nd edition, Springer, Berlin, Heidelberg. 10.1007/978-3-642-34362-9
Ko, A.J., LaToza, T.D. & Burnett, M.M. (2015), "A practical guide to controlled experiments of software engineering tools with human participants", *Empirical Software Engineering* 20, pp. 110–141, https://doi.org/10.1007/s10664-013-9279-3
Razzaghi, M.; Ramirez, M.; Zehner R. (2009), "Cultural patterns in product design ideas: comparisons between Australian and Iranian student concepts", *Design Studies*, Vol. 30, Issue 4, pp. 438-461, https://doi.org/10.1016/j.destud.2008.11.006.
Ruckpaul A., Fürstenhöfer T., Matthiesen S. (2015), "Combination of Eye Tracking and Think-Aloud Methods in Engineering Design Research". In: Gero J., Hanna S. (eds) *Design Computing and Cognition '14*. Springer, Cham. https://doi.org/10.1007/978-3-319-14956-1_5
Reich, Y. (2010), "My method is better!", *Research in Engineering Design* 21, pp. 137–142.
Svahnberg, M.; Aurum, A.; Wohlin, C. (2008): "Using Students as Subjects – An Empirical Evaluation", *Proceedings of the Second International Symposium on Empirical Software Engineering and Measurement*, ESEM 2008, Kaiserslautern, Germany. 10.1145/1414004.1414055
Seepersad, C. C.; Pedersen, K.; Emblemsvåg, J.; Bailey, R.; Allen, J. K.; Mistree, F. (2006), "The validation square: How does one verify and validate a design method?", *Decision Making in Engineering Design* (ed. Lewis, K. E.; Chen, W.; Schmidt, L. C.), pp. 303–314. ASME, DOI: https://doi.org/10.1115/1.802469.ch25
Üreten, S.; Eisenmann, M.; Nelius, T.; Garrelts, E.; Krause, D.; Matthiesen, S. (2020a), "Current Challenges and Solution Approaches in Empirical Engineering Design Research - A Workshop for Empirical Research", *Proceedings of the Design Society: DESIGN Conference*, 1, Dubrovnik, Croatia, 2020, pp. 61-70, https://doi.org/10.1017/dsd.2020.280
Üreten, S.; Spallek, J.; Üreten, E.; Krause, D. (2020b), "Validation of the Design for Mass Adaptation Method - A Case for Higher Medical Treatment Quality", *Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care*, vol. 9, 1, pp.88-100, https://doi.org/10.1177/2327857920091059
Üreten, S.; Eisenmann, M.; Nelius, T.; Cao, S.; Matthiesen, S.; Krause, D. (2019), "A Concept Map for Design Method Experiments in Product Development - A Guideline for Method Developers", *Proceedings of the 30th Symposium Design for X (DFX 2019)*, Jesteburg, Germany, pp. 147-158, https://doi.org/10.35199/dfx2019.13
Üreten, S.; Krause, D. (2018), "A Deeper Understanding of Students' Method Acceptance through Focus Group Interviews", *Proceedings of the 29th Symposium Design for X (DfX 2018)*, Tutzing, Germany, pp. 37-48
Üreten, S.; Krause, D. (2017), "Discursive vs. intuitive - An experimental study to facilitate the use of design catalogues", *Proceedings of the 21st International Conference on Engineering Design (ICED 17)*, Vol. 9, Design Education, Vancouver, Canada, pp. 99-108.
Üreten, S.; Beckmann, G.; Schwenke, E.; Krause, D.; Cao, S. (2017), "Continuing Education and Personalization of Design Methods to Improve their Acceptance in Practice – An Explorative Study", *Procedia CIRP*, Vol. 60, 27th CIRP Design Conference, pp. 524-529, https://doi.org/10.1016/j.procir.2017.01.012
Vermaas, P. (2016), "A logical critique of the expert position in design research: Beyond expert justification of design methods and towards empirical validation", *Design Science*, Vol. 2, No. e7, https://doi.org/10.1017/dsj.2016.6.

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