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Validating a method to enable distributed development teams in an engineering simulator

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Abstract

To improve distributed collaboration of product development teams, the EDiT method (Enabling Distributed Teams) was developed as support. To successfully introduce the EDiT method into development practice, it is essential to validate the method in a practice-oriented but at the same time controllable environment. Therefore, this contribution aims to validate the EDiT method in the laboratory-based validation environment of an engineering simulator. The engineering simulator covers the further development of a bending machine within two agile sprints in two days. Through the validation in a test and control group design, the effects of the EDiT method on the teams' collaboration are investigated based on three criteria: functional fulfillment, monetary return, and improvement in fields of potential. The analysis of the functional fulfillment of the developed bending machines shows that only the test groups were able to achieve comprehensive functional fulfillment. Moreover, the test groups achieve an average monetary return of €21, whereas the control group recorded a loss of €3. Finally, a subjective evaluation of the satisfaction in the fields of potential based on a 1 (not satisfied) to 5 (totally satisfied) scale shows an improvement in all measured fields of potential for the test groups compared to only one improved field of potential for the control group.

Keywords: Collaborative design; distributed collaboration; design methods; virtual teams; distributed product development

1. Introduction

The demand for intelligent, highly networked socio-technical systems is increasing. The development of these so-called advanced systems requires the intensive and continuous collaboration of various disciplines, such as mechanical engineering, and computer science but also non-technical domains like psychology and sociology. [1] Due to the geographical distribution of competence centers over the last 100 years, domains are found in different locations. As a result, companies must successfully collaborate across locations. The Corona pandemic has also intensified this need. New working models require companies to ensure a structural shift toward enabling good distributed working [1]. This can increase efficiency and productivity, make the employer more attractive, and also reduce the fluctuation rate [2].

On the other hand, new challenges, such as the lack of a shared sense of achievement or omnipresence in virtual events, are increasingly emerging [3]. Accordingly, it is necessary to support product development teams to successfully collaborate in a location-distributed manner to address the requirement formulated by Dillenbourg, Baker, Blaye and O'Malley: "... collaboration is in itself neither efficient nor inefficient" and that it is the responsibility of research to determine the conditions under which effective collaboration is possible [4]. Albers et al. have developed the EDiT method - Enabling Distributed Teams, which enables product development teams to improve their distributed collaboration [5]. For the successful

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transfer of the method into practice, its contribution to success has to be demonstrated [6]. This research complements existing field studies to validate the EDiT method and identifies direct causalities and correlations by using a laboratory-based setting. The validation focuses on the added value of the EDiT method which aims at improvements of distributed collaboration.

2. State of Research

2.1. Current understanding of distributed collaboration in product development

In literature, various definitions of distributed collaboration in product development exist. Some authors use the terms “virtual teams” or “distributed teams” instead of collaboration. Bal and Gundry describe virtual teams as conventional teams with added spatial, temporal, technological, and organizational aspects [7]. Albers et al. summarize various definitions as “Distributed product development describes the form of product development in which collaboration in the activities is characterized by at least one individual being spatially separated from other individuals. The geographical separation can be extended to organizational and temporal separation. Information and communication technologies have to be used for collaboration. Collaboration can take place both synchronously and asynchronously.” [5]

The introduction of distributed teams leads to a variety of both, new advantages and new disadvantages. The independence of a certain location, e.g., leads to a wider field of potential employees. The specific know-how, qualifications, and competencies can be kept in focus [8]. Furthermore, remote work leads to an overall cost reduction, based on lower site costs, travel costs, and personnel costs [9]. On the other hand, distributed collaboration can hamper communication and results in information loss [10]. The efficiency of a team is hence compromised. Additional disadvantages based on organizational and technological aspects broaden the dimensions of the lack of efficiency and effectiveness of a team, leading to numerous dimensions that offer possible causes for effectiveness and efficiency losses [11].

2.2. The method under investigation: EDiT – Enabling distributed teams

The EDiT (Enabling Distributed Teams) method addresses the beforementioned challenges by enabling distributed development teams to identify and develop individual improvement potentials [5]. The structure of the EDiT method follows the SPALTEN problem-solving method after [12]. Central components of the method are the success-relevant influencing factors [13] and the criticality factors [11] of distributed product development, as well as the 16 requirements of a method that enables distributed collaboration in product development [14]. Four phases represent the scope of the method: Potential Analysis, Measure Definition, Measure Implementation, and Measure Evaluation [14]. Fig. 1 shows the overview of the method and its four phases.

The EDiT method is outlined in an online guideline that provides a procedure supported by resources, tips, and tools to apply the EDiT method in a distributed development team. When applying the method, it has to be adapted to the individual development situation to unfold its full potential. This process is supported by the online guideline as well.

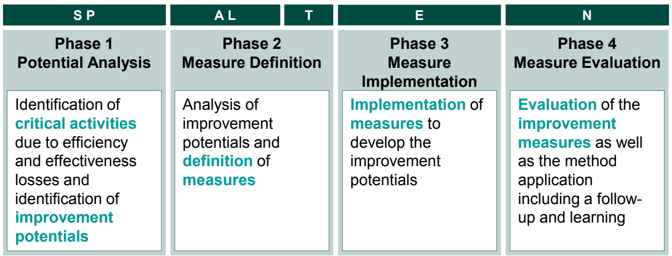

Fig. 1. Phases and the contents of the EDiT method based on Duehr et al. [15].

To foster a successful transfer of the EDiT method into practice, a focus is placed on the early and incremental validation and development of the method [15]. Different field studies have been conducted to evaluate the effects the EDiT method shows on the improvement of distributed collaboration in product development [15–19]. For this purpose, a process model for validation was developed [15]. To extend the high external validity of the field studies by studies with high internal validity, it is necessary to conduct studies in a laboratory-like environment.

2.3. Method validation in an engineering simulator

The validation of methods can be performed in different ways. This work is oriented on the Design Research Methodology (DRM) after Blessing and Chakrabarti [20]. They split the validation criteria into support, application, and success evaluation. During the development of a method, the support evaluation aims at the verification of the functionality of the method. It must be performed continuously during the method development process. The application evaluation examines the usability and applicability of the method. The third criterion, the success evaluation, targets the added value and usefulness of the method and is hence the most extensive evaluation. [20]

Both field and laboratory environments can be used to validate a method regarding the DRM criteria. On the one hand, laboratory studies show a high internal validity while they reduce the complexity of the study. On the other hand, field studies offer a better image of reality (high external validity), which makes the transfer to real situations easier. [21] A practice-oriented but laboratory near environment like the engineering simulator by Hofelich et al. [22] provides an answer to this conflict of objectives. Hofelich et al. [22] developed a concept to use an existing engineering simulator based on Omidvarkarjan et al. [23] as an environment to specifically validate product development methods regarding purpose and added value. The study simulates a product development project within a two-day timeframe. Four participants develop further an existing wire bending machine in two sprints so that it can build three-dimensional wire models. All phases of the product development process will be passed by the team. The required skills in programming, manufacturing, designing, and, laser cutting as well as the complexity of the assigned task force the participants to teamwork and a structured way of working. [22]

Based on a requirements analyses, Duehr et al. used the environment of the engineering simulator, adapted it to a distributed collaboration environment and implemented the EDiT method [24]. They created an initial validation concept based on subjective and objective criteria for the success evaluation. On the one hand, ten fields of action of distributed product development are used to perceive the subjective added value of the EDiT method. The comparison of the factors before and after applying the EDiT method in the engineering simulator can show an improvement or degradation of the participants' satisfaction with their collaboration. On the other hand, the objective determination of the added value of the EDiT method can be demonstrated by the method developer through an evaluation of two more main results: The functional fulfillment of the solution concepts and the monetary return of the bending machine. The C&C²-approach after Albers und Wintergerst [25] and Matthiesen [26] offers the possibility to quantify fully or partially fulfilled functions during the product development process. A simulated delivery to the customer allows the definition of the monetary return based on revenue and expenses. Additional information on the validation concept can be found in [24].

3. Research objective and methodology

Based on the state of research, a need arises for validation of the EDiT method to support the transfer and the acceptance of the method into practice. Based on the state of research, a need arises for validation of the EDiT method to support the transfer of the method in practice. The validation should take place in a practical yet controllable environment. In previous studies, the engineering simulator proved to be a suitable validation environment to cover the need [5]. Therefore, the goal of this contribution is to validate the EDiT method in the environment of the engineering simulator to determine the added value of the EDiT method regarding the improvement of distributed collaboration. The following research questions (RQ) are to be answered:

- RQ 1: What is a validation approach that allows determining the added value of the EDiT method regarding the improvement of distributed collaboration in the engineering simulator?
- RQ 2: What added value does the EDiT method provide regarding the improvement of distributed collaboration in the engineering simulator?

Based on initial studies by Duehr et al. that focused on a process model for the validation of the EDiT method [15] and where an initial concept to validate the EDiT method in the engineering simulator is developed [24], the validation approach to answer RQ1 is designed. Subsequently, three applications of the EDiT method in the engineering simulator with two test groups and one control group with a group size of five people are conducted. By evaluating the studies, the contribution to success of the method, i.e. if the EDiT method leads to improved collaboration, is investigated. Based on three main results from qualitative and quantitative, subjective, and objective data, that can be used to describe success in distributed collaboration, the added value of the EDiT method in the development simulator is determined. Finally, based on this, further development potentials for both, the EDiT method and the validation approach of the method in the engineering simulator are derived.

4. Study design

The initial process description of the application of the EDiT method in the engineering simulator by Duehr et al. originally contained five modules: *intro*, *sprint 1*, *retrospective*, *sprint 2*, and *outro* [24]. This procedure was extended by the authors of this work to include a second retrospective between sprint 2 and the outro. Fig. 2 shows the process description of the engineering simulator with information about the implementation of the EDiT method. During the first retrospective, the potential analysis and measurement definition occurs while the measure implementation takes place during the second sprint. The final measure evaluation is performed during a second retrospective.

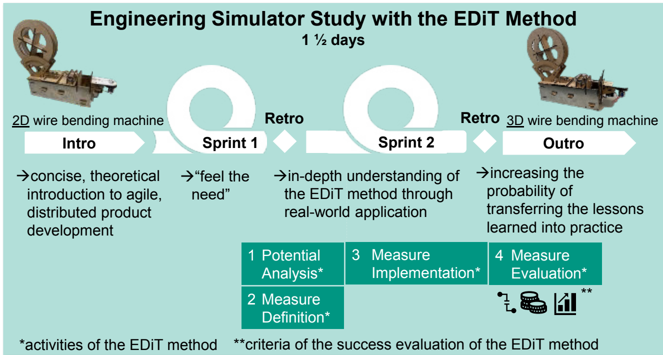

Fig. 2. Implementation of the EDiT Method in the engineering simulator (adapted illustration after Duehr et al. [24]).

Three teams participated in the study, two of them as test groups and one team as a control group. Five study participants built one team. The first two teams, the test groups, consisted of the scientific staff of the Karlsruhe Institute of Technology (KIT), while the control group consisted of students of the FOM University of Applied Sciences. The participants' professional and academic backgrounds, however, differed only slightly between the teams. The scientific staff of KIT showed a higher level in academic training whereas the students of FOM have more experience in practical design. Additionally, the team composition was not randomized since existing teams show more practical relevance. The before mentioned retrospectives contained surveys that were executed in all groups whereas the specific activities of the EDiT method (highlighted in green in Fig. 2) were only included in the engineering simulator of the test groups.

The success evaluation of the EDiT method in the engineering simulator is examined with three main results of the engineering simulator as success criteria. First, the degree of functional fulfillment of the developed solution. Second, the monetary return, and third, the improvement in the fields of potential. The data on the functional fulfillment of the developed solutions were gathered at four measuring points during the experiments by the study lead. The monetary return was based on expenses during the development process and the revenue due to the simulated delivery to the customer after each sprint. The data of the third factor was collected through the surveys during the retrospectives. The participants rated the fields of action after each sprint (t_0 and t_1), i.e., the test groups rated the fields before and after applying the EDiT method. A five-point Likert scale addressed the participants' satisfaction with the fields of action (1 – fully not satisfied, 5 – fully satisfied). Afterward, each team agreed on two fields that should be improved. Exclusively, these so-called "fields of potential" are considered within the success evaluation of the EDiT method. Since each team experienced different issues in collaboration and teamwork, the fields of potential differ and cannot be directly compared. Only when a test group and the control groups choose the same field of potential, a comparison is possible.

Based on the core result of improvement in the fields of action of distributed product development, the statistical evaluation of the development of improvement potentials was carried out to make statements about the effects of the EDiT method on the development of individual improvement potentials. For this purpose, the subjective assessment of the individual fields of potential by the study participants before and after the application of the EDiT method was used to analyze the significance of the improvement in the fields of potential. The non-parametric alternative of the t-test, the one-sample Wilcoxon test, was used to analyze the significance of the effect of the EDiT method within a group. This test was chosen because a sufficiently large sample for the t-test could not be ensured in the validation study and thus no normal distribution could be assumed [27]. The result was assumed to be statistically significant with a p-value of less than 0.05. To evaluate the statistical relevance of the effect of the EDiT method on the test groups compared to the control groups, the Mann-Whitney U test was used. There are different ways to calculate the effect sizes. Among the best known, and used in this work, are Pearson's correlation coefficient r and Cohen's effect size d [28]. The Pearson correlation coefficient r was used to calculate the effect size of the one-sample Wilcoxon test and Cohen's d is a measure of effect size for the Mann-Whitney U test, which indicates the deviation of the mean values between test and control groups [29].

5. Effects of the EDiT method in the engineering simulator

The analysis of the first core result to evaluate the success of the EDiT method is the degree of functional fulfillment. Fig. 3 displays the gathered data at the four measuring points in the middle and at the end of each sprint.

The analysis shows that only the test groups were able to gain complete functional fulfillment (100%). Although the EDiT method was not applied in the control group, the group showed a strong increase in the degree of functional fulfillment after the beginning of sprint 2. In comparison to the control group, the test groups were sensitized regarding the importance of good teamwork and collaboration at the beginning of the engineering simulator through a presentation of the EDiT method. This led to a greater focus on teamwork from the beginning, even before the first phase of the EDiT method.

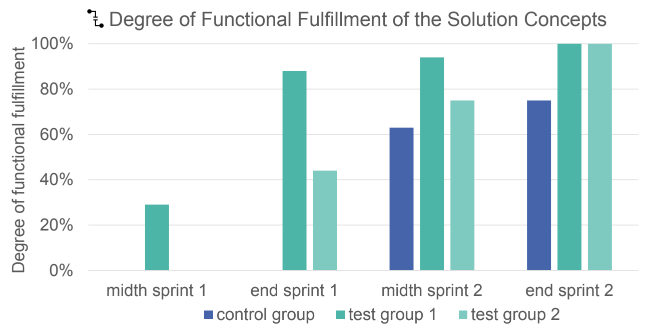

Fig. 3. Functional fulfillment of the developed solutions shows only full fulfilment for the test groups.

The data collection of the second main result, the monetary return, was executed by simulated product deliveries to the customer at the end of each sprint. Fig. 4 displays the monetary return at the end of the engineering simulator.

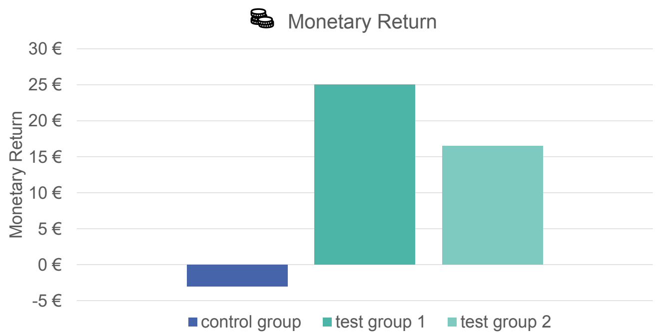

Fig. 4. The monetary return of the developed solutions shows that only the test groups achieved a monetary profit.

The test groups gained a return of +€17 and +€25 while the control group showed a negative balance of -€3 due to high expenses and low revenue. Consequently, the implementation of the EDiT method holds a positive effect on the monetary return. Yet, the uncertain validity leads to a relativization of the conclusion. The great deviation between the control and test groups could also be explained through other influences, such as the different previous knowledge of product development, agile methods, and teamwork.

The third main result to evaluate the EDiT method is the improvement of the fields of potential.

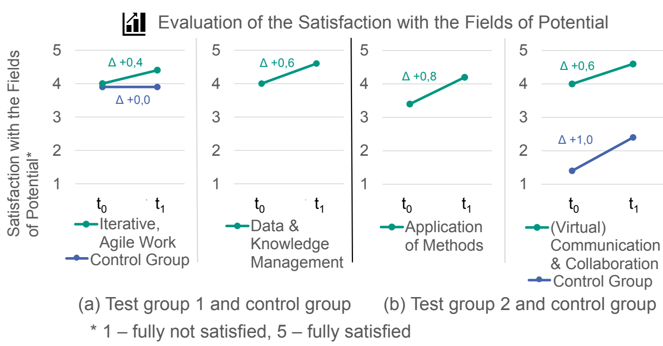

Fig. 5. The improvement in the fields of potential shows an improvement in all measured fields of potential for the test groups compared to only one improved field of potential for the control group.

Fig. 5 shows that the satisfaction with the fields was increased from retrospective 1 (t_0) to retrospective 2 (t_1) in all measured fields of potential, except for *Iterative, Agile Work* in the control group. On average, the increase in the satisfaction of the test groups was 0.6 while the average increase of the control group lists at 0.5. For that reason, a positive effect of the EDiT method regarding the improvement of the fields of potential can be observed. Nevertheless, the control group was able to gain improvement in one of their specific fields of potential without applying the EDiT method.

Table 1 shows the results of the improvements on average across all fields of potential sorted by the division into test and control groups. In addition, the table shows the reached significance and which effect size *r* was achieved by applying the EDiT method in the individual observation.

Table 1. Results of the evaluation of the improvement potentials of the control and test groups.

	Participants n	Improvement ø	Significance *p*	Effect size *r*
Control group	5	0,50	0,32	-
Test group	10	0,60	0,66	-

The average improvement in the fields of potential of the control groups is 0.5 in the development simulator with no statistical significance due to a p-value of more than 0.05. By comparing the average improvement with the values of the control groups, the test groups achieved higher values with an average of 0.6. Accordingly, the test groups with the EDiT method achieved a greater improvement than the control group without the EDiT method. In the test groups, no statistical significance is measured. The application of the Mann-Whitney U test to the improvements in the fields of potential of the test and control groups also shows no statistical significance. Due to the sample size of less than 30, the exact significance was calculated.

6. Summary, discussion, and outlook

6.1. Summary

The goal of this contribution was to validate the EDiT method in the environment of the engineering simulator to determine the added value of the EDiT method regarding the improvement of distributed collaboration. The implementation of the EDiT method in the engineering simulator war conducted based on previous studies [24]. Three main results of the engineering simulator *evaluation of the functional fulfillment of the solution concepts*, *monetary return of the solution concepts* and *improvement in the fields of potential*, were used to evaluate the effect of the EDiT method on the improvement of distributed collaboration. The analysis of the evaluation of the functional fulfillment of the solution concepts showed that only the test groups that applied the EDiT method during the engineering simulator reached complete functional fulfillment at the end of the development simulator. The evaluation of the achieved monetary return by the solution concepts showed that the application of the EDiT method by the test groups resulted in a positive monetary return. As a third result, the improvement in the fields of potential showed that there is on average a greater positive effect of the EDiT method on the fields of potential selected for improvement in the test groups.

6.2. Discussion and limitations

Several limitations must be noted. First, the success of the functional fulfillment of the solution concepts of the test groups must be contrasted with the fact that the application of the EDiT method took place after the first sprint. Accordingly, it can be observed that especially the control group shows a strong increase in functional fulfillment after the start of the second sprint, but without having received any support from the EDiT method. Nevertheless, the test groups were already made aware of the relevance of good, distributed collaboration at the beginning of the engineering simulator through the presentation of the EDiT method, which led to a stronger focus on improving collaboration even before the first phase of the EDiT method. Second, the uncertain internal validity relativizes the significance of possible conclusions regarding the monetary return. The significantly higher return of the test groups compared to the control group also could have been triggered by other influences, such as different prior knowledge. Third, despite the non-significant statistical relevance, the qualitative analysis of the improvement in the fields of potential shows a greater improvement on average. However, the control group was also able to achieve a considerable improvement in at least one of the selected fields of potential without the method.

6.3. Directions for further research

Although these results show a successful contribution to the improvement of distributed collaboration through the EDiT method, the results will be supported by further research. First, the validation environment itself offers potential for optimization. Therefore, the reduction of disturbance variables will be considered. For example, the pin for the wire bending became detached from the machine in test group 2, resulting in a time delay. In addition, the vertical movement of the pin was prevented by the design of the bending machine in some cases. Second, further research will develop a new product design task to be applied within the environment of an engineering simulator to investigate the influence of the design task on the method evaluation and the added value. Third, for the next validation activities, the definition of test and control cases will be addressed. Statistical tests support the empirical demonstration of effects so that correlations can be established. In this work, statistical tests yielded only non-significant results due to the small sample size. Accordingly, sensible sample size planning is important. Complementary, when classifying test and control cases, attention will be paid to similarities among individuals and their professional and academic backgrounds. Equal prerequisites of the participants will offer higher comparability and reduce possible advantages of individual groups.

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References

[1] Dumitrescu R, Albers A, Riedel O, Stark R, Gausemeier J. Engineering in Deutschland - Status quo in Wirtschaft und Wissenschaft: Ein Beitrag zum Advanced Systems Engineering. Paderborn; 2021.
[2] Landes M, Steiner E, Wittmann R, Utz T. Führung von Mitarbeitenden im Home Office: Umgang mit dem Heimarbeitsplatz aus psychologischer und ökonomischer Perspektive. 1st ed. Wiesbaden: Springer Fachmedien Wiesbaden GmbH; 2020.
[3] Gimpel H, Bayer S, Lanzl J, Regal C, Schäfer R, Schoch M. Digitale Arbeit während der COVID-19-Pandemie: Eine Studie zu den Auswirkungen der Pandemie auf Arbeit und Stress in Deutschland. Sankt Augustin; 2020.
[4] Dillenbourg P, Baker M, Blaye A, O'Malley C. The evolution of research on collaborative learning. In: Reimann P, Spada H, editors. Learning in Humans and Machine: Towards an interdisciplinary learning science, 1st ed. Oxford: Pergamon; 1996, p. 189–211.
[5] Albers A, Duehr K, Zech K, Rapp S. The EDiT method guideline - enabling distributed teams through situation-adequate method application. In: Anwer N, editor. Procedia 32th CIRP Design Conference: Design in a Changing World. Gif-sur-Yvette, France, 28.-30.03.2022. Amsterdam: Elsevier; 2022, 155–160. https://doi.org/10.1016/j.procir.2022.05.229.
[6] Eisenmann M, Grauberger P, Üreten S, Krause D, Matthiesen S. Design method validation – an investigation of the current practice in design research. Journal of Engineering Design 2021:1–25. https://doi.org/10.1080/09544828.2021.1950655.
[7] Bal J, Gundry J. Virtual teaming in the automotive supply chain. Team Performance Management: An International Journal 1999;5(6):174–93. https://doi.org/10.1108/13527599910298190.
[8] Hunsaker PL, Hunsaker JS. Virtual teams: a leader's guide. Team Performance Management: An International Journal 2008;14(1/2):86–101. https://doi.org/10.1108/13527590810860221.
[9] Gaul H-D. Verteilte Produktentwicklung: Perspektiven und Modell zur Optimierung [Dissertation]. München: Technische Universität; 2001.
[10] Ahuja J. Modelling the Success Factors of Virtual Team. Indian Journal of Science and Technology 2016;9(48). https://doi.org/10.17485/ijst/2016/v9i48/105874.
[11] Duehr K, Hettel V, Nix B, Dernbach F, Heimicke J, Albers A. Evaluation of the Effect of Distributed Collaboration on the Effectiveness and Efficiency of Design Activities. Journal of Design Research 2023:submitted.
[12] Albers A. Five Hypotheses about Engineering Processes and their Consequences. In: Horvath I, Mandorli F, Rusak Z, editors. Proceedings of TMCE 2010 Symposium. Ancona, Italien, 12.-16.04.2010; 2010, p. 343–356.
[13] Albers A, Weissenberger-Eibl M, Duehr K, Zech K, Seus F. Literature-based identification of success-relevant influencing factors of distributed product development. In: Mpofu K, Butala P, editors. Proceedings of the 30th CIRP Design Conference: Enhancing Design Through the 4th Industrial Revolution Thinking. 05.-08.05.2020. Pretoria, South Africa: Elsevier; 2020, 415–420. https://doi.org/10.1016/j.procir.2019.11.007.
[14] Duehr K, Schiele A, Mueller H, Kopp D, Hofelich M, Albers A. EDiT – Requirements of Enabling Distributed Collaboration in Product Development Teams. In: The ISPIM Innovation Conference: Innovating Our Common Future. Berlin, 20.-23.06.2021. Lappeenranta, Finnland: LUT Scientific and Expertise Publications; 2021.
[15] Duehr K, Grimminger J, Rapp S, Bursac N. Enabling Distributed Teams - A Process Model for Early and Continuous Method Validation. In: Proceedings of the 17th International Design Conference. 23.-26.05.2022. Cambridge: Cambridge University Press; 2022, 161–170. https://doi.org/10.1017/pds.2022.17.
[16] Duehr K, Hirsch M, Albers A, Bursac N. A METHODOLOGY TO IDENTIFY AND ADDRESS IMPROVEMENT POTENTIALS IN COMMUNICATION PROCESSES OF DISTRIBUTED PRODUCT DEVELOPMENT – AN INITIAL APPROACH. In: Proceedings of the 16th International Design Conference (DESIGN). Cavtat, Kroatien, 26.-29.10.2020. Cambridge: Cambridge University Press; 2020, 541–550. https://doi.org/10.1017/dsd.2020.35.
[17] Duehr K, Efremov P, Heimicke J, Teitz EM, Ort F, Weissenberger-Eibl M et al. The Positive Impact of Agile Retrospectives on the Collaboration of Distributed Development Teams – a Practical Approach on the Example of Bosch Engineering GmbH. In: Proceedings of the 23nd International Conference on Engineering Design (ICED21). Gothenburg, Sweden, 16.-20.08.2021. Cambridge: Cambridge University Press; 2021, 3071–3080. https://doi.org/10.1017/pds.2021.568.
[18] Duehr K, Burkhardt M, Endepols S, Machauer T, Albers A. Improving distributed collaboration at Porsche Engineering Services GmbH through the application of the EDiT Method. In: Anwer N, editor. Procedia 32th CIRP Design Conference: Design in a Changing World. Gif-sur-Yvette, France, 28.-30.03.2022. Amsterdam: Elsevier; 2022, 239–244. https://doi.org/10.1016/j.procir.2022.05.243.
[19] Duehr K, Luft T, Vierbacher D, Ebner L. Improving distributed collaboration for the development of advanced systems. In: The XXXIII ISPIM Innovation Conference: Innovating in a Digital World. Copenhagen, Denmark, 05.-08.06.2022. Lappeenranta, Finnland: LUT Scientific and Expertise Publications; 2022.
[20] Blessing LTM, Chakrabarti A. DRM, a Design Research Methodology. London: Springer; 2009.
[21] Roe BE, Just DR. Internal and External Validity in Economics Research: Tradeoffs between Experiments, Field Experiments, Natural Experiments, and Field Data. American Journal of Agricultural Economics 2009;91(5):1266–71. https://doi.org/10.1111/j.1467-8276.2009.01295.x.
[22] Hofelich M, Mantel KV, Omidvarkarjan D, Matthiesen S, Meboldt M, Schneider T. Attributes of Research Environments for modelling Engineering Simulators for design support validation. In: 31st CIRP Design Conference 2021 (CIRP Design 2021): Accelerating Product Development. Twente, The Netherlands, 19.-21.05.2021. Amsterdam: Elsevier; 2021, 678–683. https://doi.org/10.1016/j.procir.2021.05.143.
[23] Omidvarkarjan D, Conrad J, Herbst C, Klahn C, Meboldt M. Bender – An Educational Game for Teaching Agile Hardware Development. In: Ramsauer C, Wolf M, Hulla M, editors. Proceedings of the 10th Conference on Learning Factories (CLF2020). Graz, Austria, 15.-17.04.2020. Amsterdam: Elsevier; 2020, 313–318. https://doi.org/10.1016/j.promfg.2020.04.023.
[24] Duehr K, Hofelich M, Beck L, Albers A. A Validation Environment for a method to enable distributed agile product development teams. In: R&D Management Conference 2021: The future of R&D Innovation. Glasgow, Scotland, 07.-08.07.2021; 2021.
[25] Albers A, Wintergerst E. The Contact and Channel Approach (C&C²-A): relating a system's physical structure to its functionality. In: Chakrabarti A, Blessing LTM, editors. An Anthology of Theories and Models of Design: Philosophy, Approaches and Empirical Explorations. London: Springer London; 2014, p. 151–171.
[26] Matthiesen S. Gestaltung – Prozess und Methoden. In: Bender B, Gericke K, editors. Pahl/Beitz Konstruktionslehre: Methoden und Anwendung erfolgreicher Produktentwicklung, 9th ed. Berlin, Heidelberg: Springer Berlin Heidelberg; 2021, p. 397–465.
[27] Kline RB. Beyond significance testing: Reforming data analysis methods in behavioral research. 1st ed. Washington, DC: American Psychological Association; 2004.
[28] Cohen J. A Power Primer. Psychological Bulletin 1992(112):155–9. https://doi.org/10.1037//0033-2909.112.1.155.
[29] Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. New York: Lawrence Erlbaum Associates; 1988.
[30] Mai J. Validation of a Method to Enable Distributed Teams in the Engineering Simulator [Unpublished master thesis]. Karlsruhe: Karlsruhe Institute of Technology (KIT); 2022.
[31] Duehr K. EDiT- Enabling Distributed Teams: Eine Methode zur Identifikation und Erschließung von Verbesserungspotenzialen in der standortverteilten Produktentwicklung: Dissertation. (Dissertation). In: Albers A, Matthiesen S, editors. Forschungsberichte des IPEK - Institut für Produktentwicklung: Systeme, Methoden, Prozesse. Karlsruhe: Karlsruher Institut für Technologie (KIT); 2023.