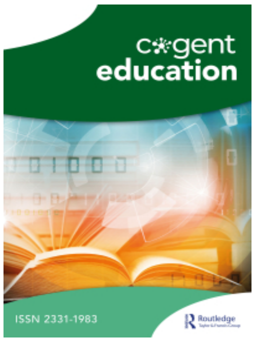
Introducing pre-training workshop sessions to enhance learning in multidisciplinary environments: a case study in computer-aided engineering



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ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/oaed20

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To cite this article: Roham Sadeghi Tabar (2024) Introducing pre-training workshop sessions to enhance learning in multidisciplinary environments: a case study in computer-aided engineering and design, Cogent Education, 11:1, 2367896, DOI: 10.1080/2331186X.2024.2367896

To link to this article: https://doi.org/10.1080/2331186X.2024.2367896

Published online: 22 Jun 2024.

COGENT EDUCATION
2024, VOL. 11, NO. 1, 2367896
https://doi.org/10.1080/2331186X.2024.2367896

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Introducing pre-training workshop sessions to enhance learning in multidisciplinary environments: a case study in computer-aided engineering and design

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ABSTRACT

Technological advancements are pushing new simulation and analytical tools, driving the research fields in design forward. In this environment, for introducing new modeling, simulation, and analytic tools, the pre-training aspect becomes important, presenting the ideas behind the tools and preparing the students to structure their already grasped knowledge and future learnings. This study aims to address the potential of efficient workshops for pre-training activities via active learning methods for introducing new concepts and tools in advanced computer-aided design. The students participate in the workshops after lectures and before their exercise session to enhance learning and reduce the ambiguity of the newly introduced topics and tools. For performing the study, a design research methodology is followed to design an efficient workshop based on research clarification, descriptive, and prescriptive study phases. The study results are assessed by direct student feedback and quantitative analysis of the student performance followed by a qualitative teacher evaluation compared to previous years. The results show that active learning workshops support pre-training, impacting the students' performance on comprehension of the utilized tools and reducing ambiguity on the related topics.

ARTICLE HISTORY
Received 20 November 2023
Revised 7 March 2024
Accepted 28 May 2024

KEYWORDS
Pre-training; workshop; interactive learning; computer aided engineering; design

REVIEWING EDITOR
A. Y. M. Atiquil Islam, East China Normal University, China

SUBJECTS
Mechanical Engineering Design; Design; Industrial Engineering and Manufacturing; Manufacturing Engineering

1. Introduction

The interdisciplinary applied education in the digital transformation era has become more challenging compared to traditional theory-based education. Technological advancements are pushing new simulation and analytical tools, driving the fields forward. In this environment, the education of applied science, i.e. mechanical engineering and design, has become challenging, not keeping pace with technological advancements. For introducing new modeling, simulation, and analytic tools, the pre-training aspect has become eminent, presenting the ideas behind the tools and preparing the students to structure their already grasped knowledge and future learnings. One critical attribute in multidisciplinary learning is the existence of students with different backgrounds and different skill sets. It is essential that the students interact before the introduction of the tools to establish a common understanding of the introduced modeling and simulation tools. In this study, a scientific approach is taken to address the pre-training aspect for the introduction of new concepts in computer-aided tools. The approach is to introduce and design a collaborative workshop environment where the students and teacher share their knowledge to create a common understanding of ambiguous or new topics. Through these workshops, the students interactively establish an

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understanding surrounding the tools and the involved disciplines to enhance their performance of individual assignments and learning.

One challenge in introducing new modeling and simulation tools and topics is the students' prior background with the tools of similar functionality. In the course, Advanced Computer-Aided Design, offered in the first study period for the Master's programs in Product Development, Production Engineering, and Industrial Design, the diverse technical background of the students creates an uneven starting point for using the modeling and simulation tool introduced in the course. In this study, the potential of pre-training activities via flipped classrooms and active learning methods are evaluated for enhancing the learning process and software familiarity. The target is to introduce pre-training activities via interactive workshops before the exercise session.

1.1. Reference course background

The course advanced computer-aided design is about creating and analyzing geometric properties of products. The course focuses on applying the theoretical geometric perspectives to create advanced geometries utilizing CAD systems, managing product attributes with Product Lifecycle Management (PLM), Systems and analyzing the geometric features with Computer Aided Tolerancing tools. The fundamental learning objectives that are tackled during this study are:

- Create advanced surface models.
- Use CAD, CAT, and PLM systems as tools in integrated product development processes.
- Apply Design for Manufacturing principles for creating assembly models.

To evaluate the learning outcome of the course, project deliveries composed of mandatory and extra, bonus assignments, as well as a final written exam are conducted. The course final grade is based on the project work (50%), and a written exam (50%). The project compromises the development of a real-sized excavator. Figure 1 visualizes a sample excavator that is designed throughout the project. The parts Bucket, Arm and Boom, Cab, Counterweight body, Undercarriage, and wheels are specifically designed for this project. The project tasks include the design and analysis aspects of the proposed design. There are eight mandatory assignments, which are performed in groups of two, and eight bonus assignments performed individually. All the tasks are approved by the course supervisors during the dedicated project sessions. During this pedagogical project, specifically, two of the mandatory tasks, namely Geometry Assurance analyzing the assembly variation of the cabin and door of the cabin assembly, and the design of the counterweight body are triggered.

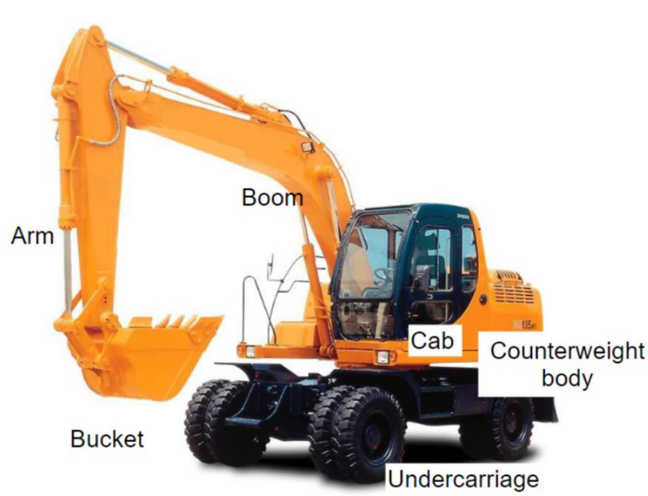


Figure 1. An overview course project: an excavator and its composing parts.

1.2. Problem statement

The main research question in this study is how the introduction of new modeling and simulation tools be supported by pre-training activities in higher education. An essential element for answering the above question is understanding what the role of pre-training activities is and how efficient pre-training activities can be designed. This question is driving this study forward to evaluate the potential of the pre-training activities to support multidisciplinary education.

The term 'complexity' in geometry design is known to be ambiguous for students. Geometric complexity is one of the main requirements for succeeding in the project assignment. Therefore, students face difficulty transferring their knowledge of complexity through the modeling tool and applying it to a designed geometry. Secondly, the introduction of new topics within computer-aided tolerancing (CAT) requires prior knowledge of positioning systems, by which the degrees of freedom are being locked in space. To be able to grasp the topic, one needs to be able to analyze and apply positioning systems on simpler geometries and later implement this aspect for geometry analysis in the project assignment. The main aim of the study is to answer the research questions surrounding the above topics.

1.3. Aim and objectives

The aim of this study is to evaluate the potential of pre-training activities to enhance learning and reduce ambiguity in multidisciplinary courses, where modeling and simulation tools from different disciplines are introduced and used. This study evaluates the potential of pre-training activities for the newly introduced topics in advanced computer-aided design and modeling and simulation tools used in this context. The designed workshops enhance learning via active learning methods and ease the implementation of the introduced topics in the tools. This aspect helps the student to perform a successful project while assuring to achieve the course learning objectives. The students will participate in the designed workshops on two occasions, once in the initial stages of the course, to enhance their knowledge about geometric complexity in a CAD context. Later, the students participated in a workshop to design and evaluate positioning systems using the CAT tool.

1.4. Scope of the paper

For designing the efficient workshop, a design research methodology is followed. In the research clarification phase, literature studies are performed to understand the role of pre-training activities in multidisciplinary education. In the descriptive study phase, the gathered data from literature analysis and expert interviews are utilized to address what the needs are and what the state of the art is for establishing pre-training activities to enable active learning in computer-aided design. Based on this data, in the prescriptive study, efficient workshops via active learning methods are designed to enhance the learning in the course advanced computer-aided design. The workshops will be designed to reduce the ambiguity of the newly introduced topics and modeling and simulation tools. Initially, a workshop will be designed to establish a common ground for the students and teachers regarding geometric complexity. Later, a workshop is introduced where the students familiarize themselves with the positioning systems and analyze and design them on simpler geometries. The simulation tool is used to analyze the stability of the designed positioning systems. To assess the success of the introduced activities, direct feedback will be gathered after each introduced activity from the students. Supervisor feedback will be gathered with respect to the ambiguity surrounding the topics of the designed activities. Finally, the course grades are analyzed to evaluate the success of the designed workshops.

2. Literature review

Workshops have been a widely utilized tool to enhance learning in STEM fields. The Webster English dictionary has defined the word workshop as: 'A usually brief, intensive educational program for a relatively small group of people in a given field that emphasizes participation in problem-solving efforts.' However, the workshop outcome is not often as desired. This aspect relates to how efficiently the outcomes are measured and compared and how the workshop is designed (Connolly, 2006). Successful workshops are often designed with a backward approach, that is, starting with the end-learning outcome. Sork has introduced a model for planning educational workshops (Sork, 1984), where the learning outcomes play a central role and formative and summative evaluations are utilized to assess the learning outcomes. Sork's model is composed of six components, firstly, surveying the planning environment. Secondly, justifying and focusing on the plan. Thirdly, clarifying the intended outcomes. Fourth, developing a summative evaluation plan. Fifth, formulating an instructional plan, and finally, formulating the workshop administration plan. Liem and Sanders (2013) have designed a series of human-centered design workshops in collaborative strategic design projects and have compared educational and professional scenarios. They have shown that the implementation of human-centered design methods is not likely to lead to diversification in educational product planning exercises concerning the innovative front of the tasks. Neumann et al. (2010) have studied and reported the outcome of interdisciplinary math and science learning design expert workshops. They have studied a framework of elements that can describe any design of a teaching-learning process in a formal way. They have highlighted the impact and the role of the learning management systems in this context. In another study, online workshops have been studied in STEM courses (Weinhandl et al., 2021). The simplest way to conduct a workshop is reported as the three elements, including a walkthrough moment, exercising around the topic, and debriefing the outcomes. In this setup, it is deemed to be essential to show and exemplify the participant's individual work rather than the workshop holder's own work. It is also essential to present insights and observations. This eventually leads to higher participation and engagement from the workshop members. Steinert has proposed twelve tips for running effective workshops for medical practices (Steinert, 1992). These twelve are: While planning for the workshop, defining the objectives, studying the audience, determining the teaching method, and designing the appropriate workshop activities. During the workshop moment, holding an introduction around the table, outlining the learning objectives, creating a relaxed atmosphere for learning, encouraging active participation, and providing relevant and practical information. During the final stages of the workshop, reflecting on the principles of adult learning, varying activities, and style, and finally summarizing the session requesting feedback, and showing enthusiasm.

Apart from the prescriptive workshop design approaches, descriptive studies on the role of interactive workshops have been conducted for educational purposes. Radke et al. have raised the importance of workshops on skill development, hands-on learning, and critical thinking of engineering students engaging in medicine-related applications (Radke et al., 2024). Pavel et al. indirectly specify the role of workshops contributing to engineering physics education in Europe, emphasizing on higher education and training actions (Pavel et al., 2024). In another study, the implementation of communication workshops for STEM students is discussed, aiming to enhance their communication skills alongside technical expertise (Jamil, 2024). Lattuda et al. have investigated the relationship among professional development, departmental contexts, and engineering faculty members' use of workshops as a part of student centered teaching activities. They identified that these activities should support faculty engagement for more efficient education enhancements (Lattuca et al., 2014). Furthermore, workshops are shown to be vital for enhancing faculty competence in implementing innovative educational approaches. In a study focusing on delivering active learning workshops utilizing experiential learning as a framework, it has been shown that the workshops result in high learner satisfaction and later success with the implementation of subject learned (Zenni & Turner, 2021). Shekhar and Borrego report a post-workshop implementation of an active learning approach for faculty development in electrical engineering (Shekhar & Borrego, 2017). Engineering workshops have been shown to contribute to the dissemination of educational innovations and the development of a community of practice in education (Bucciarelli et al., 2000). This aligns with the previous findings, which emphasize the role of workshops in overcoming barriers to reform in engineering education and promoting effective policies for the future. Moreover, workshops have been shown to be effective in strengthening engineering education research and enhancing the skills of engineering faculty in research methodologies (Soriano et al., 2019). Additionally, it has been shown that workshops play a crucial role in enhancing engineering education by integrating indigenous cultures, and pedagogical perspectives. This approach, as demonstrated in a series of faculty workshops, enriches the educational experience and promotes diversity within engineering education (Cicek et al., 2019).

Analyzing the literature, as presented above, several prescriptive studies have been identified on how a workshop should be performed. Other descriptive research has focused on the significance of the workshops in enhanced learning in engineering education and faculty development. While most of the studies on workshop design have been designated to achieve the learning outcome directly, to the author's knowledge, no studies establish a workshop as a pre-training aspect to achieve complex topics in computer-aided engineering education.

For the content of the workshop and how learning is achieved through the workshop, the literature relies much on learning theories. The nature of the multidisciplinary task requires reflections of the individuals on the task, both teacher and students, and the learning environment (Paulsen & Feldman, 1995). The content of the workshop may be designed from a meta-cognitivist and constructivist point of view (Newstetter & Svinicki, 2014). In this environment, the applicability of the active learning activities (Henderson, 2008) suite well with intriguing the reflection mechanism of the students, exposing them to multi-media material during the session and interactively asking for student responses and reflections of the tasks that are performed. With this background and the presented literature, in the next section, the methodology for designing a pre-training workshop activity is presented.

3. Methodology

The methodology to design the workshop moments has been based on a Design Research Methodology (DRM) (Blessing & Chakrabarti, 2009). The fundamental elements of this methodology are non-hierarchical loops between the clarification phase and the descriptive and prescriptive studies. Figure 2 visualizes an overview of this method. Initially, the research clarification is established, based on the presented literature analysis. Based on this analysis, an understanding of the applicability of the pre-training workshop is realized for transferring knowledge from the teachers to the students and for the students to encode information from short-term memory to long-term memory. This discussion is under the assumption of the meta-cognitivism perspective of learning (Newstetter & Svinicki, 2014), where the learner's reflective mechanism is triggered to achieve new knowledge. The ambiguous topic, based on the experiences from the previous years, has been identified, and the goals to improve these aspects of the course via the workshops have been agreed upon. The ambiguous topics have been creating advanced surfaces

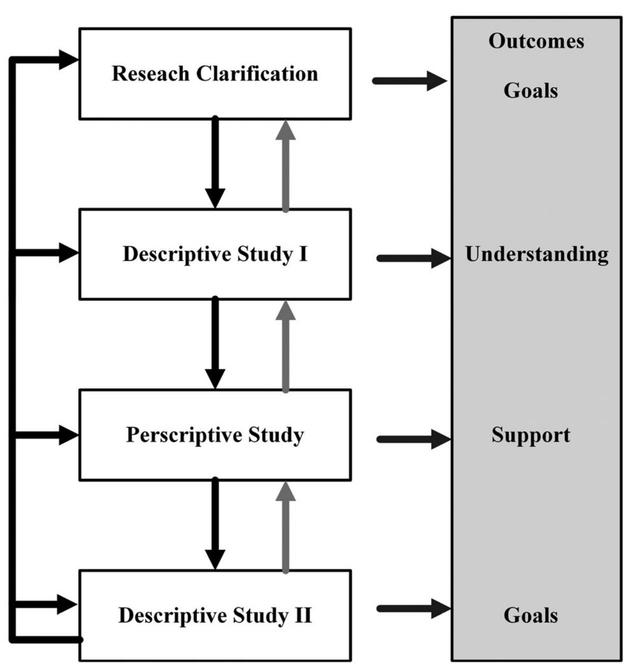


Figure 2. Design research methodology.

and performing variation simulations on the developed models. In the descriptive study 1 phase, the success criteria and design perspectives of the workshop have been studied. This is achieved through a brainstorming session, including the previous and future course supervisors. Based on this information, in the prescriptive study phase, the contents of the workshop have been established. The contents have been developed based on the teaching and evaluation method identified to be suitable during the descriptive study. For the workshop on advanced surfaces, the workshop moment was composed of an introduction part and active learning moments, followed by two demonstrations and applications in the CATIA software. The workshop on Geometry Assurance is composed of active learning activities followed by software demonstrations, applications, and reflections.

The methodology, due to time limitations, cannot be completed with the second descriptive study, as the evaluations of the results and implementations, cannot take place in the two academic years. The intention is to follow up on the achieved results and re-evaluate the goals and proposed workshop design. The other limitation of the approach is that the proposed workshop design can be considered for topics within the curriculum of the course. The application of the DRM concerning the first three phases can be represented by Kolb's cycle of experiential learning (Christie & De Graaff, 2017) and in general an action search strategy (Avison et al., 1999), where historical observations and reflections establish the problem statement, which is addressed through conceptualization and experimentation. Finally, a concrete experience around the performed action is achieved. The next section Introduces the details of the workshop design process.

4. Workshop design

In this section, the details surrounding the workshop design and its content are presented. During the clarification phase of the project, based on the literature analysis presented, it was identified that research surrounding the workshop design exists in-depth. However, comprehensive research on describing the role of the pre-training workshops in engineering education courses, specifically for computer-aided design and engineering, is limited. Therefore, in this study, the intention is to introduce workshop sessions as a medium to transfer theoretical knowledge to practice based on pre-training workshop sessions. The purpose is to identify the impact of such workshops on enhanced learning in multidisciplinary environments.

4.1. Workshop implementation

To design the workshop, based on the historical information in the course, mainly through the involved supervisors and examiners, two ambiguous topics have been identified. The two topics have been the inability to apply advanced surface models on the Counter Weight Body Assignment and Incomprehensibility of the Geometry Assurance task.

For these two topics, initially, a brainstorming session was performed to gather ideas for the workshop content, workshop administration, and organization, student evaluation, and success measures for the workshops. During the brainstorming session, six supervisors involved in the course participated and contributed. Figure 3 is the idea-board outcome of the proposed activities gathered. During this session,

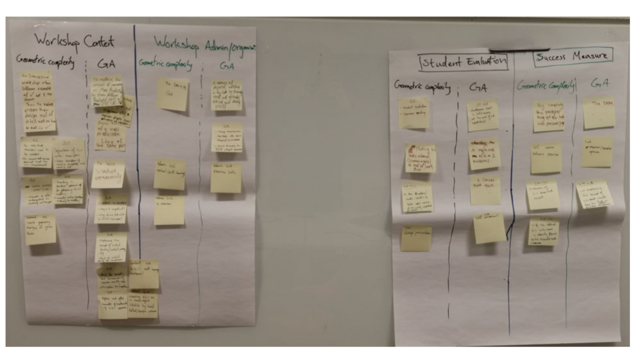


Figure 3. Idea-board outcome from the teacher brainstorming session.

22 ideas for the workshop content, nine organization alternatives, 13 assessment plans, and nine success measures have been gathered. After analyzing the gathered data, the overlaps of the suggestions have the following three contents for the Advanced Surfaces workshop:

1. Performing Geometry Analysis (Motivating why we need to create surface models and not solids).
2. Catia Demonstrations of how to create a complex geometry by surface modeling.
3. Describing the functions that are used to achieve the complex geometry.

Similarly, the following have been the overlapping content for the Geometry Assurance task:

1. Explaining the context of variation in mass production by showing different produced parts of one CAD model.
2. Real-life examples and consequences of geometric quality issues.
3. Self-learning material for the positioning systems.
4. Sketch exercise on creating 3-2-1 positioning systems and reflect and analyze the outcome.
5. Software demonstration of the relation between positioning systems, tolerances, and variation.

To cover the above aspects, two workshop moments are considered to be designed. In the advanced surfaces workshop moment, an active learning activity session is considered to cover the geometry analysis. Figure 4 is a schematic view of the workshop layout and content. The moment is comprised of a demonstration of sample products created with surface modeling and solid modeling and motivation of what, why, and when they are used. The moment is followed up by five interactive elements, where the students respond to a question about whether a product is made with surface modeling or solid modeling. Later, in the workshop, two real product design demonstrations are established to describe the functions and how surface modeling is used in industrial applications. The demonstrations include 10-min visualizations of creating a model for an airplane Wing-to-Fuselage connection. This is followed up by designing a computer mouse. After each demonstration, the students are provided with a computer exercise, where they work in CATIA and replicate the model that is created during the demo.

For the Geometry Assurance workshop, the session is composed of four segments. The session starts with a simple product visualization, both the physical part and the digital model, to show what geometric variation is and how it can impact the requirements of a product. Figure 5 visualizes the layout and content of the designed workshop. In the initial active learning activities, points 1–4 from the outcome of the brainstorming session are triggered. The second segment of the workshop encompasses live software demonstrations, followed by a computer exercise from an industrial application based on the software demonstration. After the computer exercises are completed, the active learning activities are continued with interactive questions about the analysis of the exercise.

At the beginning of the workshop sessions, the learning objectives that are stimulated are clearly specified. The workshop content is designed based on the guidelines identified in the literature studies, surveying the environment, justifying the plan, and clarifying the intended outcomes. The evaluation plan and instructional and administration plan are developed and formulated accordingly. For the

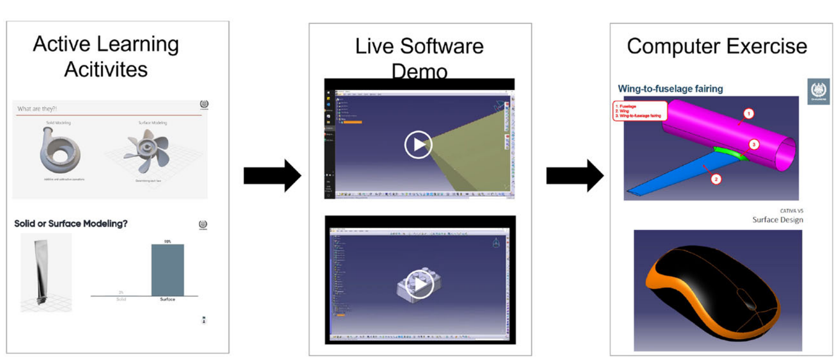


Figure 4. Workshop advanced surfaces.

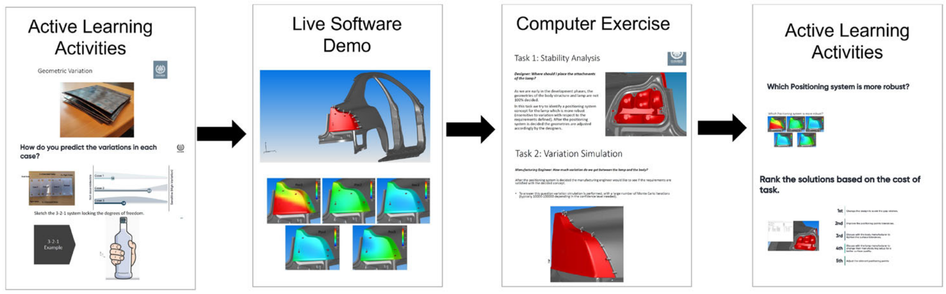


Figure 5. Workshop geometry assurance.

uniformity of the transferred information during the workshop, one large group session takes place for each workshop. This means that the class is not divided into different groups in different rooms. The workshop moments were not mandatory moments, but participation was recommended in the course memo. Due to the limitation of the availability of the computer halls for accommodating a large class, it was decided that the workshop sessions take place in a lecture hall. Although not optimal for the workshop session, the students were motivated to work in groups of two during the workshop exercises and discuss with the neighbouring participants in the active learning activities. Moreover, the students were asked to bring personal laptops to the workshop session with the installed software to be able to complete the computer exercises. The evaluation of students has been considered to follow in two perspectives. Firstly, monitoring the responses during the interactive sessions. Secondly, the performance of the students on the follow-up project tasks.

To be able to evaluate the applicability of the developed workshops, a test run of the workshops has been performed. In the next section, the details of the test run session are presented.

4.2. Test run analysis

The test run of the workshop took place, including the four supervisors involved in the course. The test run of the workshop was organized to rehearse and reflect on the content and time requirements of the designed workshop. For the workshop on advanced surfaces, the active learning environment Mentimeter was tested, and the two live demonstrations were performed, followed by computer exercises. During this session, it was identified that due to practical issues of downloading the workshop material, and potential software issues, the complete exercise could not be performed for both demonstrations. Therefore, the decision was made to prepare a follow-up exercise, which encompasses the mandatory elements triggered in the project task, based on the software demonstrations. The complete computer exercise is available for the students to perform as an extracurricular activity. The comprehensive guidelines to perform this task are prepared and made available on the course home page before the workshop. To enable student participation in the workshops, it was decided to send out an announcement on the course homepage, including an invitation to participate in the moments and instructions for how to prepare for the workshops, i.e. downloading the software and workshop material in advance. Similarly, the second workshop on Geometry Assurance was performed and tested. After running the test analysis to enable student reflection after performing the computer exercises, it was decided to include multiple reflective questions about the outcome of computer exercises, utilizing the active learning environment Mentimeter.

After the test run analysis, the workshop contents are finalized, as shown in Figures 4 and 5. In the next section, the teachers' reflections on the workshop moments are presented.

4.3. Workshop moment reflections

The two workshop moments were conducted as planned during the first two weeks of the course after the students had been lectured on the topics. Therefore, the students come to the workshop session with a background on the theory of the provided topics, and during the workshop, they get an opportunity to encapsulate the learned theories towards the application of the introduced theories. This can be seen as a meta-cognition aspect of the learning objective, enabling the reflective mechanism toward self-learning and establishing mental models.

The first reflection on performing an active learning class is never to underestimate the technical issues that may occur during the session. One issue that occurred during the second workshop session was embedding the active learning workshop content into a PowerPoint presentation. This has caused problems with the live answer updates during the sessions and interfered with the presentation mode and interrupted the workshop moment. Another obstacle has been identifying the right location to perform the workshop. Since the class is composed of ∼90 students, the smaller classrooms were not a feasible alternative since consistent presentations and tasks in all the rooms are prioritized. The other challenge has been accessing a classroom with computers where students who do not own computers can participate in the workshop. However, the majority of the students have been able to install the required software on personal computers, with the exception of five students having difficulties using their own computers during the workshop sessions. Due to this classroom limitation, the workshop moments have been performed in a lecture hall. For this reason, the nature of the workshop, where students can learn from different groups, did not function at its utmost potential. However, the students have been engaged in discussions with neighbors sitting beside them; also, discussions across the rows have been noticed.

Another aspect has been the time limitation for a workshop in the course. Performing a 45 min workshop, including several moments, can become hectic, as the time limitation may impact student focus during the hands-on exercises. It was noticed that some students did not engage in the exercises and kept themselves occupied with the exercise descriptions. Ideally, a 90-min workshop for each topic would enable more engagement, as there is no time limitation for submissions during the workshops.

Considering these reflections from the workshop moments, the students' performance on the project tasks for which the workshops are designed is monitored. In the next section, the outcomes of the workshops are presented with a qualitative and quantitative analysis.

5. Workshop outcome

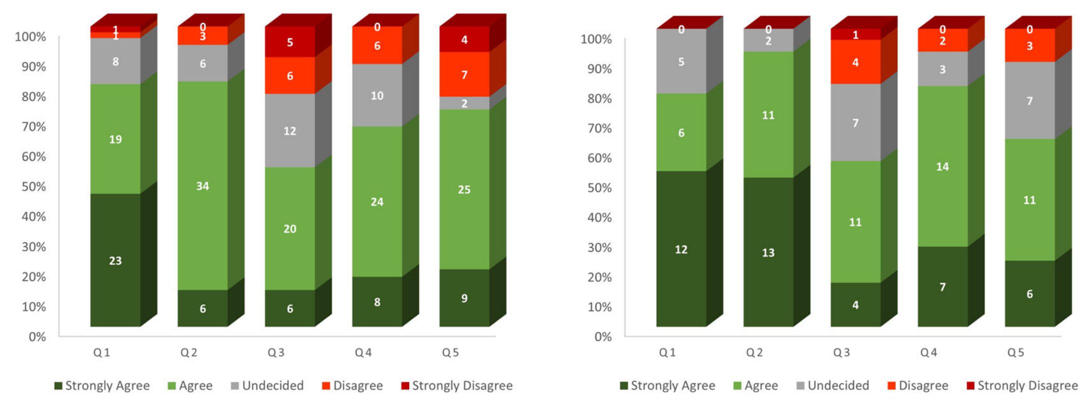
The outcomes of the workshops are measured by direct student evaluation after the workshop sessions and the performance of the workshop participants on the dedicated project tasks.

5.1. Student evaluation

To measure the students' subjective opinion on the impact of workshops, five survey questions are raised. The questions are as follows:

Q1. Would you like to participate in similar workshops built around the course learning objectives?
Q2. Were the workshop contents built around the course learning objectives?
Q3. Advanced surfaces: Was the workshop content presented to cover a range of modeling approaches (from basic to advanced surfaces)?
Q3. Geometry Assurance: Did the workshop help you to understand and perform variation analysis of different geometries?
Q4. Was the workshop moment appropriate, helping to grasp and build on previously gained knowledge?
Q5. Were the activities during the workshop clearly explained?

Question 1 (Q1) is designated to capture the willingness of the students to participate in workshops in general. Q2 intends to grasp the students' perception of how much the workshop contents were inline with the course learning objectives. The third question is about the design aspect of the workshop and reflects on the students' learning from the workshops. The fourth question aims to capture the students' reflections on the administration aspect of the workshop, i.e. appropriate date and time for the workshops. Finally, Q5 reflects on the workshop execution and workshop leaders' roles.



(a) (b)

Figure 6. Participant evaluation of the workshop, 1-strongly agree to 5-strongly disagree. (a) Advanced surfaces workshop. (b) Geometry assurance workshop.

These questions were asked in the final 5 min of each workshop, utilizing the active learning tool Mentimeter. The students could respond to each question on their smartphones or computers. The possible options for answering the questions are based on a 5-level Likert scale (Likert, 1932). The possible answer options have been 1-Strongly Agree, 2-Agree, 3-Undecided, 4-Disagree, 5-Strongly Disagree. The results of this evaluation are presented in Figure 6. The number of responses for each opinion is visualized for the above five questions Q1–Q5, for the Advanced Surfaces workshop in Figure 6(a), and for the Geometry Assurance workshop in Figure 6(b). In the next section, the teacher evaluation of the impact of the workshop is presented.

5.2. Teacher evaluation

At the end of the course, the supervisors involved in the course were asked to reflect on the outcome of the workshop. At the time of this evaluation, the students have completed their projects, and the involved supervisors have monitored the performance of the two project tasks directly related to the workshops. The two related project tasks to the workshops have been:

- Designing the Counter-Weight Body of the excavator.
- Performing geometry assurance analysis of the Door and Cab assembly.

For the approval of the project tasks, each student group has to demonstrate and discuss the performed task with a supervisor. This task is then either approved or returned for revision. Each time one of the above tasks is returned for revision, the name of the student and the tasks are noted by the supervisors. This data is later used for quantitative analyses of the workshop impact.

For teacher evaluation, a survey is completed by the seven included supervisors and senior students helping with the project tasks. The supervisors have been asked the following three questions:

1. How was the performance of the students on the counterweight body task compared to previous years?
2. How was the performance of the students on the Geometry Assurance task compared to previous years?
3. What is your opinion about the impact of the workshops on the student performance on the topics: Advanced surfaces and geometry assurance?

The results of this survey are presented in Figure 7, where Figure 7(a) visualizes the performance of the students on the Advanced Surface task compared to previous years. Similarly, Figure 7(b) is the evaluation of the Geometry Assurance task. Figure 7(c) visualizes the teacher evaluation of the perception of the overall impact of the workshops on students' performance.

Furthermore, the supervisors were asked to provide recommendations to improve the workshop or if they identified new ambiguities during the course. The responses to these questions are summarized below:

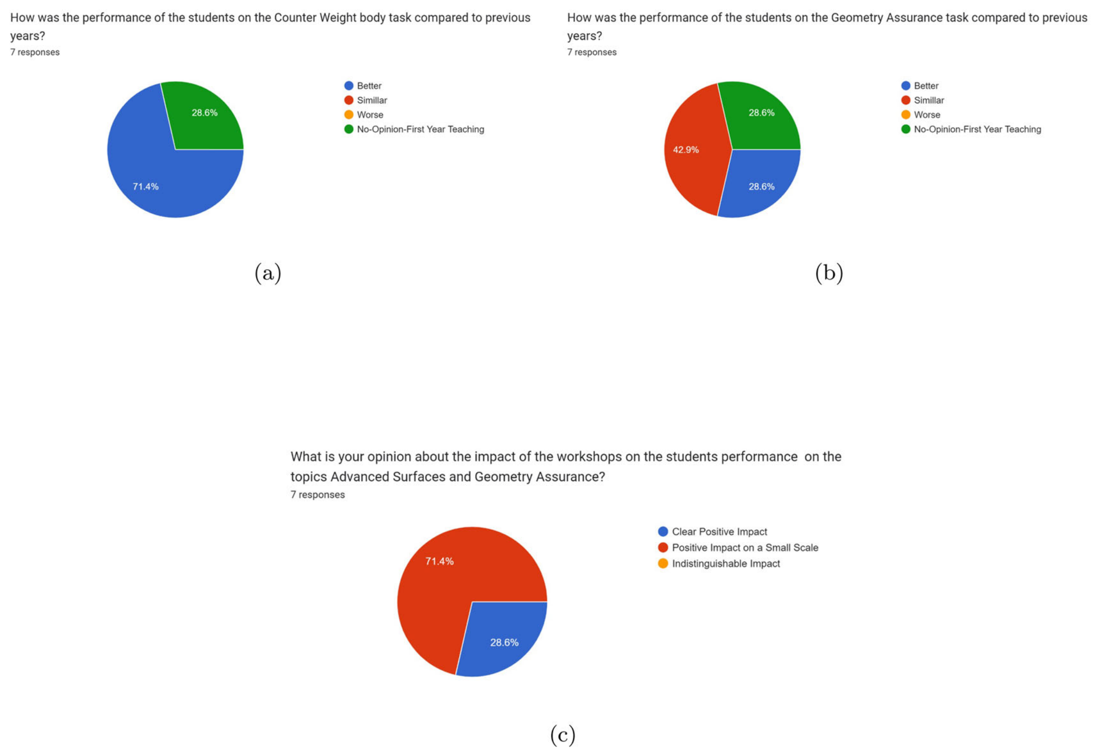


Figure 7. Teacher evaluation of the impact of the workshops. (a) Advanced surfaces workshop. (b) Geometry assurance workshop. (c) Workshops overall impact.

- **Question:** What can be done to improve the impact of the workshops on the students' understanding of advanced surfaces and Geometry Assurance?
- Response 1: Instead of several different exercises during the workshop, focus on only one so that they can go deeper into the analysis.
- Response 2: Focusing more on answering What's and Why's than How's.
- Response 3: Include a workflow of the utilized software in the workshops.
- Response 4: Inviting guest lectures or introducing industrial reports in the workshops.
- Several Responses on having longer workshop time.

Further, the supervisors have been asked if they could identify ambiguity in the project task due to a lack of understanding of the addressed topics. The responses to this question have been mostly related to the details of the project work, and going through the responses is outside the scope of this study.

- **Question:** What can be done more to improve the understanding of the new ambiguous topics?
- The summary of the responses is as below:
- A better task description, raising reflective questions.
- Improving the project memo.
- More concrete examples during lectures and exercises.

With the information about the teacher and student evaluation on the impact of the workshop, the performance of the students on the project is analyzed quantitatively. The next section introduces this analysis.

5.3. Workshop impact

For analyzing the impact of the workshop quantitatively, three sets of data have been gathered. Initially, participation in the workshop was monitored. The workshops have not been mandatory moments; for this reason, a natural division in the studied population occurs, the participating members and non-participants. Furthermore, the performance of the students on the relevant tasks is monitored. This is achieved by gathering the number of revisions that are assigned to the related project tasks for each workshop, Section 5.2. Thirdly, the project and final grades of the students have been used to analyze the performance of these two groups. The number of participants in the course has been 86 students. The first workshop session on Advanced Surfaces had a participation rate of 72.1%, and the second workshop on Geometry Assurance had a participation rate of 54.6%. The summary of the results is presented in Table 1. For the related project task, the Advanced Surface related project task had a revision-required rate of 27.9%, and the Geometry Assurance related task had a return rate of 31.4%. This is calculated by the number of revisions for each task by the number of students. This ratio is checked mostly as a point for comparison for the teachers assessing the upcoming years' student performance. To get a better understanding of the impact of the workshop, the portion of the students who participated in the workshop and completed the related project task without revision is calculated. For the Advanced Surfaces workshop, this impact rate has been 72.6%. For the Geometry Assurance workshop, the impact rate has been 63.8%. This is calculated as the portion of the students who participated in the workshop and completed the related project task without revision. Furthermore, the performance of the students who did not participate in the workshop has been monitored. For the portion of the students who did not participate in the workshop and completed the related project tasks without a revision, the ratio has been 70% for the Advanced Surfaces workshop and 74% for the Geometry Assurance. Similarly, the revision rates for the participants and non-participants are compared. For this, the number of revisions for the participants and non-participants is counted, and the ratio to the number of students in each category is established. The revision rate for the participants of the Advances Surfaces has been 27%, and for the Geometry Assurance has been 36%. For the non-participants, the revision rate has been 29% for the Advanced Surfaces and 26% for the Geometry Assurance workshop (Table 1).

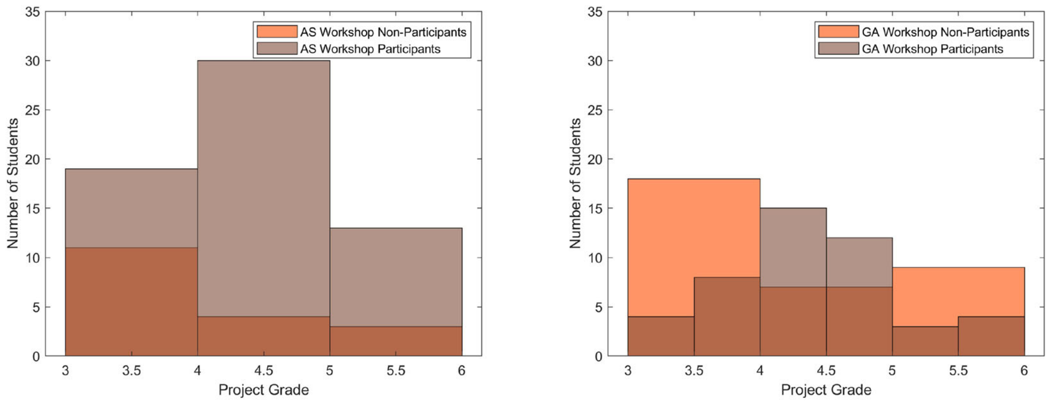
To relate the workshops to the performance on the project grade, which encompasses the topics covered in the workshop, these two aspects have been analyzed. The histograms of the project grades of all students and the participants in the workshop have been presented in Figure 8. In 8(a), the project grade related to the participants of the Advanced Surfaces workshop and the non-participants are compared. Similarly, for the Geometry Assurance workshop, these two have been compared in 8(b). The mean and the standard deviation of the project grades for the two groups have also been calculated and presented in Table 2.

This comparison has raised curiosity to further analyze the student's performance on the final grade; this grade is composed of 50% project grade, directly associated with the workshops, and 50% final written test concerning the theories of the raised topics. For this purpose, the final grades of the workshop participants and non-participants are compared in Figure 9. Again, this figure is divided into the participants of both workshops. The mean and standard deviation concerning the final grades for the two groups have been presented in Table 2.

In the next section, the discussions around the achieved results are provided.

Table 1. Summary of the workshop impact results.

Workshop	Advanced surfaces	Geometry assurance
Attendance		
Participants (P)	62	47
Non-participants (NP)	24	39
P/Total number of students ($S = 86$) ratio (%)	72.1	54.6
Revisions		
Revisions (R) (From 86 students)	24	27
R/S ratio (%)	27.9	31.4
No-revisions (NR) (From 86 students)	62	59
NR/S ratio (%)	72.1	68.6
Participation and performance		
Participants with no revisions (PNR)	45	30
PNR/P ratio (%)	72.6	63.8
Participants with revisions (PR)	17	17
PR/P ratio (%)	27.4	36.2
Non-participants with no revisions (NPNR)	17	29
NPNR/NP ratio (%)	70.1	74.4
Non-participants with revisions (NPR)	7	10
NPR/NP ratio (%)	29.2	25.6

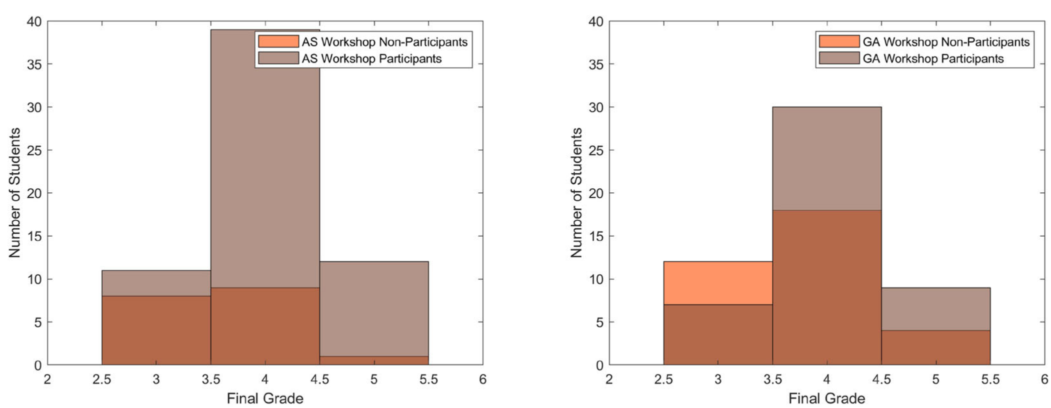


(a) (b)

Figure 8. Performance of the students participating in the workshops considering the project grade. (a) Advanced surfaces (AS) workshop. (b) Geometry assurance (GA) workshop.

Table 2. Summary of final and project grades.

AS workshop	Mean	Standard deviation
Project grades		
Participants	4.42	0.85
Non-participants	3.95	0.95
GA workshop		
Participants	4.51	0.76
Non-participants	4.05	0.99
Final grades		
AS workshop		
Participants	4.02	0.61
Non-participants	3.5	0.86
GA workshop		
Participants	4.04	0.59
Non-participants	3.71	0.80



(a) (b)

Figure 9. Performance of the students participating in the workshops considering the final grade. (a) Advanced surfaces (AS) workshop. (b) Geometry assurance (GA) workshop.

6. Discussion

The analyses of the introduced workshop impact have been provided in three facets. Student perception, teacher evaluation, and quantitative performance analysis.

6.1. Student evaluation

As visualized in Figure 6, the majority of the students are willing to participate in the workshops and have considered the workshops to be helpful with respect to content and administration being conceived as well performed. Some disagreements exist regarding the exercises and the moment of the workshop. This has been mainly due to the limited time of the workshops, not allowing all the students to concentrate on the designed exercises. Unclarity regarding the gained knowledge still exists among the students, and this is due to the uncertainty about the upcoming project, for which the students did not receive the details at the time of the workshops.

6.2. Teacher evaluation

With the responses gathered from the supervisors' experience of the course, the experienced supervisors considered the Advanced surface workshop to have an impact on the performance of the students compared to previous years. For the Geometry Assurance workshop, there has not been a major consensus among the supervisors. This can be discussed from two perspectives. Firstly, the supervisors involved in the Advanced Surfaces workshop were not directly engaged with the development of the workshop material for the Geometry Assurance task and, thereby, may have been unaware of the content. Secondly, the nature of the Geometry Assurance task requires quantitative analysis, as opposed to the Advanced surface workshop, which has been design-oriented. For this reason, the perception of the 'performance' may have been different, as the revision can be given by quantitative deviation in the student's achieved results in the project task.

In general, the teacher considered the workshops to have an impact on a small scale on the performance of the students, which agrees with the achieved quantitative results presented in the next section.

6.3. Workshop impact

The quantitative analysis of the impact of the workshop shows that the advanced surface (AS) workshop has been more successful with 73% impact, where participants performed the related task without a revision, while this rate has been 67% in the Geometry Assurance (GA) workshop. This result is also in line with the teacher evaluation where they considered the Advanced surface workshop to have a higher impact. This aspect can also be related to the participation rate of the workshops, where the AS workshop has had a 72% participation rate compared to the 55% participation for the GA workshop. Comparing this result to the students who did not participate in the workshop and succeeded with the tasks without a revision shows that a small improvement is achieved in the AS workshop, while the GA task revision does not imply any improvement between participation and succeeding in the task. Similarly, the revision rate for the participating and non-participating members shows a small improvement in the AS workshop, but the GA revision rate does not infer improvement. One discussion point in this comparison is ignoring the repetitive revisions. In this ratio, a binary approach has been performed to calculate the number of revisions. This means if a student needed revision multiple times, this has been noted as one revision. Calculating the exact number of revisions for each member may change the ratio and the comparison.

The analysis of the project grade (Figure 8) shows that the students who have participated in the workshops have a tendency to achieve a better project grade compared to the non-participating members. This can also be observed in the mean value and standard deviation of the achieved project grades in the participating and non-participating members (Table 2). From one perspective, this can be associated with the impact of the workshops on students learning of the project tasks. Looking at the final grades of the same groups (Figure 9 and Table 2), a similar trend can be observed, where the students who participated in the workshop had higher final grades. This aspect may imply that the participating students have had higher ambitions in the course in general, where they have striven to achieve higher grades, which could also drive them to perform better in the project. It should also be considered that the student groups are divided based on participation. This measure may already correspond to the students' ambition levels. Aside from this aspect, the gathered qualitative and quantitative analyses and observations imply that the Advanced Surfaces workshop has had an impact on the students' learning, enabling them to perform better on the designated project tasks, while this impact on the geometry assurance task has been marginal.

7. Conclusion

To enable student learning and transfer theoretical knowledge to application, pre-training workshop sessions have been introduced. The workshops have been designed by combining active learning activities, software demonstrations, and computer exercises. Two workshops have been designed, and the participation and performance of the students during the course have been monitored. The qualitative and quantitative results have shown that the designed workshops have had an impact on the student's performance during the course, enabling them to succeed in the related tasks. Based on the performed analysis, it can be concluded that pre-training for the introduction of new modeling and simulation tools can be achieved through efficient workshop design.

Future research includes further analyzing the impact of the designed workshops over time and monitoring the student's performance with the designed metrics. This includes taking into account different groups of students over time on different tasks. Furthermore, for a more thorough analysis, the division of the control groups can be set up with the random assignment of students in a one-occasion workshop session. Further studies on analyzing the impact of the workshop in other disciplines are highly appreciated.

Acknowledgments

The work was carried out through the pedagogical development program at Chalmers University of Technology. The support is gratefully acknowledged. The author also appreciates the supervisors and examiner active in the course Advanced Computer-Aided Design for their support throughout the course of the project.

Ethical approval

Based on the ethical review performed by the Institutional Review Board for Research Ethics (IRB) at Chalmers University of Technology, DR.nr: M22023-0289:3D it is concluded that no sensitive personal data is handled in the study and no other parts of the study fall under the Swedish Ethics Review Act.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Dr. Roham Sadeghi Tabar is a researcher at the Department of Industrial and Materials Science at Chalmers University of Technology. He holds a PhD in Product and Production Development from Chalmers. His research focuses on geometry assurance of non-rigid and complex assembled products and is conducted in collaboration with industrial partners. The research aim is to establish digital twins for the assembly process and optimize the methods and simulation tools used for securing the geometric quality. He has several years of experience in the Swedish automotive industry. He is a Research Affiliate at The International Academy for Production Engineering (CIRP) and a member of the American Society of Mechanical Engineers (ASME).

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