Focusing a Technology Teacher Education Course on Collaborative Cloud-Based Design with Onshape

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Abstract. This study proposes to enhance engineering design education in schools by integrating online collaborative project-based activities that foster the learning of new disruptive technologies and the development of skills needed in the modern world. We developed a pilot course on methods of teaching engineering mechanics that included training in 3D design and printing using the cloud-based platform Onshape. The assignment was to design a web-controlled walking robot and make its mechanism through print-in-place fabrication. In the study, we examined how participants of the course learned collaborative design with Onshape and used analytical thinking to create design solutions. The research tools included questionaries, written commentaries, and data analytics with the learning management system Onshape Education Enterprise (OEE). Based on the commentaries of course participants, we identified several characteristics of learning collaborative design, while OEE documented participants' engagement in the design projects. Responses to the questionnaires indicated that the cloud-based learning environment and the collaborative design assignment prompted the participants to analytically elaborate their designs.

Keywords: Collaborative Design, Teacher Education, Onshape.

1 Introduction

The technological innovation introduced nowadays by the current Fourth Industrial Revolution (aka Industry 4.0) is the constantly increasing set of disruptive technologies such as the Internet of Things, virtual simulation, augmented reality, additive manufacturing, machine learning, intelligent robotics, and others [1]. Our society is witnessing the rapid development of these technologies and the corresponding drastic changes it brings to our lives.

These changes demand essentially new professional competencies and skills and necessitate a qualitative upgrade of technology and engineering education in schools, widely referred to as Education 4.0 [2]. The demanded skills include technological problem solving, systems thinking, creativity, self-directed learning, and design skills. The social skills prioritized in Education 4.0, relate to collaboration with others and include project collaboration, communication, and teamwork [3].

The abovementioned knowledge and skills, some of which are all the more important today under the conditions of the Covid-19 pandemic, need to be addressed in school education and teacher training. It is the mission of technology teachers to facilitate students in the development of knowledge and skills demanded in the era of Industry 4.0 and to harness the new technologies to advance learning. To fulfill this mission, teachers should not only be proficient in teaching the concepts underlying the new disruptive technologies, but also encourage learners to develop thinking and learning skills.

Engineering design is at the core of technology education in schools. Teaching this subject in a modern way requires from the teacher a high level of up-to-date professional competencies. Hence, technology teacher education programs should include studies of learning-by-design and provide the participants with practice in learning and teaching design [4]. The key issue in teaching the subject is combining design and analysis activities to provide meaningful learning of the subject matter and foster students' thinking skills [5]. Educational literature proposes to develop higher-order thinking skills by using problem-based learning and particularly recommends engaging students in collaborative solving of authentic and ill-structured problems [6, 7].

The social distancing restrictions, caused by the pandemic, confronted the educational system with the need to replace traditional classroom teaching with distance learning. One of the main challenges of adapting to these realities is associated with the implementation of laboratory experiments and projects. Specific difficulties are encountered in moving computer-aided design (CAD) courses to the online format. In the conventional format, a design practice in such a course is conducted in a dedicated lab where students use computers equipped with licensed CAD software, and prototyping facilities, including CNC machines, and 3D printers [8]. Presently, teacher education courses should offer strategies for rearranging design practice under the constraints imposed by the pandemic.

The study presented in this paper proposes to enhance preparation for teaching engineering design by integrating online collaborative activities of 3D design and printing using the cloud-based platform Onshape. We implemented this strategy in the course "Methods of teaching engineering mechanics" which is part of the technology teacher education program. We followed up the course activities to identify characteristics of the learning-by-design process. We also searched for indications of analytical thinking applied by the students as they developed design solutions during the course.

2 Onshape and Education Enterprise

The Onshape platform is an entirely cloud-based CAD system, enabling access via any web browser on a computer, tablet, or Android and iPhone-based smartphone. Onshape enables saving models for 3D printing, does not require download and installation, and is free of charge for academic use [9]. CAD systems such as Onshape, with a relatively limited range of functions, are easier to master and thus can be suitable for use in vocational training and introductory CAD courses at technological schools. [10].

Leipold [11] notes that technical characteristics and capabilities of Onshape were widely discussed, but only a few papers on using this CAD system in academic courses have been published. Those papers did not analyze the instructional strategies, educational processes, and learning outcomes of the courses. Although some of the papers mentioned the potential of using Onshape for teaching CAD to school students [10], we did not find published studies on this subject. The only source where we found reflections of school teachers on using Onshape in class is the PTC website [12].

Onshape Education Enterprise (OEE) is a version of Onshape Enterprise intended for students' practice in mechanical design in academic and school education. OEE is a cloud-based system that records students' activities and provides the teacher with the tools to analyze them. The analysis includes filtering, organizing, sorting, and visualizing the activities. Teachers and educators, who use OEE, gain access to all metadata related to CAD documents. This includes the time that the team spent on performing the design task, individual contributions of the team members, and evolution of the design itself. OEE enables to perform advanced data analytics and to draw conclusions directed to improve the design education process.

3 Analytical thinking

Analytical thinking is defined as the mental ability to break down objects or ideas and identify and analyze their components. It comprises a set of skills: identifying and defining a problem, breaking it into components, identifying their attributes, finding relationships among the components, making decisions, solving problems, and evaluating outcomes [13, 14]. Analytical thinking is one of the central skills necessary to comprehend complexity, compare and organize information, and think critically [15].

Analytical thinking plays a major role in engineering and is among the skills which are mostly demanded by the job market. Researchers recommend facilitating the development of analytical thinking skills through problem-based learning approaches [16]. In the context of engineering design, analytical skills are crucial and applied in the analysis of requirements and constraints, identifying and exploring alternative solutions, and evaluating them against the specifications [17]. Therefore, engineering design education includes practices directed to facilitate the development of students' analytical thinking skills [18]. For example, the study [19] showed that integration of learning activities in digital design and 3D printing can be a suitable approach to foster analytical thinking and applied mathematical skills among middle school students and prospective teachers. In our current study, we extend this approach and apply it in a teacher education course implementing remote collaborative design activities.

4 The course

The course "Methods of teaching engineering mechanics" is a mandatory part of the teacher education program for students majoring in mechanical engineering education at the Technion Faculty of Education in Science and Technology. In this course, the participants learned to teach engineering mechanics in high school.

The course consists of 13 weekly meetings of four hours each, two hours of lectures, and two hours of practical sessions. Conventionally, the sessions were given in the

Faculty Laboratory of Technology, but in the fall semester 2020-2021, because of the pandemic restrictions, the course was given online. The lectures dealt with the following topics: objectives of teaching engineering mechanics at high school; the curriculum, learning materials, and assessment tools; teaching methods and evaluation strategies; and practice in lesson planning, teaching, and evaluation.

The practical sessions included workshops and a design project concentrated on learning 3D modeling using Onshape and 3D printing. The project assignment was to design a walking mechanism for a robot, based on a four-bar linkage model. The Onshape platform supported remote collaborative work of the participants on the project. They were assigned to design a mechanism suitable for print-in-place fabrication, i.e., for 3D printing as a single object with moving parts, rather than a set of parts to be assembled after printing.

The three main aspects of the design and making of the walking mechanism were:

1. Analyze Jansen's four-bar linkage leg mechanism to understand the effect of the proportion between the bars on the motion profile of the tip of the "leg" during walking. Fig. 1A presents a standard Jansen's leg mechanism. The red line in the figure shows the 2D motion profile of the tip of the leg.
2. Find an optimal four-bar linkage configuration of the walking mechanism and use Onshape to design it. Fig. 1B shows an example of a two-legged mechanism design made by one of the teams.
3. Fabricate the mechanism as a print-in-place 3D printed assembly. Fig. 1C shows the printed two-legged mechanism manually tested for walking.

A. B. C.

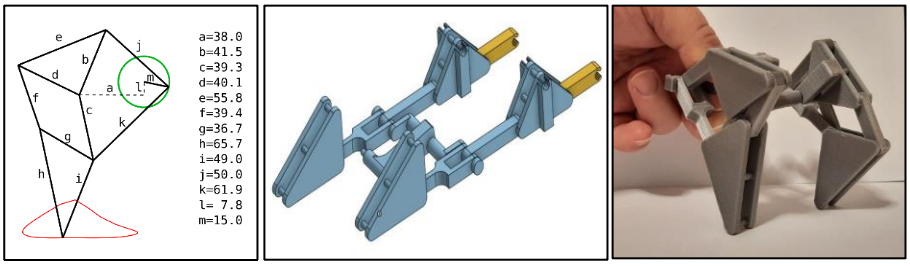

Fig. 1. A. The Jansen's leg structure and motion profile; B. A CAD model of a two-legged mechanism; C. The printed prototype.

The analysis of walking mechanisms started with a video demonstration of Jansen's mechanism. The related student assignment was to examine the geometric behavior of a simple 4-bar linkage and of a Jansen's mechanism, using online simulators. An example of such simulators can be found among the shared projects within the MIT Scratch website (https://scratch.mit.edu/). Two of those simulators, developed by "DIYwalkers" (https://www.diywalkers.com/), using Scratch are presented in Fig. 2: a simple 4-bar leg mechanism (Fig. 2A), and a Jansen's two-legged mechanism (Fig. 2B).

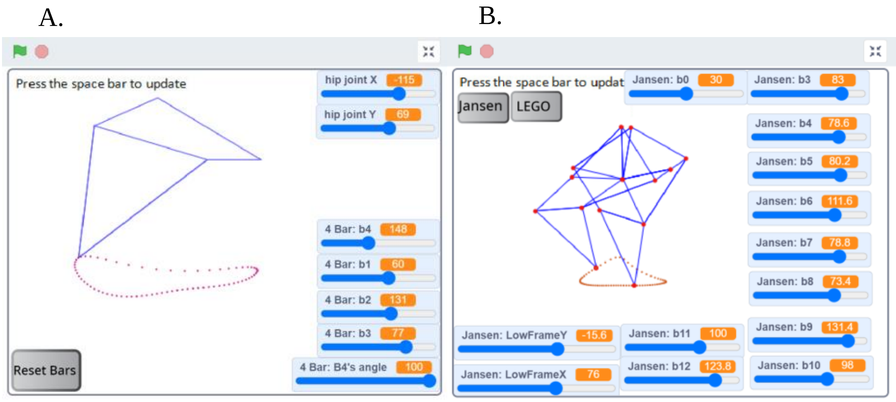

Fig. 2. A. 4-bar leg simulator; B. Jansen's two-legged mechanism simulator.

The simulators allow to change the length of each of the bars and see how it affects the motion profile leg during walking. The red dotted curve presents the trajectory of the tip of the leg. The learning assignment, based on the examination of the simulations, was to choose a four-bar linkage configuration and design a walking mechanism.

The design activity was preceded by an asynchronous (recorded) lecture that introduced 3D printing and printability. The lecture discussed the limitations imposed by the technology of 3D printing with melted plastic and print-in-place fabrication of a mechanism that should be printed in a single print task. Print-in-place design of a walking mechanism is a challenging assignment that requires careful analysis and planning and necessitates several prototyping iterations. Activities of this type are known to develop analytical thinking skills [17, 19]. Therefore, we deliberately added the print-in-place constraint to the project task to increase the complexity of the project and prompt our course participants to think analytically.

To learn print-in-place principles, the participants first designed a simple print-in-place mechanism consisting of two links connected by a joint. It took them several iterations of rapid prototyping to make a working model of the mechanism. Then, the participants designed the whole walking mechanism. After several iterations of rapid prototyping, they succeeded to fabricate a satisfactory prototype.

5 Evaluation method

The group of nine technology teacher education students participated in the course and the study was heterogeneous with regard to age (27-50), gender (one female, 8 males), academic background (mechanical, electrical, and civil engineering, and physics), academic degree (3 M.Sc, 5 B.Sc, and one undergraduate student), and teaching experience (3 in-service teachers, 5 prospective teachers). They all learned for a degree in education or a teaching certificate. The research questions were:

1. What features of teaching and learning practice in remote collaborative cloud-based design with Onshape can characterize the course?

2. How the participants applied analytical thinking to develop design solutions in a remote collaborative environment?

In this participatory case study, qualitative data were collected using questionaries, and quantitative data were extracted from records of the Onshape Education Enterprise database. The qualitative responses were analyzed to identify the characteristics of the learning practice and to find indications of analytical thinking. The quantitative data included information on participants' usage of Onshape during the design process.

To answer the first question and collect data using OEE, we set up the Onshape work environment: created an OEE group, assigned all nine participants of the course to this group, and designated 3 project teams, each comprised of 3 participants. We created a folder, in which all the working documents will be organized, and arranged access permissions for the participants. In this folder, we created a document to which the participants had ‘read/copy’ permissions, but not ‘write’ access. This document included basic tutorials, short clips, external links for reference, simple sketch examples, and hands-on work instructions. In each team, the leading team member copied this document and renamed it so the team could modify it. During the design activities, OEE automatically recorded data on each document created on or imported to this environment. The data included: authorship, modifications made to the document, Onshape geometry features used for the design, and timestamp of the design activities performed by the participants.

After the project was completed, we used OEE analytics to generate student profiles and specify for each student the total time of practice with Onshape, the created and viewed documents, the use of geometry features, and other quantitative evidence. Then we elaborated on the student profiles to characterize the learning practice with the following focal points:

- Personal contribution of team members to the collaborative design as reflected by the evidence of time spent, geometry features used, authorship of modifications.
- Instructional interactions between the instructor and the team as reflected by instructors' engagement in the team documents.

In addition, we collected qualitative data from the post-course commentaries in which the course participants were asked to openly reflect on the project task with a focus on their practice in using Onshape as a cloud-based collaborative CAD platform. We analyzed participants' reflections and used the grounded theory methodology to identify the central topics, categorize the reflections according to the topics, and extract the ideas repeatedly expressed by the participants for each topic.

To answer the second research question, we analyzed expressions of analytical thinking collected by our AlytQ questionnaire. The questionnaire was administered twice: once after the participants designed the simple mechanism, and again after designing the whole walking mechanism. Responses were received the first time from 8 participants and the second time from 9 participants. AlytQ requested the respondents to describe how they applied analytical thinking during the design process.

AlytQ also presented to the respondents a list of five cognitive processes that according to [13, 15] underlie analytical thinking:

- Problem identification - identifying and defining the problem.

- Problem decomposition - breaking the problem into components.
- Finding relationships - finding functional relationships among the components.
- Strategy formation - systematic sequencing of the process of allocating resources.
- Solution evaluation - evaluating outcomes based on established criteria.

We asked the respondents to point which of the listed cognitive processes they experienced during the collaborative design tasks.

5.1 Findings

The focus topics of the participants' post-course commentaries, revealed through data analysis, are presented below.

Prior knowledge in CAD

Though the course participants were not asked about this, most of them reflected on their background in digital design and manufacturing. The reflections indicated the group diversity regarding the CAD competencies. While some participants had little or no background in design, some others had high competencies in CAD, and experience with platforms other than Onshape. Here are two typical participants's reflections:

"For me, the field of CAD and 3D printing was completely new."

"CAD modeling is a skill I already mastered with a platform other than Onshape."

Perceptions of the project assignment

The course participants found the assignment interesting and evaluated the print-in-place design task as technically complex, novel, and challenging. They appreciated the meaningful and important learning assignment that fostered their understanding of new concepts, provided new competencies in design and 3D printing, and facilitated the development of teamwork, self-study, and thinking skills. A typical reflection:

"The idea of designing a print-in-place mechanism was new and challenging to me. It undoubtedly improved my understanding of 3D design and printing."

Perceptions of the remote collaborative design

Course participants highlighted their good and close collaboration within the project teams. The project teams were equal in strength and progressed at a similar pace. The teams were comprised of participants with different levels of competencies in design that played different roles in the team project. The participants with high design competencies led the team projects and helped their peers in learning to use Onshape. All the students noted that Onshape effectively supported their collaborative design activities. They used Onshape to follow the design progress and were highly involved in the brainstorming and decision-making during the online team meetings. The participants pointed that the project tangibly demonstrated the iterative nature of the design process. The failures in fabricating prototypes prompted their analysis and redesign iterations. From participants' reflections:

"The workload was not equally divided between team members. The team member that had CAD experience took the lead and was responsible for most of the design tasks, while others contribute ideas and did sketches or other small design tasks."

"As a team, we conducted a lot of good meetings, trying to resolve the design task. Though sometimes there was a difference of opinion, all the discussions were very pleasant and productive."

Advantages of learning CAD with Onshape

Course participants with little experience in CAD said it was easy enough to learn its basics with Onshape. For participants who had experience in CAD, practice in Onshape was an effective way to master the subject. It provides convenient conditions for remote collaborative design in online settings and good connectivity of team members working on design assignments. A typical reflection:

"Onshape is a nice software for assemblies of these sizes. The ability to share with others and work on the same folders creates a very convenient interface to work with. The software is also very convenient for those who have experience in CAD."

Aspirations to teach CAD with Onshape

All participants appreciated the contribution of the course to their progress in using Onshape to design and print artifacts, and in teaching collaborative design with this tool. Most of the participants shared their aspirations to teach CAD in high school using Onshape. A typical reflection:

"I will try to incorporate in my teaching a great deal of the skills I learned and experienced."

Participant engagement

Another source of data used to characterize the teaching and learning practice in the course project was the data analytics provided by the Onshape Education Enterprise. The collected data is summarized in Table 1. The left column lists the nine participants divided into three design teams. Each student was designated by a two-digit code. The first digit denotes the team number and the second one denotes the student number in the team. The second column shows the amount of time each student was logged in to Onshape, and the third column shows the portion of time the student work on the team-shared documents in relation to the total time spent for this purpose by the whole team. The fourth column shows the number of project documents created by each student. The fifth and sixth columns quantify the number of design features and modifications made by the course participants. The right column shows the time spent by the teacher to guide the teams.

Table 1 depicts participants engagement in the collaborative design. It indicates that three participants (1-1, 2-2, and 3-3) lead their teams: they spent much time using Onshape, mainly on designing documents and authored most of the design features and modifications. The other participants in each team used Onshape less time and with less impact on the project. The revealed differences in the level of student engagement in the design process and the differences in the perception of collaborative design can be explained by the heterogeneity of the group that included participants with different levels of competencies in design. The findings from the OEE are in line with the perceptions of the remote collaborative design expressed by the participants in the commentaries.

Table 1. Onshape use by the course participants.

Student	Logged in time [h:m:s]	Share of team time spent on documents [%]	Number of documents created	Part feature added	Number of sketch modifications	Instructor guidance time [h:m:s]
1-1	42:46:54	84%	7	143	191	02:24:21
1-2	01:23:21	10%	1	0	0	
1-3	03:07:39	6%	0	11	4	
2-1	02:41:28	4%	0	2	5	00:00:00
2-2	31:25:33	86%	9	236	197	
2-3	05:34:47	10%	3	10	20	
3-1	05:37:56	30%	10	7	0	00:00:00
3-2	03:53:38	15%	0	0	0	
3-3	12:49:14	55%	20	91	83	

Indications of analytical thinking

All the participants except one responded that they used analytical thinking during both design tasks. The participant that did not apply analytical thinking, explained that his prior knowledge of CAD software and engineering design was limited, and he felt that the level of discussion, analysis, and design was beyond his abilities. Here is a typical response:

> *"Analytical thinking was applied around the construction of the complete walking mechanism. This is a complex problem that had to be broken down into parts: the geometry of the rods, the motion of the mechanism, the translation of the motion into walking. ... Understanding each of the components' effect was necessary to combine the two legs … for a walking mechanism properly."*

We analyzed the participants' responses to the AlytQ questionnaire, to find out what cognitive processes were utilized by each of the participants. Results of this analysis are presented in Table 2. The first column of the table lists the five cognitive processes. The second and third columns present the percentage of participants that utilized each cognitive process when applying analytical thinking during the first (one joint) and second (whole mechanism) design tasks, respectively. The fourth column presents excerptions from the participants' responses that enabled us to identify the cognitive processes.

Table 2 shows that all the listed cognitive processes were applied in both tasks by the course participants. The processes of *problem identification* and *strategy formation* were identified in the first task by all the participants. We relate this finding to the fact that this was the first time that the participants faced such a collaborative print-in-place design task. Both mentioned cognitive processes remain highly relevant to the second design task. The percentage of participants who pointed out the *problem decomposition* process was about the same in both tasks. This was the most reported cognitive process in the second task. We attribute the finding to the fact that the second task was more complex. *Finding relationships* and *solution evaluation* were the least noted cognitive processes in both tasks but still identified by most of the course participants.

Table 2. Cognitive processes in the applications of analytical thinking.

Cognitive processes	Utilized by participants (%)		Typical responses
	1st task	2nd task	
Problem identification	100	75	*"Analytical thinking was [applied for] analyzing the problem. Understand what the spatial constraints are, what the printing constraints are, and how it should work."*
Problem decomposition	86	88	*"One of the steps of analytical thinking is to break down the task into elements of informative significance. We decomposed the stages of the work – in the creation of the model we designed each joint, and then they were connected for assembly. The division into tasks and preliminary planning required analytical thinking."*
Finding relationships	71	50	*"When I delved into connecting the legs to the motor, ... I realized the need to reverse (mirror) the order of the rods in the mechanism to ensure smooth movement. It also became clear that it was necessary to observe the dimensions at the point of connection of the joint axis to the mechanical arm, to allow full rotation (360 degrees) of the arm."*
Strategy formation	100	75	*"Unlike the initial task, in which we failed on several levels, here we went through another intermediate stage, in which we designed a single foot and applied lessons from all initial findings. Based on success in the intermediate stage, we designed two new legs and a body… that worked."*
Solution evaluation	57	63	*"The solution developed in the first iteration did not comply with the printability restrictions. In the second iteration, we corrected the geometric shape and re-evaluated the functionality of the part."*

6 Discussion and conclusion

The need to foster the learning of new disruptive technologies and the development of skills for life in the modern world have been widely discussed [3]. In this paper, we propose to enhance engineering design education in schools by integrating online collaborative activities. Towards this goal, we developed a teacher education course that included training in collaborative 3D design and printing with Onshape.

The Onshape platform is a cloud-based CAD system, enabling access and collaboration from any web browser. We found that this platform effectively answered the needs of our course, as it does not require download and installation, is easy to use, and free of charge for academic purposes. Our course experience with Onshape indicates the potential of using it for engineering design education at schools. The course project assignment of designing a walking robot involved the participants in a collaborative learning-by-design process. The requirement of designing and fabricating the walking mechanisms by print-in-place principles evoked the participants to deeper learning of the 3D design and printing technologies.

In this study, we had to cope with technical, pedagogical, and research challenges. The technical challenge was to develop a new online learning environment in which teacher-students can remotely acquire knowledge and skills for teaching collaborative design. To create such an environment, we had to master and apply the new cloud-based CAD system Onshape. To monitor the educational process, we applied the Onshape Educational Enterprise learning management system. To our knowledge, our paper is the first which reports on the application of this system for the evaluation of an educational process.

The pedagogical challenge was to develop and conduct a teacher education course, combining foundations of design education with project-based learning practice in collaborative design and fabrication of mechanisms. We had to engage the course participants, learning from their homes, in collective practical activities. The participants designed the mechanical systems collaboratively, while we remotely monitored and scaffolded their work.

The educational research challenge was to follow up a heterogeneous group of learners who remotely participated in collaborative design activities. We coped with this challenge by applying the OEE system as a tool that provided objective data on the participants' engagement in the collective design activities.

Our findings characterize the design practice in the course regarding participants' prior knowledge in CAD, their perceptions of the remote collaborative design project with Onshape, and aspirations to teach CAD with Onshape. All the participants, both CAD beginners, and experienced users found the remote collaborative activities rewarding, instructive, and meaningful for their future teaching practice.

The multifaceted design task prompted the participants to apply different thinking skills, among them analytical thinking, which is regarded among the central professional life skills. The participants developed design solutions by actively applying analytical thinking and the underlying cognitive processes.

In conclusion, we believe that despite the limited research sample and extent of design activities, our case study shows the value of learning practice in online collaborative design and the potential of Onshape to support different learners, even under the condition of remote access. We call for further exploration of such practice to enhance engineering design education in schools.

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