Title:

Examining CAD Usage in a Two-Day Design Sprint

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Introduction and related work:

Design sprints, the problem-solving events tailored to specific organizational contexts, have evolved beyond their traditional applications. They are increasingly utilized as active learning approaches within project-based learning (PBL) across diverse domains in an educational setting. Design sprints are relevant in computer programming, UX/UI design, design, and product development [1]. These well-planned events incorporate steps and tools to generate creative solutions and test them [2], thus offering students a problem-solving setting within shorter and more intense time frames.

The growing emphasis on design sprints within engineering design raises a question of whether the Computer-aided design (CAD) systems and their associated activities are suitable for integration within that format, particularly in the context of PBL. Examining CAD activities has been gaining considerable research attention, especially after the transformation of CAD systems from standalone to collaborative, transitioning from local computers to cloud-based, synchronous systems accessible from any web browser. This attention is driven by the ability of collaborative CAD systems to address common collaboration challenges within standalone CAD, such as seamless file-sharing issues, synchronous creation and editing limitations (e.g., working on the same CAD model in the same CAD environment in real-time), and the real-time visibility of design changes [3]. Furthermore, collaborative CAD systems also provide a platform for non-intrusively capturing information about the design process within CAD, ensuring it does not impact or interfere with either the designer or the process [4]. Specifically, collaborative CAD systems enable the recording of designers' CAD actions. This data can then be used as a proxy when examining the overall design process within CAD.

Regarding the research studies conducted in that manner, Gopsill et al. [5] proved the potential of that approach for the monitoring and assessment of designers and the engineering design process. In addition to that, researchers have been extensively studying various aspects of collaborative CAD activities by examining both behavioural (e.g., CAD user actions and their sequences) and outcome aspects (e.g., quality of representations of design compared to design requirements) [6]. Individual- or team-based activities are often compared when studying collaborative CAD. Thus, Sadeghi et al. [6] proved that teams outperform individual designers. In contrast, individuals within teams demonstrated slightly lower performance (in terms of completeness of the CAD model and time required to complete the model) compared to their counterparts working alone. Conversely, Phadnis et al. [7], by comparing pairs with individual designers working in collaborative CAD, found that the pairs demonstrated lower CAD performance and generated CAD models of lower quality. Furthermore, recording CAD designer actions enabled Celjak et al. [8] to compare low- and high-performing student teams during the PBL CAD course and to analyse individual contributions of teams' members and found that they performed more creating than editing actions at the beginning, while this trend inverted at the end of the course. In the other study, the same authors discovered CAD user archetypes in a design team setting based on the analysed CAD actions:

- Part specialist or a team member performing the majority of part CAD actions,
- Assembly specialist or a team member performing the majority of assembly CAD actions,
- A versatile team member which covers both part and assembly domains and tends to perform the most CAD actions within the team.

The various aspects mentioned present a potential for examining collaborative CAD activities. It is particularly interesting within the context of PBL, especially in the format of design sprints. Therefore, as the initial step toward the overarching goal of investigating the suitability of CAD activities in the design sprint format within an educational context, this preliminary and exploratory study's objective is to analyze collaborative CAD activities on a team and an individual level.

Methodology:

The study collected data from an internationally distributed PBL design course, focusing on the two-day design sprint event with four virtual student teams (Teams A, B, C, and D) from four European universities. Each team, consisting of ten members, included participants from all four universities, totaling 40 mechanical engineering students spanning both undergraduate and graduate levels. The gender distribution comprised three females and 37 males, leading to Teams C and D being exclusively male, while Teams A and B had 2 and 1 female participants, respectively (Table 1). Participation required completion of a CAD course at the associated university. Throughout the course, each team received support from one or two academic coaches who facilitated the process. Furthermore, the project task was to develop a personal transportation sidewalk vehicle guided by design requirements provided by an industrial partner involved in the project. The project lasted the entire semester, starting with the initial workshop, followed by three phases (problem definition, conceptual design, and embodiment design), each initiated as a design sprint activity.

Our research primarily focused on the third phase, specifically the third design sprint activity, conducted online. During this design sprint, teams conducted an embodiment design for concepts selected in the previous conceptual design phase. The objective was to create a detailed CAD model utilizing Onshape, the collaborative, multi-user, cloud-based CAD system. The third design sprint spanned two days, totaling eight hours, with four hours allocated daily (from 16:00 to 20:00 on Thursday and 15:00 to 19:00 on Friday). Due to the geographical separation of student team members, they utilized MS Teams as the online communication tool. Students had the flexibility to self-organize while working collaboratively. After the design sprint, each team presented the final CAD models to the industrial partner representatives, receiving feedback and grades on CAD model maturity, design approach, and the feasibility of the solution. Based on the grades outlined in Table 1, teams A and C are designated as the higher-graded teams, and teams B and D are the lower-graded teams.

	Participants		**Grades**			**Team label within the study**
	Male	Female	CAD model maturity	Design approach	Solution feasibility	
Team A	8	2	4	4	4	Higher-graded
Team B	9	1	2	2	3	Lower-graded
Team C	10	0	4	4	3	Higher-graded
Team D	10	0	3	2	2	Lower-graded

Tab. 1: Team participants and design sprint outcome information.

Additionally, to analyse CAD usage patterns at both team and individual levels during the design sprint, CAD user actions were recorded as analytical data in a chronological audit trail (Onshape log file). The data within the log files encompasses CAD actions related to constructions and modifications in the CAD document, such as sketch creation or part deletion, as well as behavioural actions like tabswitching. Each data point in the collected dataset includes timestamps, document and tab details, the performing team member, and the name of the CAD user action. Furthermore, CAD actions, such as those automatically logged by a CAD system and the redundant actions from the multiple recorded actions for only one CAD action (e.g., when a user creates a sketch) [8] were excluded from the dataset (data cleaning). The subsequent analysis of the acquired dataset utilised a coding scheme derived from previous works [5,9]. The coding scheme includes four classes of CAD actions: *Creating*, *Revising* (*Editing*, *Deleting*, *Reversing*), *Viewing*, and *Organizing*, with details provided in Table 2 Finally, to fulfil the study's objective, the analysis centres on identifying shares of each CAD class at both the team and individual levels. The data analysis was performed using Python scripts created by authors.

Creating	**Revising**			**Viewing**	**Organizing**
	Editing	Deleting	Reversing		
Add part studio feature, Add assembly feature, Add assembly instance, Copy paste sketch	Start edit of part studio feature, Start edit of assembly feature, Set mate values	Delete sketch feature, Delete part studio feature, Delete assembly feature, Delete assembly instance	Cancel Operation, Undo/Redo Operation	Open a tab, Close a tab, Call animate actions	Create version, Merge branch, Branch workspace, Update version

Tab. 2: Classification of CAD actions.

Results and discussion:

Analysis of CAD actions performed by four student teams during a two-day design sprint in the embodiment phase was conducted on a team and an individual level. After the data cleaning, the acquired data resulted in 11192 CAD actions from four analysed teams. Team A executed 3136 actions, Team B 3782 actions, Team C 1682 actions, and Team D 2592 actions, as shown in Figure 1. Thus, the total number of CAD actions at the team level did not relate to the final grades at the end of the design sprint event. Additionally, team-based analysis revealed that actions categorised as *Revising* and *Viewing* were the most frequently executed CAD actions, regardless of the grades assigned to the four teams. Notably, the lower-graded team exhibited the smallest or the largest difference between these two CAD action classes, while the higher-graded teams displayed a similar difference. Specifically, *Revising* actions accounted for 41.5%, 33.4%, 40.4%, and 52.1% of total actions performed by Teams A, B, C, and D, respectively. Similarly, *Viewing* actions comprised 35.9%, 32.7%, 47.3%, and 21.1% for Teams A, B, C, and D, respectively. Furthermore, the percentage of *Creating* class remained at a similar value of CAD action share for two lower-graded teams and higher-graded team A, covering around 20% for higher-graded team A (20.1%) and both lower-graded teams B and D (17.8% and 20%). The other higher-graded Team C had a share of 9.3% *Creating*. The least represented CAD class in all four teams is *Organising*, with higher-graded teams having a share of 2.5% and 3.0% for Teams A and C, respectively. Conversely, lower-graded teams exhibit a higher share in the total number of performed actions per team (16.1% and 6.8% for Teams B and D, respectively). The analysis indicates that, despite variations in the total number of CAD actions, similar CAD strategies were employed across all teams.

Moreover, teams primarily created designs in CAD based on approved concepts and, most of the time, revised the created design. Differences in the shares of *Revising* and *Viewing* actions between teams indicate that analyzing CAD actions solely at a team level might be insufficient for comprehensive conclusions. Therefore, beyond the CAD usage analysis, focusing on aspects related to communication and coordination, as well as analysis of the final CAD models (their geometry and complexity) could provide valuable insights.

Furthermore, analysis of performed CAD actions on the individual level, as shown in Figure 2., provides insights into the contribution of each team member’s share of CAD actions in the four teams. Not all team members contribute equally in all four teams, with each team having at least one member who contributes the most, irrespective of the obtained team grade at the end of the design sprint. Interestingly, the higher-graded Team A stands out for uniformity in the share of CAD actions among team members. In this case, all team members (#1-3 and #8-10) with uniform contributions have the same share of *Creating* and *Revising* CAD classes. Additionally, the team member (#4) who contributed the most according to the share of CAD actions within the whole team has the same share for the respective CAD classes. However, that team member's higher contribution is in the *Viewing* class's higher share. Furthermore, all teams have at least one team member who either does not contribute or contributes below 1% of the total share of the observed team. Teams A and B have only one such member (#7 and #1, respectively), whereas Team C has three of them (#1, #2, #6, and #8), and Team D has two of them (#5 and #6).

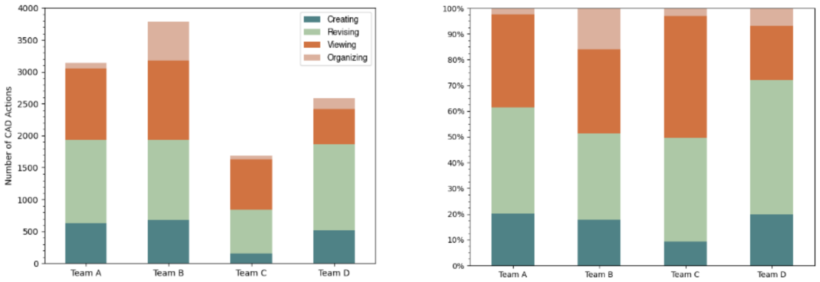

Fig. 1: CAD actions distribution – absolute (left) and relative (right).

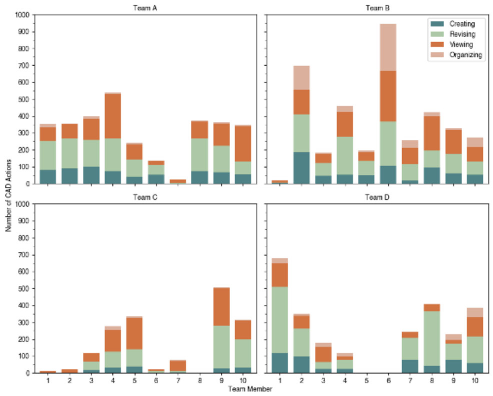

Fig. 2: Individual contribution of team members in a two-day design sprint event.

Furthermore, most team members who contribute follow the patterns described in the team-based analysis, except for a few members in each team. For instance, some members performed more *Creating* actions than *Viewing* (#1 in Team B, #2 in Team B, and #2 and #7 in Team D). Similarly, there are team members who exhibit more *Revising* actions than *Viewing*, although on the team level, those actions have a similar share (#1, #2, and #8 in team A, #2 and #4 in team B, #10 in team C, and #1-2 and #7-8 in team D). Conversely, the opposite is also evident, with some team members having more *Viewing* than *Revising* actions, including the already mentioned team member #4 in team A (#10 in team A, #8 in team B, #4-5 in team C, and #3 in team D). Although the variations among individual team members in terms of executed CAD actions (both total and concerning the CAD action class) can not be related to the team grades based on this analysis, it is evident that lower-graded teams each had two members responsible for organizing work within CAD systems. It is highlighted by the higher share of *Organizing* actions in the bar charts within Figure 2. Specifically, these team members are #2 and #6 in Team B and #9 and #10 in Team D.

In addition to the observations made on the individual level for the four analysed teams, two insights can be drawn. Firstly, aligned with the team-based analysis, the analysis should also focus on the insights related to the coordination or planning within teams during the design sprint, as teams may have planned the design sprint differently. For example, despite being higher-graded, Team C conducted fewer CAD actions with fewer members contributing than the other teams. It suggests they may have different approaches to coordinating or planning activities during the design sprint event. Secondly, there is an indication that team members exhibit different roles within teams that extend beyond CAD usage. It is evident in the varying number of inactive team members, suggesting that they might be responsible for other tasks during the design sprint. These tasks could include ensuring that the work progresses as planned or searching for possible solutions utilizing other approaches than the CAD that are further created and revised by other team members in the CAD system. Thus, the analysis can serve as a basis for evaluating teams and individuals within those teams, focusing on qualitative aspects like coordination and planning during design sprint activities. Moreover, it can be utilized to identify team members' roles within their respective teams, as reported in a study by Celjak [4]. In conclusion, the study suggests combining quantitative analysis with qualitative insights can provide an understanding of team dynamics and individual contributions.

Conclusions:

This study investigated integrating Computer-Aided Design (CAD) activities in the context of design sprints within PBL. Analyzing data from an international PBL design course, the research explored individual and team-level CAD usage during a two-day design sprint using Onshape, a collaborative cloud-based CAD system. Results showed that the total number of CAD actions at the team level did not directly relate to final grades. Teams, regardless of grades, commonly prioritized *Revising* and *Viewing* actions. On the other hand, higher-graded teams tended to prioritize the creation and revision of a design within CAD systems. Individual-level analysis revealed varying contributions among team members. This study contributes insights into collaborative CAD activities during design sprints, emphasizing the importance of understanding team and individual dynamics. Future research could explore the impact of communication, coordination, and planning design sprint activities on CAD contributions and further investigate team members' roles in the design sprint setting.

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