Title:
Exploring the Potential of Tracking CAD Actions in Project-based Courses

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Introduction and related work:

Project-Based Learning (PBL) is a student-centered pedagogical approach where students play an active role in the learning process by working on a challenging problem [1]. PBL encourages students to actively participate, integrate knowledge, and remain motivated by working on real-world problems, therefore supporting contextual learning [2]. Furthermore, by working in teams, PBL pursues students to debate ideas, exchange knowledge, communicate their ideas and findings, discuss problems, etc., which leads to students developing collaboration skills. Implementation of PBL in university CAD courses offers students an opportunity to work independently on a real-life product design assignment over an extended period [1].

Computer-Aided Design (CAD) is an indispensable tool in engineering design [3]. The current CAD paradigm supports the approach in which engineers work asynchronously on a part or an assembly [4]. This causes the emergence of several issues in the context of collaboration. Namely, file sharing is not intuitive due to the requirement of other software such as data management tools (e.g., Google Drive, Dropbox) [5] to share files. Additionally, with multiple users working on the same project and the design process being iterative, any modifications needed to be made cause longer iteration cycles [5]. Driven by the need to solve mentioned issues, as well as the improvements in geometric computing algorithms, and the emergence of cloud computing, collaborative CAD is becoming the state-of-the-art in CAD design [3]. The synchronous environment of the multi-user computer-aided design (MUCAD) enables real-time collaboration. Consequently, this simplifies the process of file sharing and the version of the model is always up-to-date [5], therefore addressing the aforementioned flaws of the traditional CAD. To improve the CAD environment in the context of PBL, another novelty is being introduced as MUCAD enables innovative ways of gathering data that may inform educators about the team and individual progress within a course. However, methods of teaching and monitoring actions in a synchronous, collaborative environment are currently uncertain. Therefore, it is necessary to design an approach for monitoring actions in the MUCAD environment to be able to assess the collaboration, as well as the individual contribution of the team member.

Both in CAD and MUCAD, research with data analytics of actions performed by users has always been part of the efforts of improving the design quality, as well as work and collaboration efficiency [3]. To gather said data, Rosso et al. [6] use a data logger for Autodesk Inventor and capture each command, its details, timestamp, a user that carried out the action, and file on which it took place. Data was

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gathered during an experiment in which 12 users were tasked to assemble given parts in the shortest time possible. Eves et al. [4] developed their collaborative MUCAD software and conducted an experimental study in which four multi-user teams and four single-user teams competed to create the best model of a hand drill. Collected user interface analytics contained the timestamp for all buttons pressed, the name of each button pressed, and the part file in which the user modeled. Leonardo [7] and Deng et al. [3] used OnShape with integrated analytics to collect data for their experimental studies. Deng et al. [3] conducted their study during an open design challenge where participants were tasked to design a playground. Leonardo [7] used cloud-CAD analytics from an industry partner.

Therefore, data of user behavioral analytics has a great potential to bring improvements to the current understanding of design team behavior within the CAD environment. While the aforementioned researchers provided insight in tracking CAD actions, they conducted their studies on small-scale experiments. This paper aims to explore the potential of tracking CAD actions during a PBL course and suggest how to analyze CAD collaboration for educational purposes.

Approach to analyze student design teams in a project-based CAD course:

Our study was set up to track CAD actions performed by students in MUCAD collaborative environment during a project-based course and explore their potential in conducting collaboration analysis. As shown in Fig. 1, firstly, CAD data requirements for the PBL course are to be identified. For the purposes of this research, the gathering of CAD actions data in terms of modeling was identified as a requirement. Secondly, it is important to prepare a CAD environment for the PBL course. With collaboration analysis being an objective of this study, it is essential to secure a MUCAD collaborative environment capable of registering and storing the data of CAD actions performed by students. Stored CAD action data is then ought to be acquired in a format that contains all actions performed during the PBL course conduction, a user who performed them, timestamp of their execution, and the name of the document in which they were performed. Furthermore, to prepare gathered CAD actions data for analysis, software-specific actions should be filtered and separated from those performed by users. Subsequently, a classification is defined for recorded actions. This is vital as interrelations between categories are more comprehensible than those between actions themselves. Finally, the analysis of CAD log data is conducted, both on a team and an individual level. The purpose of the analysis conducted on an individual level is to understand the individual contribution and impact on the created model, while the analysis conducted on a team level provided insight into the overall dynamics of model making.

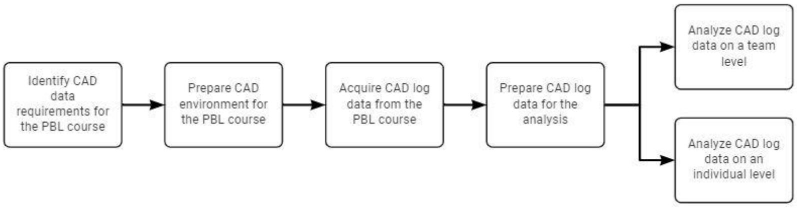

Fig. 1: Suggested approach for tracking CAD actions.

To better understand modeling patterns, data of CAD modeling actions must be collected. The implementation of this approach starts with identifying a suitable CAD software that meets the aforementioned requirements. Hence, OnShape was selected as a CAD tool which students will use to complete their assignments. OnShape is a cloud-based MUCAD software that offers a synchronous collaborative environment. OnShape features versions, branches, releases, and merges which expand the capabilities of data management, as well as automatically recording actions performed by each user within a document as a chronological audit trail. Given that the requirement of this course is for students to work in teams, this course implements OnShape as the MUCAD tool.

Data was gathered using the aforementioned data analytics feature which registered and stored actions performed by students within an audit trail throughout the duration of the CAD course. Besides actions performed by students, audit trail records “OnShape-specific” actions as well (e.g., Update Metadata, Content update, etc.). To provide an accurate representation of the collected data, it is important to filter one from another before conducting data analysis. Furthermore, actions performed by users associated with creating technical documentation were also isolated due to the focus of this study being on the creation of a CAD model. The remaining actions performed by the user were then analyzed. This preliminary analysis led to the discovery of redundant actions clustered by timestamp values, e.g., when a user inserts a sketch, OnShape registers four actions – Add part studio feature, Commit add or edit of part studio feature, Insert feature: Sketch, Add or modify a sketch. Redundant actions were addressed and removed. The remaining actions were then categorized based on the action type classification shown in Fig. 2. The classification was adapted from previous research [2,6] and includes seven general categories: *creating*, *editing*, *deleting*, *reversing*, *viewing*, *organizing*, and *other*.

Action Type Name	Creating	Editing	Deleting	Reversing	Viewing	Organizing	Other
Summary of Sample Actions	Add part studio feature Add assembly instance Add assembly feature Copy paste sketch Linked document insert STEP file import Paste: instance	Start edit of part studio feature Start edit of assembly feature Set mate values Change configuration Configure suppression state Start assembly Move to origin Move part Replace part Fix part Unfix part Suppress part Unsuppress part	Delete assembly instance Delete part studio feature Delete assembly feature	Undo Redo Operation Cancel Operation Reset mates to initial positions	Show Hide Animate action called	Delete tab Create tab Rename tab Move tab Rename document Restructure subassembly Create new folder Update document description Change Vendor Copy workspace Move document Branch Workspace Select context Update context Create version	Assign material Metadata updated by user Change properties Change part appearance Export STEP/pdf/doc file Open tab Comment on a Document Restore previous Use best available tessellation Use automatic tessellation setting

Fig. 2: Action type classification, adapted from Deng et al. [3] and Rosso et al. [6].

The final requirement is a tool for processing and analyzing data recorded in audit trails. We modified open-source Python scripts from Deng et al. [3]. Sample actions shown in Fig. 2 are defined in a python script which then counts the number of occurrences of a specific action in the audit trail. Python script then visualizes the number of occurrences of all actions defined within a category in form of a graph.

The proposed approach is implemented on a design course. The main goal of the course is to familiarize students with CAD tools and the CAD environment in the context of designing CAD models, while also developing cooperation, problem-solving, and time management skills. As part of the course, students work in three-member teams on embodiment and detail design assignments. The assignments are given in the form of a preliminary sketch based on which students had to design. Hence, as the goal of the course is to teach students CAD modeling, it is necessary to understand their modeling patterns and potentially help them correct their approach.

Empirical study results and discussion:

Analysis of CAD actions performed by one team was conducted on an individual level as well as on a team level. The acquired data results in 22324 actions from an analyzed team. After the filtering and eliminating of actions not generated directly from user actions, as well as those associated with technical documentation, this number was reduced to 8820 actions. Fig. 3(a) shows how these 8820 actions are distributed. Actions defined within the *editing* category were most frequently used with 25% overall usage, followed up by the *reversing* category with approximately 20 %, *creating* and *other* categories are next with around 15% each, while *viewing* category records slightly above 10% usage. Finally, *deleting* and *organizing* categories are the least frequently used. As shown in Fig. 3(b), actions performed by students throughout the duration of the CAD course are analyzed on a team level and equally distributed in deciles. The percentage of the *creating* category through the first four deciles is maintained at about 20% and slightly higher than in the other six deciles. *Editing* actions are generally increasing throughout the duration of the course as they grow from 12% to slightly below 50% in the ninth decile. Students focused more on creating new parts and assemblies in the first four deciles. Later, their focus gradually shifted towards editing existing parts and assemblies. However, in the last decile, there is a sudden drop in the percentage of *editing* actions. This drop could be due to finishing the design and moving to the last phase of creating initial technical documentation. Percentage of *reversing* actions varies between 10 % and 25 % across all the deciles. A higher percentage of *reversing* actions may be contributed to users exploring different features (e.g., versions and branches, assembly mates, etc.) of the software [3]. As for the *deleting* category, it registers its highest percentage in the first decile. This can be attributed to the lack of user experience with new software, as well as trying out the possibilities. Similarly, there is a high percentage of *viewing* actions performed in the first decile, as well as in the second one. A high percentage of *viewing* actions is also recorded in deciles 8 and 9, which implies that users were using hide and show functionalities to achieve a better overview during the modeling of the final assembly. Finally, *organizing* actions are notably used in deciles 2, 5, 6, and 10. This can be attributed to students not managing their workspace properly and reorganizing it by renaming tabs and documents, changing the description of a part or a document, updating context, etc.

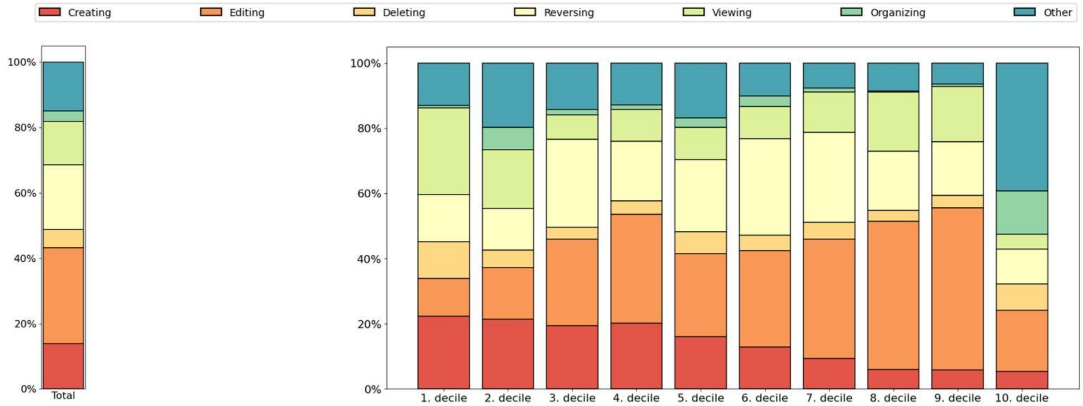

Fig. 3: (a) Decile distribution of actions performed by a team through the design process, (b) Total distribution of actions performed by a team through the design process.

Actions recorded in the audit trail were further analyzed for each student team member (TM) and divided into deciles. Results in Fig. 4 show the number of performed actions by a user from each category defined in the classification, as well as their overall contribution to the assignment. For most of the deciles, TM3 has the most actions performed, while TM2 had the least. TM1 greatly contributed in deciles 1, 2, and 4, moderately contributed in deciles 3, 5, 8, and 10, and barely contributed in the remaining deciles. Fig. 4 shows TM1 and TM3 working collaboratively at the start of the CAD course, while the assigned design was not fully defined yet. Actions performed by TM1 and TM3 in the first decile show similarities in percentages *creating*- and *editing*-wise. The second decile shows TM1 increasing the number of performed *creating* and *editing* actions, while TM3 focused more on organizing the workspace. The third decile shows TM3 performing close to 400 *creating* and *editing* actions, while also recording a rather large number of *reversing* actions. After the fourth decile, most of the work was done by TM3, with TM1 joining in occasionally, viewing the progress, and contributing with *editing* actions. TM2 contributed to the last decile by performing some *organizing* actions as well as the *other* actions.

Despite the project-based course being a team activity, students must be graded individually and fairly to reduce the imbalance between contributions of each student [1]. Accordingly, the results shown in Fig. 4 greatly simplify the process of identifying students who are not contributing at all due to the bar chart providing an insight into the overall contribution of each student. Eves et al. [4] report different sources of frustration for MUCAD users being identified, with one of them being discontent with colleagues' contributions. We imagine this was surely the case for the analyzed team with TM2 barely contributing. Deng et al. [3] state that quantitative data provides a more objective insight into CAD learning for educators to use for the assessment of students. Furthermore, quantitative data should be used complementary to qualitative data for a credible assessment of students' work. Indeed, this study revealed disparity between the contribution of team members during their work in a PBL CAD course, supporting the thesis of assessing student teams using both quantitative and qualitative data.

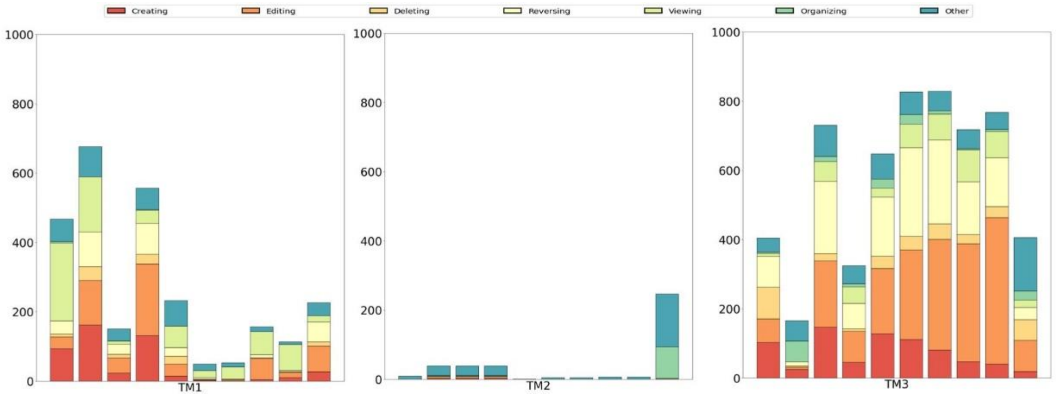

Fig. 4: Decile distribution of actions performed by an individual user through the design process.

Conclusions:

By recording and categorizing students' performed actions during their course in a collaborative CAD environment, an approach for analysis of actions performed by students, both on a team and an individual level, as well as their behavior has been presented. Through the analysis of data recorded in the audit trail, it was possible to analyze and observe actions performed by students during their work on the assignment of the CAD course. The proposed approach could be used to better understand team collaboration while working in CAD as well as provide insights into individual contributions to the design. Based on obtained results, conclusions that relate to the *creating* and *editing* actions were drawn. Students were prone to conducting more *creating* than *editing* actions in the beginning, later that trend inverted. We conclude this is due to students firstly creating all parts needed for assembly and later on, after receiving feedback from control points, editing said parts.

Scholars and educators can utilize this approach to analyze actions performed by students in PBL design courses. The proposed approach could be helpful for educators to visualize and assess individual students' performed actions. These insights may also assist educators in developing workflows optimized for MUCAD collaboration.

Future work should include assessment of the overall CAD model, its completeness, features used, functionality, etc., as well as a better understanding of individual students' contribution and identifying the amount of synchronous collaborative work between students. This should yield conclusions that may lead to better collaboration practices as well as to a better overall designed product.

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