Title:
All’s not Fair in CAD: An Investigation of Equity of Contributions to Collaborative Cloud-based Design Projects

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Introduction:

The need for collaboration with Computer-Aided Design (CAD) tools is rising in all contexts. In industrial practice, development is increasingly happening on distributed, global teams. In education, teamwork and collaborative design are now widely recognized as critical attributes of graduating engineers. Collaboration requires the contribution of many, and can be a key driver for innovation. Yet traditional CAD, which is on-premise, licensed by seat, and hardware dependent, has long been a solitary activity, with not-yet-seamless collaboration.

The rise in collaborative need is matched by a transformation of CAD software with the emergence of cloud-based collaborative CAD, or multi-user CAD [4], [6], [7]. These new platforms make it possible to collaborate with other designers in real-time, in a multi-tenant environment, where changes are synchronously updated to the model. For example, Onshape’s multi-tenant cloud architecture means that, rather than storing copies of the document in a cloud database, all changes to the document are recorded to the database. This enables real-time collaboration on CAD models (like Google Docs), and also allows the export of an “audit trail” of any users’ actions over time for more detailed analyses. Cloud-CAD lowers access barriers to use, since the most up-to-date version of the software is automatically shared with all members of a team, and all users have access on their own machines.

In this paper, we will re-examine a cloud-CAD data set from a team design exercise to describe how the analytics from Onshape can deliver a metric of team member contribution. We expand on a published analytics framework, namely the Multi-User CAD – Collaborative Learning Framework (MUCAD-CLF) [2]. We will identify a trend of individual dominance, where one team member does a majority of the CAD work, and we will then analyze the CAD actions that this dominant individual takes, looking for gatekeeping behaviour. We discuss implications of this phenomenon and propose future work towards improved contribution equity on collaborative CAD teams.

Data Collection and Analysis:

In order to demonstrate the problem and our analytical approach, we re-examine data collected from a design project assigned in a 13-week course, previously published in [1]. The course is a mandatory part of the teacher education program at the Technion Faculty of Education in Science and Technology, training students who major in mechanical engineering education to teach high school students. A group of nine students participated in the course and completed the design project in groups of three. The group consisted of one female and eight males, with age ranged between 27 to 50, and more demographic details were reported in [1].

The assignment was to teach students 3D modeling and 3D printing by tasking them to design a walking mechanism for a robot using the Jansen's four-bar linkage leg mechanism. Students needed to collaboratively analyze the mechanism, find optimal configuration of the mechanism, design the mechanism in CAD, and eventually fabricate the mechanism through 3D printing. A sample of this design sequence, from the initial analysis to the final prototype, is shown in Fig. 1.

All students were asked to design in Onshape, a web-based multi-user CAD platform. Onshape's cloud-native architecture stores all changes made to a document along with a timestamp and the user who made the change. In any Onshape Edu Enterprise, users with sufficient permissions can access this full list of changes (called the audit trail) through the Analytics portal, and filter it by user or other criteria. The resulting audit trail data can be downloaded, as was done here for this analysis.

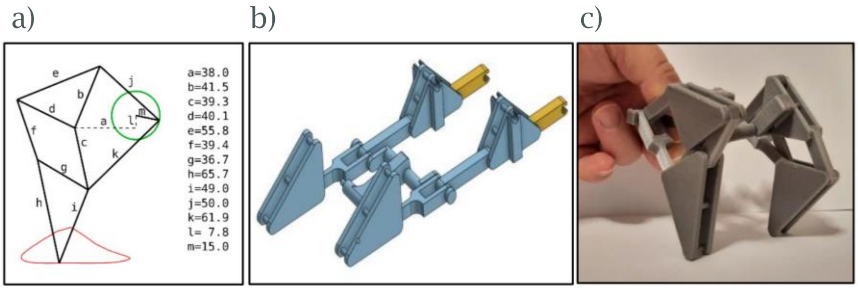

Fig. 1: The design activity, a Jansen's leg structure a) structure and motion profile b) CAD model and c) printed prototype. Image from [1].

Analytical Approach

The MUCAD-CLF aims to study collaborative learning activities in a MUCAD environment by first classifying user actions in two classification frameworks. Through grouping and comparing different action types in the framework, special characteristics of users and teams can be identified. With 22,270 data entries (10140, 8855, and 3275 entries from each of the three teams) collected from Onshape Analytics, data were analyzed through self-built Python scripts, open-sourced in [3].

The Design Space Classification, shown in Tab. 1, separates all Constructive Actions, actions that make visible changes to the CAD document, from other Organizing Actions, such as Browsing and version control. A typical design process first starts with creating a sketch, then the sketch is converted to a 3D part through different 3D Features. These parts are then inserted in an Assembly, where various Mating tools are available. Users can navigate the Assembly through different Visualizing actions.

Design Space	Constructive Actions				Organizing Actions	
	Part Studio		Assembly			
Action Type	**Sketching**	**3D Features**	**Mating**	**Visualizing**	**Browsing**	**Other**
Summary of Sample Actions	Add/ modify a sketch	Add/edit a Part Studio feature	Add/delete a part from Part Studio	Drag parts/ workspace	Create/ delete/ rename a tab	Create/merge version/ branch
	Copy/past a sketch	* Delete a sketch/ Part Studio feature	Insert/edit/ delete an Assembly feature	Call animate actions	Open/ close a tab	** Undo/redo/ cancel an operation

* Deleting a sketch is classified under 3D Features-related actions because a sketch is considered to be a Part Studio feature in Onshape Analytics once it is created; ** Undo/redo/cancel operations are included under Other Organizing actions because they are recorded unlinked from design spaces.

Tab. 1: Design Space Classification [2].

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The Action Type Classification, in Tab. 2, groups actions under six command types of a generic CAD design process [5].

Action Type	**Creating**	**Revision**			**Viewing**	**Other**
		Editing	**Deleting**	**Reversing**		
Summary of Sample Actions	Add a sketch/ Part Studio feature/ Assembly feature Add a part from Part Studio in Assembly	Edit a sketch/ Part Studio feature/ Assembly feature	Delete a sketch/ Part Studio feature/ Assembly feature Delete a part in Assembly	Redo/ undo/ cancel an operation	Open/ close a tab Call animate actions	Create/ delete/ rename a tab Create/ merge version/ branch

Tab. 2: Action Type Classification [2].

Results:

First, each student is randomly assigned a code in their team. For example, student 2 in team 3 is coded with code 3-2. An overview of the usage data of all participants is summarized in Tab. 3, where the trend of one team member (students 1-1, 2-2, and 3-3) dominating the design contribution is evident. The dominance is prominent across all metrics, whether measured by time, number of documents creates, part features added, sketches modified, or total action contribution.

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	Share of team actions contributed [%]
1-1	42:46:54	84%	7	143	191	95%
1-2	01:23:21	10%	1	0	0	3%
1-3	03:07:39	6%	0	11	4	2%
2-1	02:41:28	4%	0	2	5	4%
2-2	31:25:33	86%	9	236	197	89%
2-3	05:34:47	10%	3	10	20	7%
3-1	05:37:56	30%	10	7	0	18%
3-2	03:53:38	15%	0	0	0	15%
3-3	12:49:14	55%	20	91	83	67%

Tab. 3: Table of participant usage data based on high-level software platform analytics. Reproduced from [1], with new column "Share of team actions contributed."

Comparing students' design processes with the two classification methods in the MUCAD-CLF, several common behaviours are observed for most students while some specific observations only exist for the dominant user in the team. Using the Design Space Classification, most students, despite percentage contribution to the team, spent a relatively larger amount of actions in Sketching rather than 3D Features in Part Studios, as shown in Fig. 2a. In Assemblies, however, the dominant user of each team was the only one who performed Mating actions. With actions analyzed with the Action Type Classification, the distribution of actions can be visualized in Fig. 2b. Besides Viewing actions, Reversing actions also take up a large proportion of students' design process. However, the dominant users are observed to be the only one who performed Deleting actions as they worked. In general, all users tended to commit a very large proportion of actions in Browsing (or Viewing) activities.

a)

b)

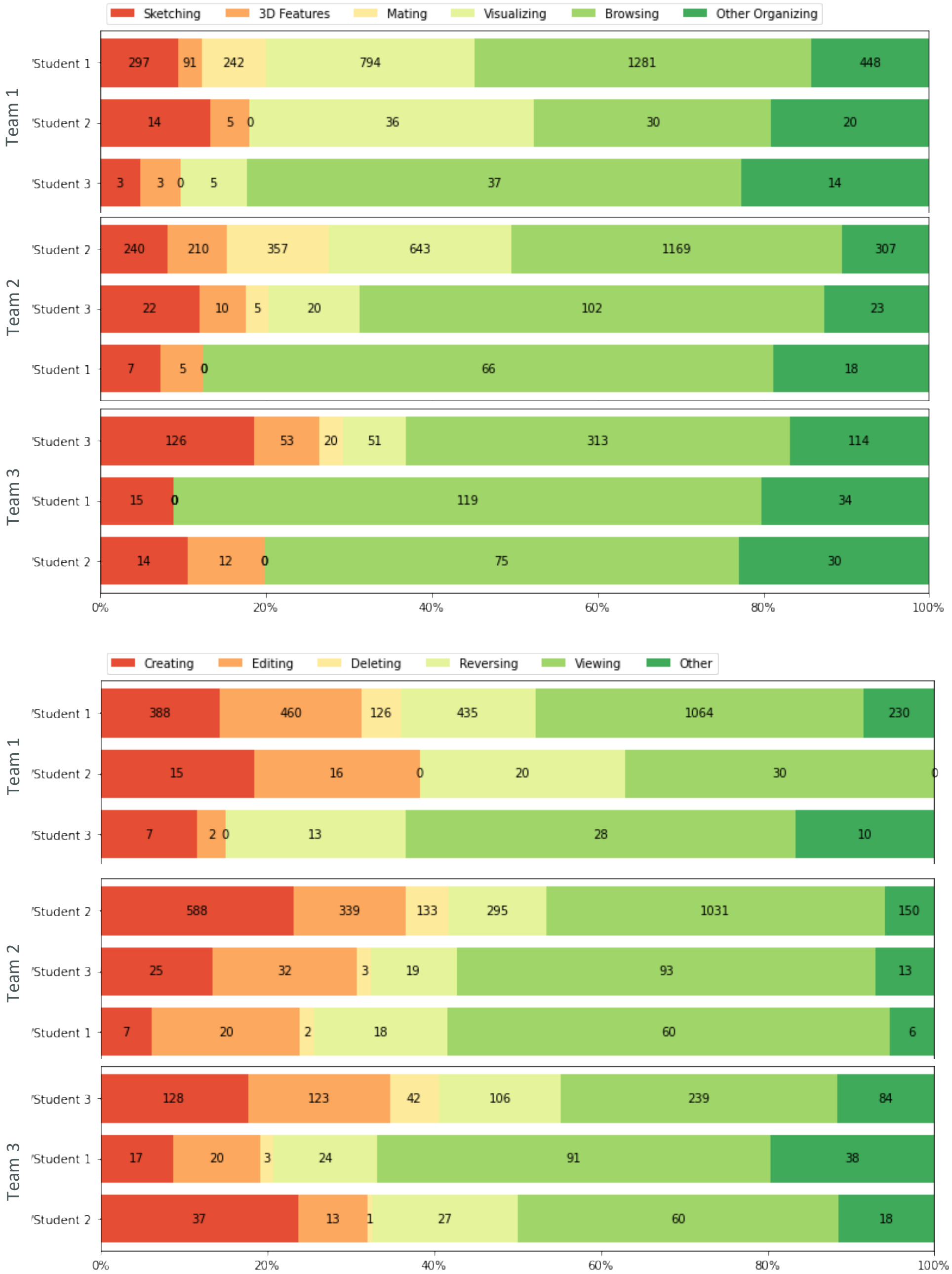

Fig. 2: Distribution of user actions by classification a) in Design Space and b) in Action Type.

<u>Discussion and Implications:</u>

This small-sample study presents initial evidence to suggest that even when the CAD tool is accessible and collaboration is facilitated, contributions to CAD design tend to be unequal. Not only do we find that there is one team member who dominates the design, but this team member is also the only designer who contributes mates, and performs deletions in the model. These two actions are highly linked to the sense of ownership of the design, representing definitive and important decisions, and people may think that only the one who's dominating contributions has the right to do these two things. These observed tendencies have important implications for CAD stakeholders.

From an educator's perspective, we typically expect that the team's outputs are indicative of a collective contribution, and therefore reflective of learning by each team member. What our study points to is the possibility that when engineering design projects rely on CAD, the contribution, and therefore learning, is likely to be unbalanced. Educators should be aware of this reality.

In industry, the undetected sole-contributor, or "owner" of a CAD model presents a problem of non-generalized knowledge. Organizations invest a great deal in information technology systems, and lessons learned meetings, in order to transfer knowledge more broadly. In this way, the success of the project, team, or business ultimately is not dependent on one employee, who may leave their role. On the flipside, it may be possible that the psychological ownership experienced by the main contributor could lead to deeper dedication to improving the model, and ultimately, a better product.

To address these problems, a promising opportunity exists to further exploit the type of analytics of this paper. These analytics can be observed in real-time, and either shared as feedback to the team, or used to initiate interventions by the teaching team. We expect important future work to investigate the prevalence of this phenomenon more broadly, by collecting additional team CAD data. We further anticipate that individual team member factors such as gender or race may play an exacerbating role on the inequality of contribution, and should be examined in greater depth. Ultimately, we expect to see new development of interventions and thoughtful training to increase the equality of contributions on design teams using CAD.

Conclusions:

We analyzed data from a study of nine designers working in teams of three with a cloud-CAD tool. We uncovered a pattern whereby on each team, one team member dominated the contribution to the model. Next, we showed that there are some CAD actions, mates in assemblies and deleting entities, which only this dominant team member perform. We aim to bring attention to the unequal contributions.

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