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

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Abstract. Cloud-based Computer-Aided Design (CAD) tools are changing the way design happens in industrial and educational settings. These tools enable a streamlined collaborative process, unlocking the potential for technical and teamwork integrated teaching and learning. Further, cloud-based CAD can enable distant teamwork in which information and ideas are shared in real time among team members and between students and instructors. In team projects, it is important not only to fairly assess the outcomes, but also to reduce the likelihood of unequal contributions among team members. In this paper, we re-examine a cloud-CAD data set from a team design exercise to describe how the analytics from CAD tool Onshape can deliver a metric of team member contribution by expanding on a published analytics framework, namely the Multi-User CAD – Collaborative Learning Framework (MUCAD-CLF). We identify a trend of individual dominance, where one team member does a majority of the CAD work, and we then analyze the CAD actions that this dominant individual takes, looking for gatekeeping behaviour. We discuss implications of this solo-dominance phenomenon and propose future work towards improved contribution equity on collaborative CAD teams.

Keywords: Collaboration, collaborative learning, contribution, teamwork, equity, analytics, cloud CAD.
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1 INTRODUCTION

The need for collaboration with Computer-Aided Design (CAD) tools is rising in many contexts, from industry to education. In industrial practice, work is increasingly happening on distributed, global teams; even before COVID-19, 16% of the American workforce worked remotely at least part of the time [1]. Collaboration requires the contribution of many, and can be a key driver for innovation [22]. In post-secondary studies, teamwork and collaborative design are now widely recognized as critical attributes of graduating engineers [14]. 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 [8], [20], [24]. 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 investigate how the analytics from Onshape can deliver a metric of team member contribution. We achieve this by expanding on a published analytics framework, namely the Multi-User CAD – Collaborative Learning Framework (MUCAD-CLF) [6]. 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 solo-dominance phenomenon and propose future work towards improved contribution equity on collaborative CAD teams.

2 BACKGROUND

2.1 The Need for Collaborative CAD

The incidence of distributed design teams is increasing; these teams need different supports than those working in traditional co-located environments [4]. In the context of CAD, there have long been discussions of how team collaboration could be more effective [15], [17], but only now does there exist the cloud-based design technology and learning management infrastructure to support this reality in the professional setting.

Anticipating this workforce shift towards collaboration, engineering programs are increasingly focusing on teamwork skills as a targeted learning outcome [19]. In particular, studies have shown that in practice, "engineers' technical work is inseparably intertwined with team-player collaboration" [19]. This points to design with CAD as a powerful tool for the integrated skill-building of both technical design and teamwork.

2.2 Challenges of Teamwork in Education

As the shift toward more team projects and assignments is underway, there is an accompanying challenge related to fair assessment of team members' contributions. Not only is it challenging to assign individual grades based on a team-output [10], [18], but one must also be conscious of team dynamic issues, often fueled by unequal contributions. Studies show that there exist students who do not contribute and "free ride," and more generally the phenomenon of "social loafing" whereby individuals working alone put out more effort than when working with others [2], [10], [12].

One effective treatment for social loafing is formative evaluation; Harkins and Jackson showed that social loafing decreases when participants feel their contributions are individually identifiable and comparable with outputs of their teammates [13]. To further tackle team disfunction, contribution information could be used for team-debriefing, which is a proven intervention to improve team effectiveness [16].

Finally, though little addressed in the literature, an individual team member's over-contribution can lead to a monopoly on the learning opportunities of the team. In an analysis of peer evaluation data, Sridharan et al. found that students themselves are willing to penalize over-contributors, those who "'hog' or do not equally share their workload (or if they are overenthusiastic, demonstrate controlling behaviors or do more than their share of the work)" [23].

The approach proposed in this work addresses the need for assessable opportunities for integrated technical-teamwork, and learning-by-design; we demonstrate a framework to individual contributions to a collaborative CAD project, identifying trends that will be important for educators to address in order to provide equal access to and assessment of learning opportunities in their courses.

3 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 [5]. The course "Methods of teaching engineering mechanics" 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 [5].

The design 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 Figure 1. For the purpose of this study, only data on design activities performed in CAD are analyzed.

All students were asked to design in Onshape, a web-based multi-user CAD platform. Onshape's cloud-native architecture enables real-time collaboration through a browser or mobile app by storing 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. From the audit trail dashboard in the Analytics portal, educators can filter the results to get all changes made by certain users over a specified period of time. The resulting audit trail data can be downloaded to a computer, as was done here for this analysis.

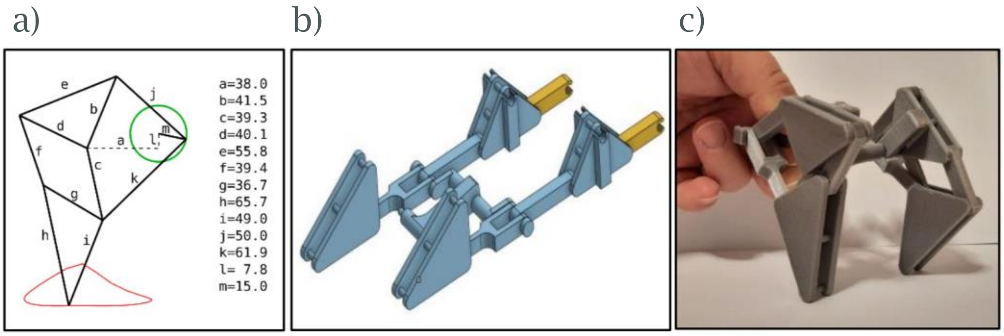

Figure 1: The design activity, a Jansen's leg structure a) structure and motion profile b) CAD model and c) printed prototype. Image from [5].

3.1 Analytical Approach

The multi-user CAD – collaborative learning framework (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 different users and teams can be identified. The framework groups the actions in two different ways: by design space and by action type. These two distinct lenses allow for different comparisons to be made based on different theoretically-motivated metrics. 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 [7].

The Design Space Classification separates all Constructive Actions, actions that make visible changes to the CAD document, from other Organizing Actions, such as Browsing and version control. Under Constructive Actions, actions are further classified under Part Studio and Assembly, the two most-commonly used design spaces in Onshape. A typical design process first starts with creating a sketch in a Part Studio, then the sketch is converted to 3D structures through different 3D Features available in Part Studios. After the detailed structures of parts are prepared in Part Studios, they are then inserted in an Assembly, where various Mating tools are available for assembling. Meanwhile, users navigate the Assembly through different Visualizing actions.

Design Space	Constructive Actions				Organizing Actions	
	Part Studio		Assembly			
Action Type Name	**Sketching**	**3D Features**	**Mating**	**Visualizing**	**Browsing**	**Other Organizing**
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.

Table 1: Design Space Classification [6].

The Action Type Classification groups actions under six command types of a generic CAD design process [11]. The classification consists of Creating actions, a group of Revising actions (Editing, Deleting, and Reversing), Viewing actions, and Other actions that do not fit in other command types.

Beyond simple comparisons that can be made between counts of actions, this classification method also enables us to quantify the iterativeness of a design process by introducing the creation/revision (C/R) ratio [25]. The C/R ratio divides the number of creating actions by the number of revising actions counted in a design process, where a lower ratio indicates a more iterative design process, previously proposed as being indicative of good engineering design practices.

Action Type Name	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

Table 2: Action Type Classification [6].

4 RESULTS

Analyzing data collected from the design project, 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 in this design project is summarized in Table 3. With results presented in Table 3, 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	89%
2-2	31:25:33	86%	9	236	197	7%
2-3	05:34:47	10%	3	10	20	4%
3-1	05:37:56	30%	10	7	0	67%
3-2	03:53:38	15%	0	0	0	18%
3-3	12:49:14	55%	20	91	83	15%

Table 3: Participant usage data based on high-level software platform analytics. Reproduced from [5], 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 Figure 2. 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 Figure 3. 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.

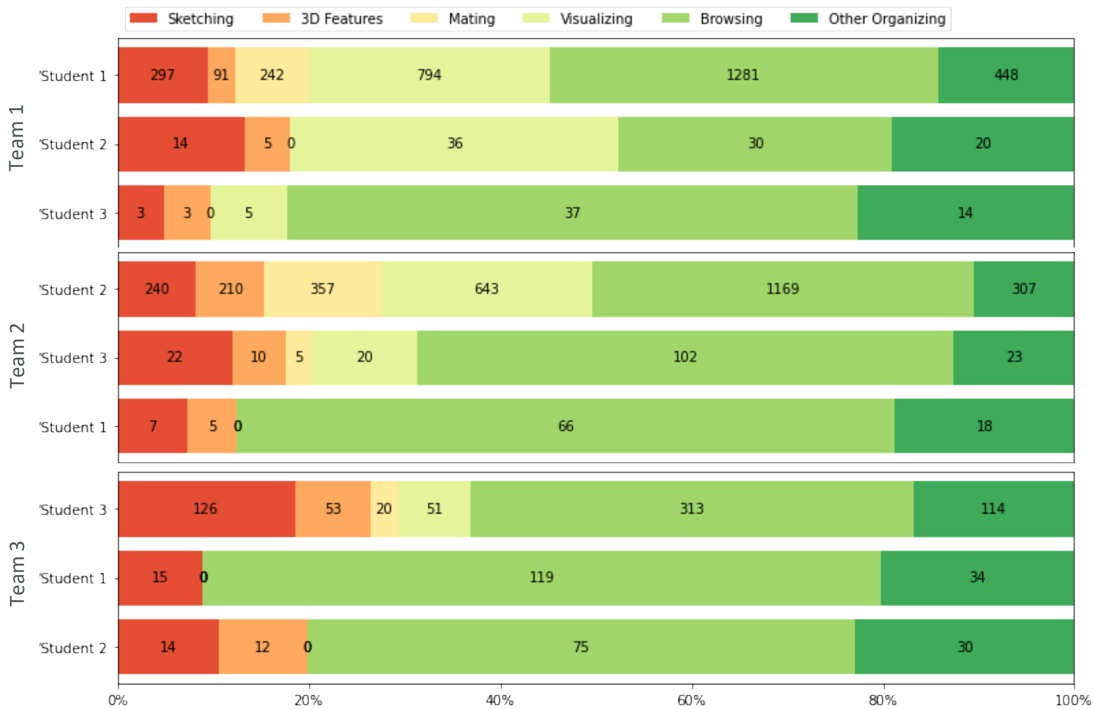

Figure 2: Distribution of actions in Design Space Classification.

The creation/revision ratios of the participants are presented and compared in Figure 4. No trends that are common to all three participating teams could be identified. Specifically, CAD behaviors with a similar degree of iteration were observed for each member of Team 1, despite the significant difference in percentage contribution of CAD actions on the team. On the other hand, while the dominant user in Team 2 (Student 2) exhibited a C/R ratio that is higher than all other team members, the dominant user in Team 3 (Student 3) exhibited a lower-than-average C/R ratio.

5 DISCUSSION AND IMPLICATIONS

This case 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 learners may think that only the one who's dominating contributions has "earned" the right to do these two things. Further, data records show that Student 1 from Team 1 was the only participant that left a substantial number of comments on the CAD document; this Student was the dominant contributor of the team. These observed tendencies have important implications for CAD stakeholders in industry and academia.

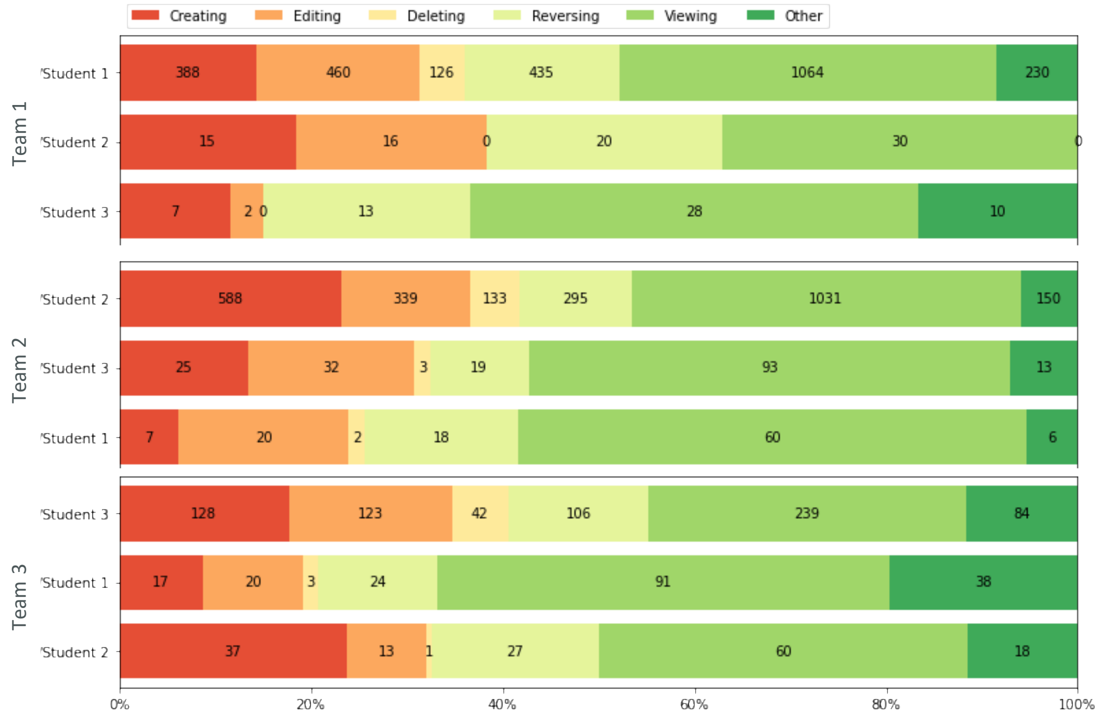

Figure 3: Distribution of actions in Action Type Classification.

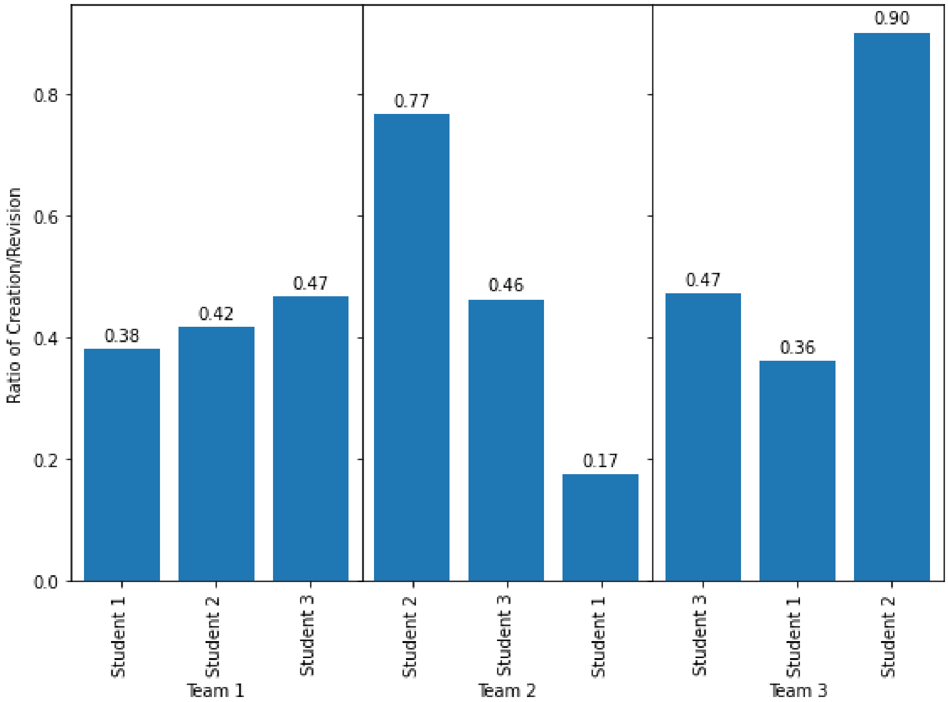

Figure 4: Creation/Revision Ratio of the participants.

From an educator's perspective, we typically expect that the team's collective 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 [3] 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.

Our findings suggest that Cloud-CAD platform developers could integrate analytics in their platforms, thus providing easy-access to team contribution statistics on shared CAD files. In addition, it could be effective to develop software functionality to monitor contributions, and nudge team members based on inequalities – sending messages to both over- and under-contributors.

Meanwhile, the fact that no clear trends could be concluded from the creation/revision ratio analysis may indicate differences in CAD styles of the dominant users. Although these users all led their design team with a significantly large amount of CAD actions, the dominance did not seem to directly correlate to the level of iteration of their design processes. For future research, increasing the sample size of this experiment will be beneficial to observe more dominant users. At the same time, it will also be interesting to examine the iterativeness of these dominant users at different stages of the design process to better understand their CAD and collaboration behaviors in the design process.

Placing a strong emphasis on the novel use of backend analytics should not undermine the importance of traditional behavioral data collection methods. For example, while the dominant contributor was making the highest number of edits on the CAD document, it does not necessarily mean that other members of the team were not involved in the design process in other ways. Other means of contribution, such as verbal commenting, brainstorming, and initiating constructive discussions, could also be valuable to the team, but could not be captured by the analytics data. A participant quote from the post-course commentaries, originally published in [5], reflected this reality:

> *"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."*

This quote does not only describe team involvement that was not captured by our learning analytics, but it also confirms our findings about the dominant CAD contributor. This only emphasizes the need for the further development of a learning strategy for meaningful contributions for all team members.

While our focus has been on the potential benefits of cloud-CAD learning analytics – improving student learning and support – it is important to consider the potential ethical issues of such analytics. Recent work has discussed this issue in depth [9], [21]. For example, data cannot fully capture the social complexity of student lives and group work; data can entrench inequalities. With this in mind, we expect important future work to investigate the prevalence of over- and under-contribution 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.

6 CONCLUSIONS

Motivated by the capacity of modern cloud-CAD tools to facilitate CAD-based collaborative design learning opportunities, we investigated the potential for analytics to inform the assessment of such work. We analyzed data from a previously published 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 performed. We aim to bring attention to the unequal contributions to the projects, and anticipate future work will explore these trends at a larger scale. Our findings motivate important awareness for instructors, as well as promising features for CAD software platform developers

7 ACKNOWLEDGEMENTS

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8 REFERENCES

[1] Abrams, Z.: The future of remote work, Monit. Psychol., 50(9), 2019, 54..

[2] Adenso-Díaz, B.; Lozano, S.; Gutiérrez, E.; Calzada, L.; García, S.: Assessing individual performance based on the efficiency of projects, Comput. Ind. Eng., 107, 2017, 280–288. https://doi.org/10.1016/j.cie.2017.03.026

[3] Blau, I.; Caspi, A.: What Type of Collaboration Helps ? Psychological Ownership , Perceived Learning and Outcome Quality of Collaboration Using Google Docs, in Proceedings of the Chais conference on instructional technologies research, 2009, 48–55.

[4] Cash, P.; Dekoninck, E. A.; Ahmed-Kristensen, S.: Supporting the development of shared understanding in distributed design teams, J. Eng. Des., 28(3), 2017, 147–170. https://doi.org/10.1080/09544828.2016.1274719

[5] Cuperman, D.; Verner, I. M.; Levin, L.; Greenholts, M.; Rosen, U.: Focusing a Technology Teacher Education Course on Collaborative Cloud-Based Design with Onshape, 24th Int. Conf. Interact. Collab. Learn., 2021, 146–157..

[6] Deng, Y.; Mueller, M.; Rogers, C.; Olechowski, A.: The Multi-User Computer-Aided Design Collaborative Learning Framework, Adv. Eng. Informatics, 51, 2022, 101446. https://doi.org/10.1016/j.aei.2021.101446

[7] Deng, Y.; Olechowski, A.: ReadyLab-UToronto/MUCAD-CLF (v2.0), 2021. https://doi.org/https://doi.org/10.5281/zenodo.5748151

[8] Eves, K.; Salmon, J.; Olsen, J.; Fagergren, F.: A comparative analysis of computer-aided design team performance with collaboration software, Comput. Aided. Des. Appl., 4360, 2018, 1–12. https://doi.org/10.1080/16864360.2017.1419649

[9] Ferguson, R.: Ethical challenges for learning analytics, J. Learn. Anal., 6(3), 2019, 25–30. https://doi.org/10.18608/jla.2019.63.5

[10] Friess, W. A.; Goupee, A. J.: Using Continuous Peer Evaluation in Team-Based Engineering Capstone Projects: A Case Study, IEEE Trans. Educ., 63(2), 2020, 82–87. https://doi.org/10.1109/TE.2020.2970549

[11] Gopsill, J.; Snider, C.; Shi, L.; Hicks, B.: Computer aided design user interaction as a sensor for monitoring engineers and the engineering design process, Proc. Int. Des. Conf. Des., DS 84, 2016, 1707–1718..

[12] Hall, D.; Buzwell, S.: The problem of free-riding in group projects: Looking beyond social loafing as reason for non-contribution, Act. Learn. High. Educ., 14(1), 2013, 37–49. https://doi.org/10.1177/1469787412467123

[13] Harkins, S. G.; Jackson, J. M.: The Role of Evaluation in Eliminating Social Loafing, Personal. Soc. Psychol. Bull., 11(4), 1985, 457–465. https://doi.org/10.1177/0146167285114011

[14] Hartmann, B. L.; Stephens, C. M.; Jahren, C. T.: Validating the Importance of Leadership Themes for Entry-Level Engineering Positions, J. Prof. Issues Eng. Educ. Pract., 2016. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000301.

[15] Kunz, A.; Fadel, G.; Taiber, J.; Schichtel, M.: Towards collaboration in engineering of tomorrow - Building highly interactive distributed collaboration platforms, SAE Tech. Pap., (724), 2006. https://doi.org/10.4271/2006-01-0363

[16] Lacerenza, C. N.; Marlow, S. L.; Tannenbaum, S. I.; Salas, E.: Team development interventions: Evidence-based approaches for improving teamwork performance measurement in simulation-based-training view project, Am. Psychol., 73(4), 2018, 517–531..

[17] Nam, T. J.; Wright, D.: The development and evaluation of Syco3D: A real-time collaborative 3D CAD system, Des. Stud., 22(6), 2001, 557–582. https://doi.org/10.1016/S0142-694X(00)00041-7

[18] Ohland, M. W. *et al.*: The comprehensive assessment of team member effectiveness: Development of a behaviorally anchored rating scale for self- and peer evaluation, Acad. Manag. Learn. Educ., 11(4), 2012, 609–630. https://doi.org/10.5465/amle.2010.0177

[19] Passow, H. J.; Passow, C. H.: What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review, J. Eng. Educ., 106(3), 2017, 475–526. https://doi.org/10.1002/jee.20171

[20] Red, E.; Marshall, F.; Weerakoon, P.; Jensen, C. G.: Considerations for Multi-User Decomposition of Design Spaces, Comput. Aided. Des. Appl., 10(5), 2013, 803–815. https://doi.org/10.3722/cadaps.2013.803-815

[21] Selwyn, N.: What's the problem with learning analytics?, J. Learn. Anal., 6(3), 2019, 11–19. https://doi.org/10.18608/jla.2019.63.3

[22] Sosa, M. E.: Where Do Creative Interactions Come From? The Role of Tie Content and Social Networks, Organ. Sci., 22(1), 2011, 1–21. https://doi.org/10.1287/orsc.1090.0519

[23] Sridharan, B.; Tai, J.; Boud, D.: Does the use of summative peer assessment in collaborative group work inhibit good judgement?, High. Educ., 77(5), 2019, 853–870. https://doi.org/10.1007/s10734-018-0305-7

[24] Wu, D.; Rosen, D. W.; Wang, L.; Schaefer, D.: Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation, CAD Comput. Aided Des., 59, 2015, 1–14. https://doi.org/10.1016/j.cad.2014.07.006

[25] Xie, C.; Zhang, Z.; Nourian, S.; Pallant, A.; Hazzard, E.: Time series analysis method for assessing engineering design processes using a CAD tool, Int. J. Eng. Educ., 30(1), 2014, 218–230..