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Exploring the Effects of Solid Modeling Approaches and Manufacturing Process Knowledge on Quality of Students' Execution of Engineering Design Course Projects

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Session XXXX

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Abstract

A broad spectrum of manufacturing technologies, ranging from additive manufacturing to conventional CNC machining equipment, is now available to students in Engineering Design courses. Students face multiple challenges when developing designs and specifying manufacturing processes, one of which is acknowledging inherent interdependencies between geometric features on mating components and the processes selected for manufacturing the mating components. To address this challenge, the authors have conducted an observational study to identify the factors influencing student success when tailoring designs of geometric features on mating components to specific manufacturing processes. Factors considered in this study span both the design and manufacturing domains, ranging from alternative solid modeling approaches to process-specific guidelines for geometric dimensioning and tolerancing.

Initial results indicate that students achieve greatest success in designing compatible geometric interfaces on mating components after receiving instruction in both solid modeling approaches and capabilities of manufacturing equipment and processes. Additionally, the authors have identified specific benefits of delivering instruction on these subjects in a peer-to-peer, active learning format. Action plans for incorporating lessons learned from this study in engineering design courses are included in the paper.

Introduction

In today's engineering design courses, there are multiple methods to manufacture design; two well-known processes are additive manufacturing and laser cutting. The utilization of either method first requires students to design a part using a type of computer-aided design (CAD) software, such as SolidWorks. Due to the three-dimensional nature of most CAD programs, it can be challenging for students to ensure that all parts are dimensioned properly and that tolerancing has been taken into consideration. Manufacturing misaligned or incorrectly dimensioned parts directly translates to time and cost increases, and time for implementation decreases after the part is manufactured. These consequences can be minimized if students are not only aware of how their manufacturing choice impacts their final product, but also if they are provided information about the effectiveness of varying design methods. There are tools to improve design effectiveness that are accessible to students, but lack of awareness of these tools can prevent students from reaping the full benefit presented. In this paper, we define a need to provide information to students about the importance of increasing quality of mating components, implementing already existing tools to ensure correct dimensioning and alignment, and tolerancing when using varying machines. In addition, we examine the methods in which information is presented to students and how factors similar to those of peer instruction influence final results.

Literature Review

The field of additive manufacturing (AM) is relatively young and advancements in technology, capability, and effectiveness are everchanging. There is a need for a standardized set of design processes and accessibility to information about manufacturing to ensure students maximize time, efficiency, and gain valuable knowledge about design[1]. Hwang et al.[2] identifies the need for advancement of design theories, methods, and principles in the field of additive manufacturing. In their Crowdsourced Design Principles list, item 9 and item 20 outline that 'desired mechanical properties [can be achieved] by tailoring the geometry of the mesostructure' and 'assembly time and number of components [can be minimized] by incorporating snap fits when possible.' Design time fills a significant portion of the design process in additive manufacturing, therefore, if time can be decreased, the AM process can be more feasible. The authors have realized there is a lack of student knowledge of the importance of tailoring a part to withstand its purpose, which can lead to design flaws and increase in design and production time. It is critical that students possess a solid understanding of design concepts in varying manufacturing methods[3] despite their level of experience[4]. An example of this occurring in engineering student design is using butt joints instead of using a tab and slot design. Figure 1 provides an example of these two manufacturing choices. The concept of 'snap fits' or 'tab and slot design' can assist in quality and ensure more secure, durable, and long-lasting parts. However, students are not always familiar with the process of designing tab and slot features. When initially exposed to either of these processes, students are often fixated on additive manufacturing and do not consider the alternative method, even though it often yields quicker production time, a smaller risk of failure, and results with better quality. There is a need for design for additive manufacturing (DFAM) education that incorporates different design concepts into the design process to help students understand the capabilities and restrictions of AM[5]. Therefore, students will be able to understand risks and benefits of the available manufacturing methods. While others have identified disconnection between design and manufacturing[6], we aim to show that more advanced design features are often not an option considered by students in the design process due to their lack of knowledge.

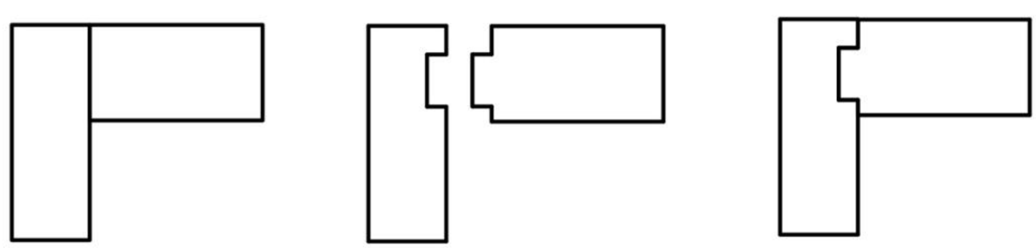

Figure 1. Difference Between Butt Joint (leftmost) and Tab and Slot Interlocking Feature (center and rightmost).

Boothroyd[7] establishes that when snap fits are directly designed into parts, the number of components can be decreased while also minimizing assembly time. This is a key concept identified: spending extra time in the early stages of the design process yields saving time during production. Design for assembly (DFA) should be the priority of the engineer at any level, and snap fits greatly aid in assembly. To the best of the authors' knowledge, the ability of the student to put these principles into practice has not been investigated and while there are already existing mechanisms to assist in this area such as AM Design Principle Cards[4], a disconnect still exists because students do not have a fundamental background. Even though there are resources available to students such as workshops, courses, and projects, design innovation may not be the focus since students do not have awareness of basic concepts. We have discovered that students need explicit reasoning as to why it is less efficient to design using a particular method. Therefore, for principles similar to those already proposed[4] to be efficient, it is first crucial to provide an explanation to students about why other methods are ineffective. It is essential to recognize that inexperienced designers will be impacted more as opposed to experienced designers, hence the authors propose to implement design concepts in introductory engineering courses as well as Engineering Design I, prior to a final capstone course such as Engineering Design II.

There are tools that exist to assist students in designing correctly aligned parts, but few are aware of them. Construction lines were formerly used in hand drawings with the intention of guaranteeing that mating components aligned, therefore proving that dimensioning was correct. Prior to advanced CAD programs, the manufacturing process began with sketches and gradually progressed to drawing boards and CAD modeling[7] where designers would design utilizing construction lines. While CAD programs and their respective tools have since been modernized, the fundamental steps put forth by Boothroyd still retain effectiveness in design. Tools such as construction lines have since been modified in CAD programs and while they serve their original purpose, they can also act as lines of rotation. The purpose of construction lines is to assist in the visualization of mating components and allow students to design with less error. There are few studies examining the modern effects of construction lines in student design, and this paper identifies that students who implement construction lines when designing have more success than those who do not.

Methods

This study was conducted approximately three quarters of the way through the fall semester at Baylor University within the School of Engineering and Computer Science (ECS). Junior and senior standing students were recruited to participate in the study. The completion of the Engineering Design I course was the only requirement when selecting students. Typically, students complete Engineering Design I in either the fall or spring semester of their junior year. Engineering Design I is a prerequisite for Engineering Design II, so students complete Engineering Design II in either the fall or spring semester of their senior year. The project description is identical amongst all teams in Engineering Design I, whereas students rank their preferences for different project selections in Engineering Design II. The study was approved by the Institutional Board of Review and verbal consent was provided by each participant prior to starting the study. There was no incentive offered to students to induce participation in the study. All participants were assured that their participation in the study would have no effect on their course grades. Furthermore, the GPA of students who opted to participate was not obtained, but students who participated had reputations of possessing a strong work ethic. Eight students participated, six of them of senior standing and two of junior standing. Prior to the day of the study, students were sent a pre-survey and based on their answers were then split into control and experimental groups to provide relatively evenly matched groups. On the day of the study, students were asked to complete three different design tasks. They were all self-paced and students were asked to make note of the time it took to complete each task and the number of iterations it took them to finish each task. Each student was provided a participant number and was given access to a pre-made online folder corresponding to their number where they could anonymously upload their files. Students were not given explicit instruction about whether peer collaboration was allowed and were free to discuss with one another if they chose. The first two tasks involved creating a box and a gear using online resources and the manufacturing time and cost was evaluated[1]. The instructions for these tasks were analogous between the control and experimental groups. For the third task, students in both groups were provided with SolidWorks part files of three different shapes, shown in Figure 1, and were told to create an assembly using those shapes. The control group was only provided with the part files and told to create an assembly. The experimental group was shown a video demonstrating a sample part being drawn in SolidWorks using the method of construction lines, and a section of the video using construction lines can be seen in Figure 2. The purpose of construction lines in CAD modeling was explained, and students in the experimental group were told to create an assembly using their new knowledge of construction lines. They received access to the video and were able to re-watch it at any time during the task. At the end of the study, both groups were also asked to complete a post-survey about the tasks they performed. The authors compared the final assemblies of both experimental and control groups to the intended final assembly that can be seen in Figure 3.

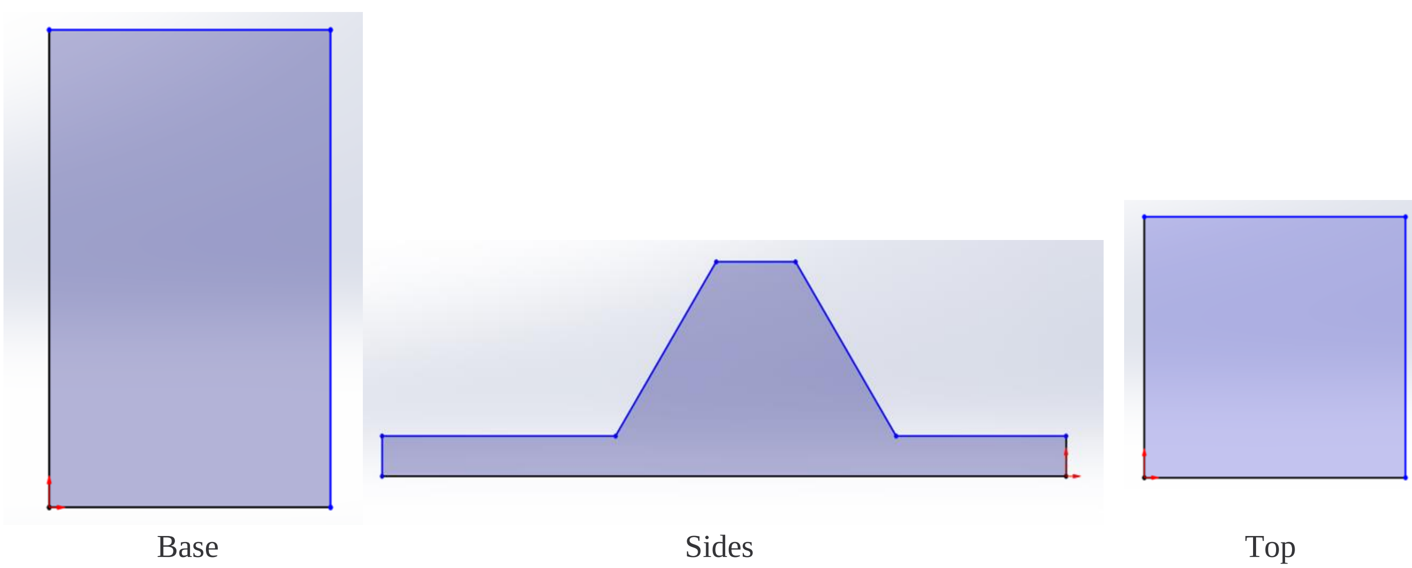

Figure 1. SolidWorks part file provided to each student to create assembly.

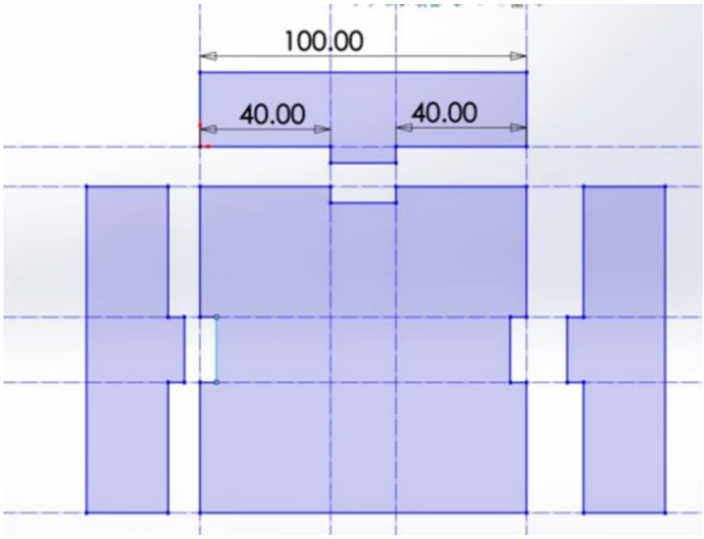

Figure 2. Portion of video demonstrating tab and slot features using construction lines.

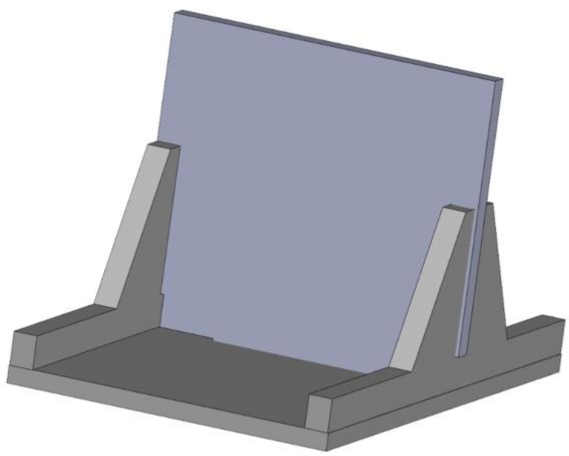

Figure 3. SolidWorks assembly of the intended final product using the parts in Figure 1.

Results

When analyzing the results, it is necessary to review the overall experience of the control and experimental groups and how participants were placed in their respective group based on this information. In the pre-survey, students were asked about their level of experience with 3D printing and laser cutting. It is important to take note of the multiple-choice options available on the pre-survey since there are circumstances specific to the School of ECS at Baylor University. Table 1 provides a summary of the available answer options.

Table 1. Answer options for respective questions provided to students on pre-survey.

How much experience do you have with 3D printing?	Number of Participants in Control Group who Selected Option	Number of Participants in Experimental Group who Selected Option
I have no experience with 3D printing	1	0
I have submitted print jobs for fulfillment	2	2
I have printed 0-10 parts on my own	0	0
I have printed 11-50 parts on my own	1	1
I have printed 51-100 parts on my own	0	1
I have printed more than 100 parts on my own	0	0

How much experience do you have with laser cutting?	Number of Participants in Control Group who Selected Option	Number of Participants in Experimental Group who Selected Option
I have no experience with laser cutting	2	2
I have created 0-10 parts	1	0
I have created 11-50 parts	1	2
I have created 51-100 parts	0	0
I have created more than 100 parts	0	0

Students who selected 'I have submitted print jobs for fulfillment' have submitted jobs to the additive manufacturing lab within the School of ECS but were not responsible for the quality, material, orientation, support features, or any other aspect of the 3D printing process except the CAD model of the part. Students who selected this option have some knowledge of the printing process but have not experienced it on their own. Based on the answers provided, the experimental group had slightly more experience than the control group in both 3D printing and laser cutting. Additionally, students were asked in the pre-survey if they had completed the semester-long CAD course offered by the School of ECS. The CAD course is an elective course that students can choose to enroll in. While it is a relatively new elective within in the School of ECS, students usually decide to take it either in their junior or senior year. Table 2 shows the breakdown of students in the control and experimental group who had already taken or were currently enrolled in the CAD course at the time of the study.

Table 2. Percentage of students who have taken or currently enrolled in CAD course:

Control Group	Experimental Group
75%	25%

The participants also indicated their CAD experience in the pre-survey with their possible response options in Table 3. While all students had received some CAD instruction from Engineering Design I, most of the experience for students was obtained through either an internship or co-op program. A visual breakdown of the responses is provided in Figure 4.

Table 3. Answer options for CAD experience on pre-survey.

Where have you received your CAD modeling instruction?
CAD course
Internship/Co-op
Engineering Design I
Classes in high school
Self-directed learning (e.g. video tutorials)

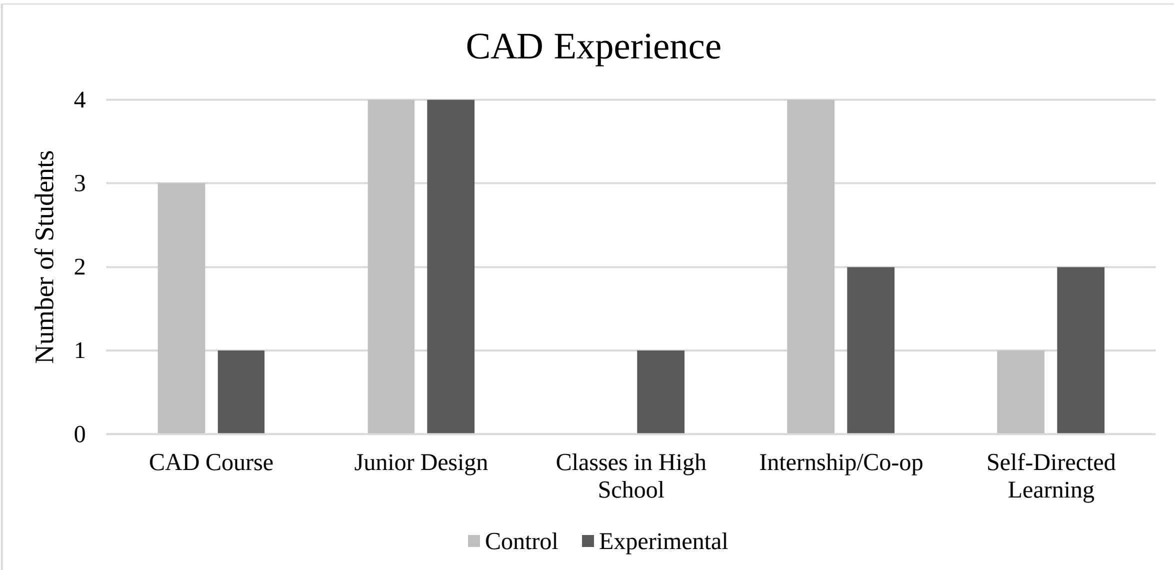

Figure 4. Representation of CAD experience for control and experimental groups.

Initially, the breakdown of CAD experience between the control and experimental group appears to show that the control group overall had more CAD experience than the experimental group, especially due to the difference in students enrolled in the CAD class. However, the end results demonstrate that the experimental group was more successful in creating a correct assembly than the control group, even though there was seemingly less CAD experience. When analyzing the results, the authors labeled each tab and slot interface with corresponding letters (A, B, C, and D) as shown in Figure 5. This allowed for different levels of success to be accounted for when viewing each students' assembly. Letter A on the side part is intended to be slotted into Letter A on the base part. Letter B on the top part is intended to fit flush to Letter B on the base part, and Letter C on the top part is intended to fit flush to Letter C on the side part. Letter D on the top part is intended to be slotted into Letter D on the base part. To assess the success of each students' assembly, the letters that each student achieved was recorded and summarized in Table 4.

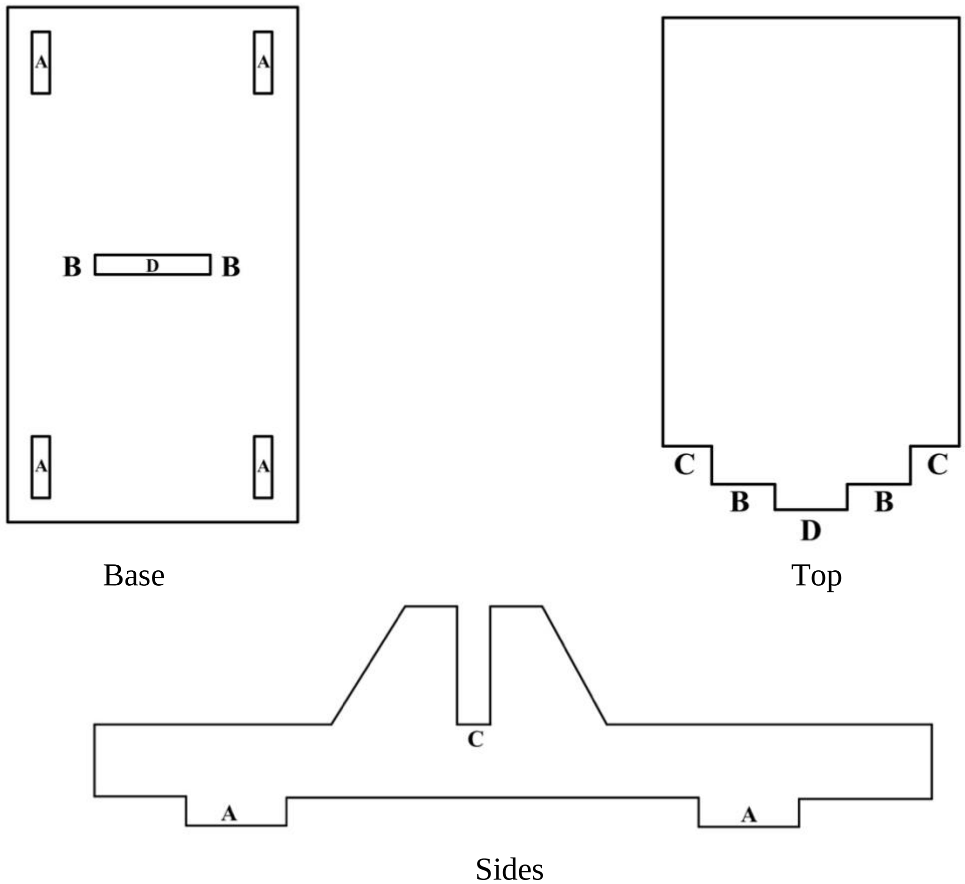

Figure 5. Base, sides, and top with their corresponding letters.

Zero participants in either group successfully achieved Letter A and therefore the number of students with the overall correct assembly reflects the decision to negate Letter A. The results surrounding Letter A leads the authors to hypothesize about the difficulty of Letter A and will be addressed in future work, since all students used butt joints as opposed to a tab and slot design. There is a clear distinction between the control and experimental groups due to only half of the control group achieving Letter B whereas the entire experimental group achieved Letter B. Therefore, the lesson about construction lines could have allowed students to visualize and achieve Letter B more easily. There was also a 75% increase in the number of students who achieved Letter D in the experimental group than the control group.

Table 4. Breakdown by Corresponding Letter

Control Group	
Achieved Letter A:	0%
Achieved Letter B:	50%
Achieved Letter C:	100%
Achieved Letter D:	0%
Overall Correct Assembly:	0%

Experimental Group	
Achieved Letter A:	0%
Achieved Letter B:	100%
Achieved Letter C:	100%
Achieved Letter D:	75%
Overall Correct Assembly:	75%

The average time of the experimental group to implement the tab and slot features and complete the assembly exceeded that of the control group by 53%. This was a result contradictory to the original hypothesis: using construction lines to implement a tab and slot design would decrease design time. This result is addressed more in the discussion below, but the authors believe that the reason for increased time is related to the fact that the experimental group posed numerous questions to the researchers during the task. While this was unexpected, the experimental group achieved an overall more correct design than the control group, thus demonstrating that time is required to design with quality in mind.

The fact that students in the control group had more CAD experience but did not achieve Letter D is not entirely clear to the authors and is an area of future work. Due to the small sample size and limited ability to evenly divide participants into control and experimental groups, a concrete conclusion cannot be drawn about CAD experience on the outcome of the letter achievement. The authors have hypotheses surrounding the impact of CAD experience that are stated in the discussion portion, but future work is needed to develop a certain response. However, the conclusion can be made that the experimental group may have been able to achieve more letters than the control group due to having slightly more 3D printing experience. A similar pattern holds true for the laser cutting experience of participants in the experimental group. The experimental group had slightly more experience than the control group in both processes which could have translated to more success because they are more familiar with the manufacturing methods.

Discussion

The initial focus of the study was to determine whether the use of construction lines in a modern context such as that of CAD modeling yielded better designed parts. The construction lines video proved to be useful in assisting the experimental group in achieving Letter D, since no students in the control group were able to. It is possible that the experimental group had collectively more 3D printing experience and were therefore able to recognize Letter D, which supports the claim that experienced designers can more easily notice information and use it to create a solution[4]. While the results provided by the control and experimental achieved the focus of the study, it was also discovered that students do not have knowledge as to why some design for manufacturing methods, such as tab and slot design, are more effective compared to their basic counterparts such as butt joints. Understanding the importance of edges aligning to make the features square and that tab and slot design can ensure longer lasting parts due to the increased surface area when welding them together is crucial. It is believed that if reasoning were provided to students about why tab and slot joints are more functional than butt joints, more students would have been able to achieve Letter A.

The results of the control group led the authors to hypothesize about why more students enrolled in the CAD course were unable to produce better designs. While students may have more experience, they are unable to make solid judgements about their own knowledge. Studies have shown that students who experience passive instruction feel as though they understand the content better than they do, versus students who experience active instruction. A factor that influences this finding is that students who are generally novices in a particular subject are unable to provide good judgments of their own learning because of their reliance on varying metacognitive factors[8]. It is possible that a similar phenomenon has occurred within the control group: students who have more CAD experience think they are more experienced, but they may overanalyze and rely too heavily on the skills they think they know. While acknowledging that CAD courses do provide students with valuable experience and knowledge, the authors believe that instruction received in the course did not prepare students to adequately solve the type of problem that was presented to them in this study. Furthermore, using the definition of ‘principle’ proposed by Fu et al[9]., the authors have deemed it reasonable to implement videos explaining design principles in entry level courses and the Engineering Design I course. In addition to this hypothesis, an element to include in the post-survey of the future work is a confidence gauge to assess in how confident students felt in their ability to complete the tasks.

The content of the study was delivered by undergraduate research students and most interactions took place between peers. During the study, the authors noticed a profound difference in the atmosphere of the control and experimental groups. The control group was conversing with one another, asking questions to peers, and comparing their own work to that of other students, whereas the experimental group was quieter, more focused, and would primarily ask questions to the undergraduate researchers conducting the study instead of their peers. Particularly on task three, the experimental group asked many questions to the researchers. When contrasting the behavior of the control group and experimental group, the level of success achieved by the control group could have been unwarranted due to their assistance from one another. It can be inferred that the control group did not fully understand the design task they were asked to perform because a lack of conceptual understanding can limit a student’s ability to solve problems[10] and therefore they ask questions to their peers. Future work investigates the effects of how peer to peer interaction increases the success of the results. It is known that peer interaction increases the likelihood of encountering conflict between ideas and therefore students must combine new knowledge with old knowledge which leads to richer explanations and greater conceptual understanding[11,12]. If students were to discuss with one another, they might encounter different ideas and be able to come to a more efficiently designed final product[13]. Studies have also shown that students perform better on conceptual tests when provided with guidelines and expectations for peer discussion[14]. Providing this clarification in the instructions could allow students to feel more comfortable working with one another, hence allowing them to further grow in their conceptual understanding. In addition, the result produced by the control group could also be accounted for by the role of the undergraduate research students, since they filled a role like that of a teaching assistant. Students may have thought of the undergraduate research students as uncertain, hesitant, or nervous, but they can also be perceived as understandable, personable, relatable, and interactive[15]. While further research is needed, interactions that took place during the study lead the authors to believe that students may have been more hesitant to ask questions about the tasks they were asked to complete if a professor was leading the study, instead of undergraduate students which could have impacted their success.

The result of the experimental group’s time to completion being significantly greater than the control group provides a unique discussion. The experimental group posed more questions to the researchers which initially gave the impression they did not have a solid understanding of the task and that was the cause of the increased time. However, the results of achieving more letters shows they had a stronger understanding of the task, and the act of asking questions indicates progress in completing the task. While the control group potentially overestimated their ability and confidence in their work which led to fewer successfully designed assemblies[16], the experimental group used more of the time provided to design an assembly of better quality. An area of future work includes developing a valid system for comparing completion time between the control and experimental groups to allow for direct comparison. In addition, more data is needed to conclude the effects of construction lines on the number of iterations. Due to the small sample size and focus on completing the tasks, few students recorded their iterations. The lack of data surrounding the number of iterations is potentially influenced by the effects of peer discussion as well. In a scenario where a student thought they may have needed to start the task over, they could have consulted with a peer and instead moved on to the next perceived step. Even though construction lines did not decrease the time to completion, students who were given knowledge about them completed higher quality assemblies and achieved more of the tab and slot interface features.

While over 40 students were recruited to participate in the study, there were only 8 students who accepted to participate. This study took place on a Saturday morning approximately three quarters of the way through the fall semester, therefore students had to assess whether they wanted to participate amidst tests, projects, and assignment deadlines. In addition, there was a highly anticipated college football game the afternoon of the day of the study which could have impacted some students' desires to take more time completing the tasks or compromised their focus. Based on the results, the authors' desire to implement tools such as instructional videos or demonstrations in entry level engineering design courses and Engineering Design I to assist in student knowledge of manufacturing methods. Principles to follow can be improved by following a structure for design principles that says 'improve a specific design goal' by 'giving an actionable recommendation'[2]. This pattern of thought standardizes the design process and introducing students to this format of 'Improve X by doing Y' early in their engineering education could potentially assist in process logic and they can then come to conclusions on their own. In addition, the Stop/Start/Continue evaluation format[17] can be used to enhance future procedures due to increasing awareness:

1. What is one thing we should STOP doing?
2. What is one thing we should START doing?
3. What is one thing we should CONTINUE doing?

The intent in providing these principles and resources to students in both freshman and junior level courses is that students will be exposed to them once during entry level courses, and therefore will be familiar with them during Engineering Design I and II courses.

Summary & Conclusions

In summary, we have identified the need to provide students fundamental information about the importance of quality when properly aligning or manufacturing parts together. It is believed that students would be able to implement the entirety of the tab and slot concept in their designs if they were provided with the reasoning behind the method. This information can be provided to students in the form of instructional videos that would be shown in introduction to engineering courses, as well as Engineering Design I to aid in project success and assist in students learning more about manufacturing and design. Initial results show that the use of construction lines can improve the overall design of a part and these results also provided insight into what would be the most effective way to enhance curriculums to improve student performance in entry level and higher-level engineering courses. Future work includes further investigation into the causes of zero students achieving the Letter A, and why only two students in the control group achieved Letter B, and how peer to peer interaction can impact results. These conclusions drawn and strategies presented allow students to develop fundamental engineering skills early on in their education with the intent of carrying them throughout their studies. Furthermore, if students can experience a more rewarding and successful time in Engineering Design I and II courses while gaining valuable experience, they will be more confident in their abilities and choices not only in the classroom but in their careers as well.

References

1. Richards, S., Retzlaff, L., Donndelinger, J., 2022, “Developing and Manufacturing Process Simulation Tools to Improve Students’ Execution of Engineering Design Course Projects,” Proceedings of the 2022 ASEE Gulf-Southwest Annual Conference, Prairie View A&M University, Prairie View, TX.
2. Hwang, D., Perez, K. Blake., Anderson, D., Jensen, D., Camburn, B., Wood, K., 2021, “Design Principles for Additive Manufacturing: Leveraging Crowdsourced Design Repositories,” Journal of Mechanical Design, Vol. 143, No. 7.
3. Mears, L., Summers, J., 2020, “Manufacturing for Design: A sustaining approach to drive manufacturing process evolution, then innovation,” Procedia Manufacturing, Vol. 48 (2020), pp. 1136-1142.
4. Hwang, D., Lauff, C., Perez, K. Blake., Camburn, B., 2020, “Comparing the Impacts of Design Principles for Additive Manufacturing on Student and Experienced Designers,” International Journal of Engineering Education, Vol. 36, No. 6, pp. 1862–1876.
5. Prabhu, R., Miller, S.R., Simpson, T.W., Meisel, N.A., 2020, “Teaching Design Freedom: Understanding the Effects of Variations in Design for Additive Manufacturing Education on Students’ Creativity,” Journal of Mechanical Design, Vol. 142, No. 9.
6. Zhang, H., Deng, L., Chao, K. -Y., Wong, M.D.F., 2008, “Manufacturing for design: a novel interconnect optimization method,” Proceedings of SPIE – The International Society for Optical Engineering, Vol. 6925.
7. Boothroyd, G., 1993, “Product design for manufacture and assembly,” Computer-Aided Design, Vol. 26, No. 7.
8. Deslauriers, L., McCarty, L.S., Miller, K., Callaghan, K., Kestin, G., 2019, “Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom,” Proceedings of the National Academy of Sciences of the United States of America, September 24, 2019.
9. Fu, K.K., Yang, M.C., Wood, K.L., 2015, “Design Principles: The Foundation of Design,” 27th International Conference on Design Theory and Methodology, Vol. 7.
10. Bransford, J.D., Brown, A.L., Cocking, R.R., “How People Learn: Brain, Mind, Experience, and School”, 2000, National Academy Press.
11. Brooks, B.J., Koretsky, M.D., 2011, “The Influence of Group Discussion on Students’ Responses and Confidence during Peer Instruction,” Journal of Chemical Education, Vol. 88, No. 11, pp. 1477-1484.
12. Michelene, T.H. Chi., De Leeuw, N., Chiu, M.H., Lavancher, C., 1994, “Eliciting self-explanations improves understanding,” Cognitive Science, Vol. 18, No. 3, pp. 439-477.
13. Nicol, D.J., Boyle, J.T., 2003, “Peer Instruction versus Class-wide Discussion in Large Classes: a comparison of two interaction methods in the wired classroom,” Studies in Higher Education, Vol. 28, No. 4, pp. 457-474.
14. Lucas, A., 2009, “Using Peer Instruction and I-Clickers to Enhance Student Participation in Calculus,” PRIMUS, Vol. 19, No. 3, pp. 219-231.
15. Kendal, K.D., Schussler E.E., 2012, “Does Instructor Type Matter? Undergraduate Student Perception of Graduate Teaching Assistants and Professors,” CBE – Life Sciences Education, Vol. 11, pp. 187-199.
16. Kruger, J., Dunning, D., 1999, “Unskilled and Unaware of It: How Difficulties in Recognizing One’s Own Incompetence Lead to Inflated Self-Assessments,” Journal of Personality and Social Psychology, Vol. 77, No. 6, pp. 1121-1134.
17. Caines, S., Lye, L., Hossain, M.R., 2014, “Teaching Assistant Training to Enhance Graduate Engineering Education,” Proceedings of the Canadian Engineering Education Association Conference (CEEA14), Memorial University of Newfoundland, June 8-11, 2014, Paper 011.

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