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Introduction of Whiteboards to Improve Sketching in Computer-Aided Design Courses

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Abstract:

This evidence-based teaching practices paper presents the study of whiteboarding learning modules to improve sketching in computer-aided design (CAD) undergraduate courses. Sketching is very important in the design process, as it allows engineers to produce, evaluate, modify, and refine ideas rapidly in a physical medium. There has been significant research in creating computer interfaces that support sketching (e.g. use of Surface Pros and pens with SolidWorks or Wacom Smartpads), however, most designers choose not to use a computer for the first stage of design because current available interfaces do not support the informality of sketching. One potential low-cost pedagogical approach to learn sketching in the classroom that can support the necessary informality of the process seen in industry is to use individual whiteboards.

The authors present the use of whiteboards in a large lecture-based undergraduate engineering CAD course to support freehand sketching processes before implementing the resulting design in CAD software. Namely, ideation, modeling strategies, and problem solving learning modules were included in the course. To determine the efficacy of this approach, the following research questions were posed: 1) is it feasible to use individual whiteboards to teach freehand sketching in a large undergraduate CAD course? 2) do students and instructors find this approach acceptable? 3) do students find that the use of whiteboards during class improves their ability to sketch? The acceptability and effectiveness of the approach was tested using pre- and post-student surveys. Additionally, performance on exam questions related to modeling strategies was analyzed across students over time to determine whether the whiteboarding modules improved their ability to develop design strategies.

It was found that 78.2% of the 124 students who took the class completed both pre and post surveys. Of these students, 73% of respondents enjoyed the use of whiteboards to learn sketching, and 78% believed that the whiteboard activities helped them learn the course materials. Furthermore, 64.7% of the students found that the sketching learning modules improved their overall ability to sketch. The instructor and teaching assistant interviews also revealed that not only were the sketching learning modules feasible to perform in a large lecture-based course, but they also assisted in the introduction of new CAD concepts to demonstrate best practices for modeling strategies. Finally, the performance on exam questions related to developing modeling strategies demonstrated that students significantly improved in their sketching ability over time through consistent use of the whiteboarding learning modules ($p = 0.0069$). The positive findings on the feasibility and acceptability as well as effectiveness to improve students' abilities to learn sketching both through qualitative and quantitative assessments demonstrates that this technique may become an important tool in undergraduate engineering design. Furthermore, this study fills the literature gap in the need for low-cost freehand sketching pedagogical approaches in CAD courses to improve the ability to learn engineering design processes.

Introduction:

Engineers often use sketching in the early stages of the design process, as it allows them to produce, modify, and refine ideas rapidly [1]. In computer aided design (CAD) education, this process enhances students' spatial visualization skills [2], as well as improves their communication with colleagues when the visualization tool is shared [3]. In particular, freehand sketching [4], or "a sketch done with only the hand and a pencil or pens", is the quickest way to communicate technical information [5], [6]. It allows students to quickly visualize the problem, consider design options, and identify questions where more information is needed [7]. These positive effects of freehand sketching on the design process have led to an improvement on the quality of the design outcomes [8]. As a result, significant research has been performed in utilizing technologies such as smart pens and touch screen computers for students to be able to sketch [4] computationally, and to enhance the designs and provide insight into the mathematics involved in the design [9].

Although there has been significant research in creating computer interfaces that support sketching [9] – [11], most designers choose not to use a computer for the first stage of design because current available interfaces do not support the informality of sketching [12]. One potential low-cost pedagogical approach to learn sketching in the classroom that can support the necessary informality of the process seen in industry is to use individual whiteboards. Whiteboards allow for the informality of sketching on paper, with the additional benefit of peer collaboration through easy sharing among multiple peers, particularly in large classrooms [13]. Furthermore, after comparing sketching using whiteboards over computer-based drawing tools, it has been found in prior research that whiteboards allow for higher group interaction and less time to complete the task [13], particularly for undergraduate students. Although many CAD courses have eliminated freehand sketching prior to using CAD software, it is clear from prior research that there is a need for freehand sketching using whiteboards in the classroom.

Related Work:

There are several benefits to freehand sketching in CAD courses. For instance, freehand sketching supports the informality and ambiguity elements [12] of early design stages such as brainstorming and ideation. In addition, from a neurological perspective, freehand sketching also allows students to improve their hand-eye coordination [14], as well as real-time discussion during collaborative design exercises [15]. Freehand sketching can also improve spatial-visualization skills [16], enhance creativity [17], and problem solving ability [18]. These factors are important in design-build-test courses, as collaborative group work is important for learning outcomes such as brainstorming, design strategy, and redesign. Furthermore, unlike pen and paper based freehand sketching, using whiteboards during freehand sketching allows for the design to more easily share their work with their classmates, as well as with the instructor.

Freehand sketching also has several benefits over software based design tools such as interactive whiteboards and smart pens (e.g. Surface Pros or Wacom Smartpads). For instance, Johnson et al. [9] reviewed current software based techniques and found that one of the greatest obstacles to widespread adoption of these tools is that the underlying architecture of these programs prevent ambiguity and vagueness that often occurs during the early stages of design [9], [13], [22]. Furthermore, whiteboards allow students to more quickly sketch a desired design [13], reducing the class time needed for sketching.

The purpose of this study is to address whether introducing freehand sketching using whiteboards prior to CAD modelling improves student performance on modeling learning outcomes and project performance. Through a 10-week design-build-test project, the students applied freehand sketching techniques the initial and re-design phases of the prototyping process. Learning outcomes related to sketching were assessed by comparing question scores at the beginning and end of the course.

Objective:

To determine the efficacy of this approach, the following research questions were posed:

1) is it feasible to use individual whiteboards to teach freehand sketching in a large undergraduate CAD course?

2) do students and instructors find this approach acceptable?

3) do students find that the use of whiteboards during class improves their ability to sketch?

The acceptability and effectiveness of the approach was tested using pre- and post-student surveys. Additionally, performance on exam questions related to modeling strategies was analyzed to determine whether the whiteboarding modules improved their ability to develop design strategies. For comparison to the prior year's course where no whiteboarding or freehand sketching was utilized in the classroom, students' final grades were compared across years.

Methods:

To assess the above questions, whiteboarding sketching was implemented during lecture in a large lecture-based sophomore biomedical engineering course that focused on the design-build-test process using CAD. Specifically, students who were enrolled in an undergraduate CAD course at an R1 (highest research level) institution completed a 10-week course that included an intensive design-build-test project to develop a wheelchair lever arm for those in developing countries. Sponsored by the Free Wheelchair Mission (Irvine, CA), students were tasked with developing a wheelchair lever arm that can easily be mounted on manual wheelchairs and is low in cost, as these wheelchairs are donated to those in need in developing countries. As part of their CAD course, students developed an assembly model of their prototype design using SolidWorks (Dassault Systèmes, Waltham, MA), and then built and tested their prototype based on their model at the end of the course. Throughout their discussion sessions, students were encouraged to use personal whiteboards to help guide them throughout the design-build-test process, particularly during ideation, brainstorming, and design/redesign. Upon completion of the project, students then "raced" each other to determine whether their prototype functioned as appropriate, and wrote a final report that reflected upon their design and redesign process. An example photo of students racing their wheelchair lever arm drivers is presented in Figure 1 below, along with the students' resulting assembly design.

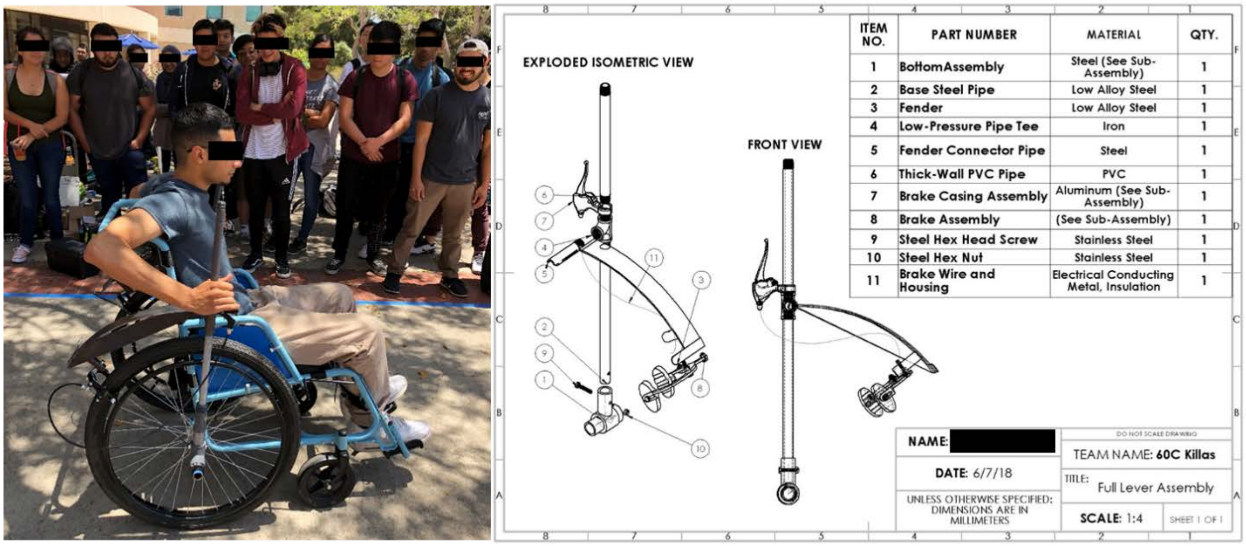

Figure 1: (left) Image of students testing their prototype on "race day", (right) resulting assembly model of a student team's prototype design.

Learning Outcomes Measured:

Students were provided with individual lap-sized whiteboards (12" x 18") and markers at the beginning of each lecture ($400 total). Prior to the CAD modelling of the below learning outcomes, students performed an in-class sketching learning module related to the sketching practices involved to achieve that specific learning outcome. Namely, ideation, modeling strategies, and problem-solving were performed. These are further described in the Whiteboarding Learning Outcomes section presented below. The following learning outcomes were presented using whiteboarding sketching activities:

1. Basic drafting design principles
2. Engineering drawings
3. Design modeling strategies
4. Design constraints
5. Stress and strain analysis
6. Material selection
7. Assembly drawings

Data Collection:

The class consisted of 124 biomedical engineering students who were enrolled in a sophomore level CAD design course. All students, instructor, and teaching assistants that participated in the study were provided informed consent (University of California Irvine IRB Approval Number: 2018-4211). At the start of the course, students were instructed that individual whiteboards and markers would be provided at each lecture, and that the submissions of images of the whiteboard question would be graded for participation after each lecture using the Canvas Learning

Management System (Canvas LMS, Salt Lake City, UT). Pre- and post- surveys to assess feasibility, acceptability, and utility of the whiteboarding learning modules were provided to the students as one extra credit bonus for each survey completed.

Whiteboard Learning Modules:

The whiteboarding learning modules focused on ideation, modeling strategies, problem-solving strategies. These techniques provided sketching practice prior to learning the CAD learning outcomes. For instance, during basic drafting and design and engineering drawing principles, students were asked to freehand sketch an isometric, front, top, and side view of a simple shape, as presented in Figure 2 below. In addition, during this portion of the course, they used freehand sketching on whiteboards to learn sketching views through different axonometric projections, as well as proportions and dimensioning for manufacturing.

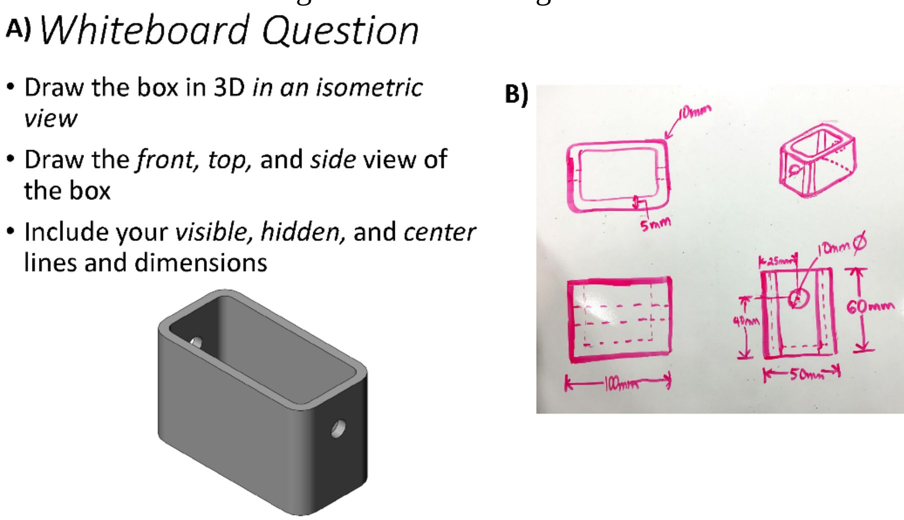

Figure 2: a) Sample question and b) student response to support engineering drafting and design.

For the learning outcomes related to design modeling strategies and constraints, whiteboard learning modules involved students identifying base features (or constraints) and the order of features (or constraints) to create a known part or assembly. An example of a design modeling strategy whiteboarding activity and a student's sketch response is presented in Figure 3 below.

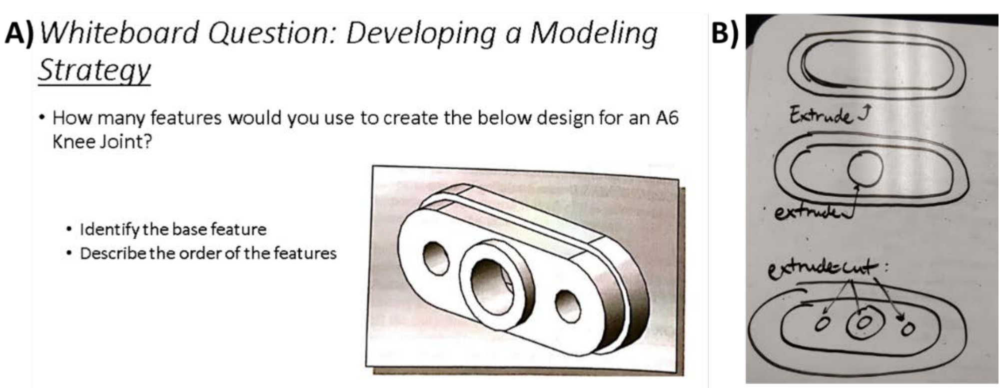

Figure 3: a) Sample design modeling strategy question and b) student response to support modeling strategy development.

To assist with problem solving prior to understanding how to perform material selection in the design process, whiteboarding modules such as stress strain analysis were presented. An example of a whiteboarding module related to materials selection can be seen in Figure 4. During this activity, students were asked to calculate the material index for minimal mass design for a circular cantilever beam. By deriving the material index using freehand sketching, and then learning how to use this information in software to perform materials selection via the Ashby method [20] (CES EduPack, Granta Material Intelligence, Cambridge, UK), students were able to apply their analysis from freehand sketching to computer-based software, and then to their own design projects. This allowed them to perform several critical steps in the design process, namely problem definition, analysis, and implementation to a real-world problem.

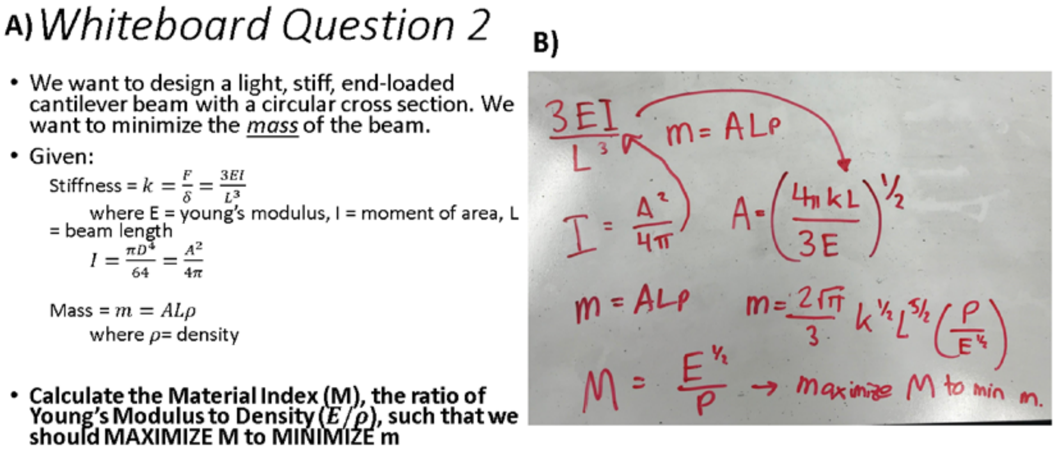

Figure 4: a) Sample problem solving question and b) student response to support materials selection learning.

Pre- and Post-Course Surveys:

To assess feasibility, acceptability, and utility of the whiteboarding learning modules, pre- and post-course online surveys were provided to the students through the Canvas LMS system. To maximize compliance, completion of each survey awarded the student with one extra credit point towards their final grade. As presented in Table 1, the following constructs were examined.

Table 1: Constructs and resulting survey questions to assess the feasibility, acceptability and utility of the whiteboarding learning modules.

Construct	**Question**
Prior perceptions of whiteboarding activities in the classroom	Have you ever used a personal lap whiteboard in the classroom before?
	If yes, did you like using a whiteboard in the classroom?
	If you have used personal lap whiteboards in the classroom before, did you find that it improved your understanding of course materials?

	Please rate your previous experience of using a personal lap whiteboard in the classroom.
Initial interest and perceptions of whiteboarding use for CAD courses	Please rate your interest in using personal lap whiteboards to learn computer aided design
	How would you envision using whiteboards in the classroom to learn computer aided design?
Acceptability of whiteboarding learning modules in CAD courses	Did you enjoy using the whiteboards in class?
	What did you like about the whiteboarding activities?
Perceived utility of whiteboarding modules to improve course learning outcomes	Did the whiteboarding activities help you learn the course materials?
Perceived effectiveness of whiteboarding to improve sketching abilities	Did the whiteboarding activities improve your ability to sketch?
Potential improvements for whiteboarding learning module activities	What did you not like about the whiteboarding activities?
	If you were to take the class again, what improvements would you make to the whiteboarding activities?

As seen in Table 1, students' perceptions of the whiteboarding learning modules were ascertained using both categorical items (e.g. "yes" or "no" or Likert scales) and open-ended questions. Both the positive and negative nature of the whiteboarding activities were examined, as well as the potential improvements that can be made. This helped determine which key factors and activities of the whiteboarding learning modules led to student acceptability and utility of the activities to improve sketching abilities and course learning outcomes.

The perceived effectiveness of the whiteboarding learning modules on course learning outcomes related to modeling strategies was assessed by comparing performances on related exam questions at the beginning and end of the course. This was done by quantitatively analyzing exam question scores of those students who perceived the whiteboarding learning modules as useful in learning the course materials to those who did not. To this end, scores on exam questions related modeling strategies was normalized and their distribution was plotted. It was found that since the exam question scores had bimodal distributions, the Wilcoxon signed-rank test was utilized, as this is a non-parametric method of the paired Student's t-test. In addition, to compare whether learning improved in the course when whiteboarding learning modules were implemented to when they were not, the prior year's final grades when sketching was not taught was compared to the final grades of the course where whiteboarding was implemented. Since specific scores on exams and whiteboarding learning module related exam questions were not available for the prior year (control year), the authors were unable to make a direct comparison. An independent samples t-test was utilized to compare grades across the control and experimental courses.

Other variables that were quantitatively explored in terms of their relationship with prior perceptions of whiteboarding in the classroom include categorical demographic variables such as sex, low income, current class level, and race. Using cross tabulation, Pearson chi-square tests were performed to determine whether the categorical variables were associated or independent. Furthermore, Pearson chi-square tests were used to analyze whether there was any association between demographics variables and the perceived acceptability, utility, and effectiveness of using the whiteboarding learning modules to learn sketching and the course learning outcomes.

Results:

Quantitative Analysis of Whiteboarding Learning Modules:

It was found that 78.23% of the 124 students who took the class completed both the pre and post course surveys (N = 97 for the pre-survey and N = 99 for the post-survey). Their demographic data is presented in Table 2 below.

Table 2: Demographics of the study participants who completed the post-course online survey.

Number of Participants: 97	
Low Income	23 (23.7%)
First Generation	24 (24.7%)
Females	54 (55.7%)
Hispanic	23 (23.7%)
Asian American	47 (48.5%)
Underrepresented Minorities	25 (25.8%)

After comparing demographic data against both pre- and post- survey results using cross-tabulation and Pearson chi-square tests, it was found that there were no statistically significant associations between demographic data and perceived acceptability, utility, and effectiveness of using the whiteboarding learning modules to learn sketching and the course learning outcomes ($p > 0.05$). This demonstrates that there were no inherent socio-economical or cultural biases observed among students and their perceived acceptability and utility of the whiteboarding learning modules to learn sketching and the course related materials.

Of the students who performed the pre-course survey, it was found that 49.5% of the respondents had used a personal lap whiteboard in a classroom prior to the course, and 38.14% of the students found that it improved their understanding of the course material for that particular course. Furthermore, 81.4% of the respondents were somewhat or very interested in using personal lap whiteboards to learn CAD related learning outcomes. This suggests a high level of student interest in using whiteboards prior to the start of the course, as it is becoming common practice in other disciplines and classrooms [21].

After analyzing the post-course survey, it was found that of the students who responded, 73% of respondents reported that they enjoyed the use of whiteboards to learn sketching, and 78% believed that the whiteboard activities helped them learn the course materials. Furthermore, 64.7% of the students found that the sketching learning modules improved their overall ability to sketch. A breakdown of the distribution of students who found that the whiteboarding learning modules improved their ability to learn the course learning outcomes and their ability to sketch can be seen in Figure 5 below.

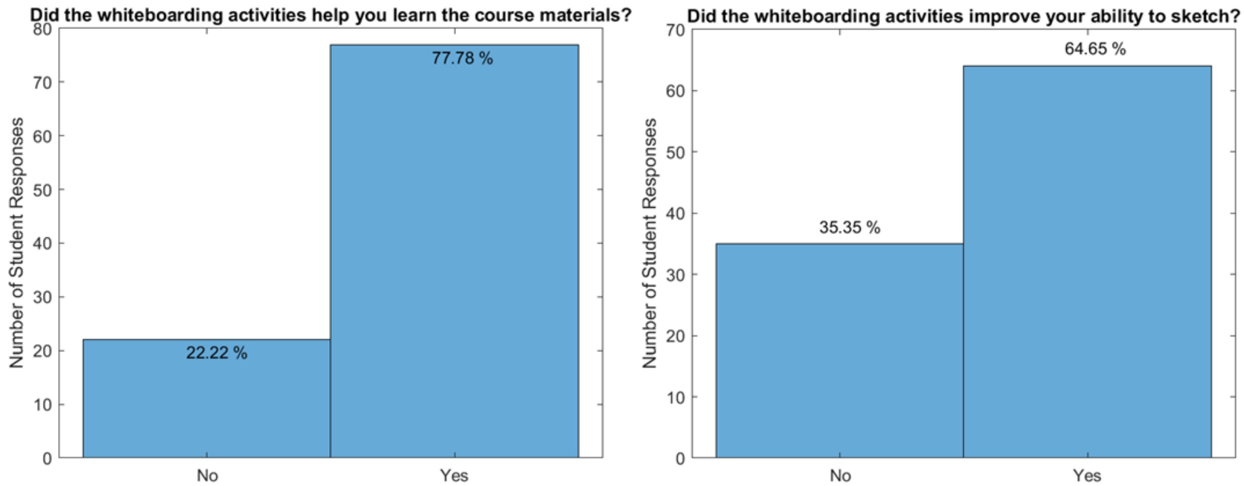

Figure 5: a) Distribution of the perceived utility of using the whiteboarding learning modules to improve course learning outcomes, b) distribution of the perceived effectiveness of using whiteboarding learning modules to improve sketching abilities.

Finally, the performance on exam questions related to modeling strategies demonstrated that students significantly improved in their sketching ability through consistent use of the whiteboarding learning modules ($p = 0.0069$). Furthermore, after comparing the final grades of the prior year's course when no sketching or whiteboarding learning modules were implemented (control group) to the final grades of the experimental group, it was found that there was a statistically significant difference in means ($p < 0.01$). Specifically, the average final grade of the course in the prior year with a similar curriculum and no whiteboarding modules was 81.94 ± 8.54%, whereas the average final grade of the course when whiteboarding learning modules were implemented was 86.87 ± 6.71%.

Qualitative Assessment of Whiteboarding Learning Modules:

The instructor and teaching assistants interviews also revealed that not only were the sketching learning modules feasible to perform in a large lecture-based course, they also assisted in the introduction of new CAD concepts to demonstrate best practices for modeling strategies. In particular, the instructor found that the images submitted for each learning outcome were helpful in determining which course learning outcomes required further reinforcement throughout the course. In the large classroom, the instructor found that it was easier to review student responses to the learning modules over pen and paper, as the instructor was able to more easily walk around and provide feedback to the students whiteboarding responses in real time. In addition, the instructor also mentioned that the whiteboarding activities allowed the students to properly ideate, problem solve, and come up with a solution as well as strategies to achieve the solution prior to implementing it in CAD software. This allowed for a more active learning environment, as students were actively engaged in the entire process, including during the CAD implementation of their solutions.

Interviews with the teaching assistants and instructor also revealed that they observed many student groups utilizing individual and large whiteboards to perform ideation, brainstorming, design selection, and redesign processes throughout their intensive group project. The ideation and brainstorming phases of the design-build-test process were being performed during the first few weeks of the course, which was also when the students learned about basic engineering and design principles as well as drafting and design principles. Anecdotally, the instructor and teaching assistants observed that some of these practices were being utilized during their group project meetings, particularly basic drafting principles such as dimensioning and design modeling strategies for parts and assemblies.

After qualitatively analyzing the pre- and post-course surveys, it was found that many students reported that the whiteboarding learning modules made the class more interactive. They also reported that it allowed the students in a large classroom to be able to participate in the class and think about the learning outcomes more in depth. For instance, students reported that:

"It was a change of pace from doing typical iClicker questions. I found it to be a more fun and creative way of getting the class to participate and making sure we attend class. I feel that whiteboards were actually appropriate for the material we covered considering the fact that CAD requires some amount of creativity."

"It allowed me to practice the topics we were learning in class in order for me to be able to ask questions while still in class. I was able to make mistakes before actually attempting the topic on SolidWorks."

"The whiteboards gave us an opportunity to apply lecture material to different problems. And further helped to reinforce what was being taught."

"I think it was nice to be able to learn how to draw our ideas out (like engineers used to before tech took over) - it's much more hands on and really requires you to think about what you're doing, as you're starting from scratch and really have to build your foundation before visualizing your ideas."

"I liked that I could brainstorm on the whiteboards before actually making the final product on SolidWorks. It also allowed for much easier collaboration with other people."

"I enjoyed using the whiteboards because it helped me be active in class. Also, the activities helped me gauge how much I have to review certain topics. For instance, many of the activities are based on material the class just covered minutes before. So if I was to struggle on the assignment I would know I have to revisit that topic."

"It got the students engaged and forced them to use their hands to actually create something, rather than to just stare at a screen all day."

"It was a unique way of engaging the class. To a small extent, it made us actually try to work out problems, unlike iClickers."

These comments highlight the effectiveness of individual whiteboards to engage the class around the learning outcomes, and to be able to practice the topics being presented prior to learning the concept in CAD software. It was also found that several students found that the whiteboarding learning modules allowed them to express more creativity in the design process, and further improved collaboration with their team members on the group project. Furthermore, several students mentioned that they preferred the whiteboarding learning strategy over the use of iClickers, another active learning technology that is becoming commonplace in undergraduate institutions. Finally, students found that the whiteboarding learning modules helped them improve their visualization skills during the ideation process of design.

Discussion:

The results of the study indicate that whiteboarding learning modules to improve sketching and course learning outcomes is both feasible and acceptable among students and instructors for large lecture based CAD courses. The pre-course survey results show that many students have already been exposed to whiteboarding active learning modules in other classrooms, and they found that the activities improved their learning of course learning outcomes in these prior classes. This is consistent with prior findings on the use of whiteboards in the classroom [21], as whiteboarding learning modules align with effective problem based and active learning strategies. Furthermore, the students reportedly had a positive interest in utilizing this technique to learn CAD concepts. The demonstrates that there was already a high level of student buy-in to perform whiteboarding learning modules prior to the start of the course, which enabled more active use and response to the whiteboarding activities throughout the course.

The post-course survey results revealed that students found the whiteboarding learning modules to be acceptable and effective in improving their abilities to freehand sketch as well as understanding the course materials. Not only did the majority of students find that the whiteboarding learning modules were enjoyable, but they also perceived that the activities were useful in improving their understanding of the course learning outcomes. In addition, the majority of students found that the whiteboarding learning modules improved their abilities to learn freehand sketching, which was never performed in prior years of the course. The quantitative analyses on demographic variables and student responses revealed that there were no socio-economical, class level, or racial biases associated with the acceptability and utility of the whiteboarding learning modules. This demonstrates that whiteboarding learning modules can become an inclusive activity for students of all backgrounds to better learn sketching and CAD learning outcomes, as it is also low in cost and easy to use.

The results from analyzing the performance of exam questions related to developing modeling strategies demonstrated that students significantly improved in their sketching ability. In addition, the improvement in exam question performance demonstrated that the whiteboarding learning modules were effective in helping students improve their ability to create optimal modeling strategies over time. These positive findings suggest that whiteboarding learning modules are effective in improving understanding of CAD learning outcomes, particularly in ideation, sketching, modeling strategies, and problem solving.

The qualitative analysis results revealed that students enjoyed use of the whiteboarding learning modules in the classroom, and even preferred the active learning technique over other commonly used techniques, such as iClickers. The comments from the post-course survey also revealed that students found the whiteboarding learning modules to be very engaging, as it allowed students to practice the learning outcomes being taught by hand prior to implementing them in CAD software. The results also revealed that students found the whiteboarding learning modules to be effective in encouraging creativity and collaboration among group members during the ideation, brainstorming, design, and redesign phases of the large group project. By combining whiteboarding learning modules in the classroom with a design-build-test project, students were able to see the utility of freehand sketching on the design-build-test process, particularly for industry-related projects. This will hopefully allow students to use whiteboards and freehand sketching during design in their first careers, which may in turn improve their project performance. Finally, the qualitative analysis of the survey revealed that students believe the whiteboarding learning modules helped them improve their visualization skills, particularly during ideation and brainstorming. This is consistent with prior findings [14], as 3D visualization skills were improved through freehand sketching rather than exclusive emphases of learning these skills using only 3D CAD software.

The instructor and teaching assistant interviews revealed that whiteboarding techniques to learn freehand sketching were valuable over engineering paper based techniques, as the instructor found that it was easier to review student responses to the learning modules in a large lecture based classroom. This led to better in class discussions of the course learning outcomes. Furthermore, through review of the student submissions, the instructor found the modules useful in determining which course learning outcomes required further emphasis in latter lectures. These benefits highlight the scalability of the approach, and its benefit over other low-cost solutions for freehand sketching, particularly in large lecture-based classrooms. The results of the interviews also revealed that instructors and teaching assistants observed many student groups utilizing individual whiteboards to perform the initial processes of the design-build-test process. This furthered collaboration among student team members, as well as among teaching assistants, instructors, and students, leading to better project performance and more functional prototypes.

In order to better assess the effectiveness of whiteboarding learning modules to improve freehand sketching, future work will include use of validated measures to assess particular skills such as visual-spatial skills. To this end, we will include a pre- and post-diagnostic test to examine whether the learning modules improved visual thinking skills through validated diagnostic measures such as those presented in Shah et al. [22]. In addition, other validated measures such as those presented in Grigg and Benson [23] will be implemented in the pre- and post-diagnostic tests to determine whether the whiteboarding learning modules improved the different stages of problem solving (i.e. problem definition, representation of the problem, organization of information, calculations, evaluation of the solution, communication of the solution). With validated assessment measures, we hope to further assess the effectiveness of the technique on principle engineering skills taught in CAD courses.

Conclusion:

In summary, whiteboard learning modules are an important tool for learning freehand sketching and learning outcomes related to design-build-test processes and CAD. The positive findings on the feasibility and acceptability as well as the effectiveness to improve students' abilities to learn sketching both through qualitative and quantitative assessments demonstrates that this technique may become an important tool in undergraduate engineering design. Furthermore, this study fills the literature gap for the need for low-cost freehand sketching pedagogical approaches in CAD courses to improve the ability to learn engineering design processes. After further validation in other CAD courses across institutions and class sizes, this technique may become a scalable and effective approach to improving sketching and learning outcomes related to design-build-test processes, an integral educational objective of today's undergraduate engineering programs.

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