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Examining the Learning by Teaching Method in Computer-Aided Design Instruction

Xiaobo Peng[1], Diwei Zhang[2], Malcolm Jackson[3], Bugrahan Yalvac[4], Antonia Ketsetzi[5], Deniz Eseryel[6] and T. Fulya Eyupoglu[7]

[1]Prairie View A&M University, xipeng@pvamu.edu
[2]Prairie View A&M University, dzhang2@student.pvamu.edu
[3]Prairie View A&M University, mjackson58@student.pvamu.edu
[4]Bugrahan Yalvac, yalvac@tamu.edu
[5]Antonia Ketsetzi, ketsetzi@tamu.edu
[6] Deniz Eseryel, deserye@ncsu.edu
[7]North Carolina State University, teyupog@ncsu.edu

Corresponding author: Xiaobo Peng, xipeng@pvamu.edu

ABSTRACT

This paper examines the effects of learning by teaching method in Computer-Aided Design instruction. A quasi-experimental pre-and-post test design was employed over four semesters. Experimental group students were asked in pairs to lead the teaching of the course content during the class meetings. Control group students received traditional teacher-centered instruction. In both groups, students' learning outcomes, such as life-long learning skill, engineering attitude, and CAD modeling skills using NX, were evaluated. Both quantitative and qualitative data were collected and analyzed. Findings indicate that first generation college students in the experimental group dramatically improved their CAD modeling knowledge and life-long learning skills in comparison to their counterparts in the control group. A discussion of the findings and recommendations for future research are presented.

Keywords: CAD education, learning by teaching, student-centered instruction.
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1 INTRODUCTION

Most of the current instructional strategies to teach Computer-Aided Design (CAD) software are teacher-centered. Students watch the demonstrations from their course instructors and then follow the directions provided for the purpose to learn the CAD software. The students are kept in a passive role in their learning and they tend to memorize the procedures without thinking or self-reflecting. When the instructor provides lectures to the students, students who are not intrinsically motivated to do their best to learn do not always follow the directions. Those unmotivated students are often left behind to complete the activities provided in the lecture. Students who sit at the back of the classroom, students who attend the class late, students who are too shy to ask questions, or students who are not confident to stop the instructor to let the instructor know they are not able to follow the directions are often left unattended. These students will most likely switch their major to the fields other than engineering and leave the Science, Technology, Engineering, and Mathematics (STEM) pipeline. In order to encourage those students to learn the CAD techniques and retain in the STEM fields, instructional strategies that are capable of involving all students should be implemented.

Educational research indicates that student-centered learning environments are more preferred than the teacher-centered learning environments [1]. When students learn in a student-centered environment, their content understanding, motivation to learn, and interest in the field develop more effectively. There are dozens of student-centered instructional strategies that their impact have been proven and documented in the literature. Among those strategies are group work, project-based learning, open-ended or directed inquiry activities, experiential learning, contextualized activities, and flip classroom settings. The problem that still exists in those student-centered activities is that if the students are not motivated to engage in the activity, they still find a way not to actively engage in the activity. In teamwork, group work, or activities that involve other peers, a leader student or a couple of leading students often complete most of the tasks. The students who need the most help are again left behind or left unattended even though the student-centered activities are assumed to advance all students' learning and skill development. A teaching strategy that does not allow the unmotivated students not to engage in the activities is needed.

"Learning by Teaching" is one of the student-centered learning methods, in which students are assigned to take the teacher's role and benefit from the activities implicit in teaching. Research has found positive results from the implementation of Learning by Teaching method, including deeper student understanding of the content knowledge, increased confidence, refined communication and social skills, changes in attitudes and motivation toward school, and higher responsibility [2],[10]. Learning by teaching approaches have been applied in different engineering disciplines. However, few literatures can be found on applying Learning by Teaching method in CAD education.

An educational study was conducted to explore the impact of the Learning by Teaching method on students' CAD knowledge, skill development, and attitudes. The Learning by Teaching method was implemented in a freshman CAD course between Fall 2015 and Fall 2017. The study was a quasi-experimental pre and post-test research design. The same course instructor taught the multiple sections of the CAD course over two years. Two of these sections were assigned as control group and five of the sections were assigned as experimental group. In the experimental group sections, students led the teaching of the course content. In the control group sections, students received traditional instruction where the course instructor led the teaching of the course content.

In the experimental groups, the leader students prepared for their teaching session and therefore learned the course content outside of the class and prior to their teaching. They reviewed multiple resources (e.g., YouTube videos, Internet, library, etc.), asked their questions to their instructor and the teaching assistants of the course, and learned the course content mostly by their own. In groups, they prepared for their teaching session. The activities the leader students completed had the potential to cultivate life-long learning skills. The students who lived through the experiences of learning the content by their own and teaching it to their peers in class are more likely to perform the same learning activities after graduating from college. It is possible that the experimental group students will develop life-long learning skills because of their experiences in learning the content by their own and preparing for teaching it to their peers.

We assumed that Learning by Teaching method may also affect the students' attitudes toward engineering. Students who experience the power and authority of knowing the content and teaching it to their peers were more likely to develop confidence, self-efficacy, and self-esteem in the CAD knowledge. These enhanced self-efficacy, self-esteem, and confidence in knowing the content may also have a positive impact on their attitudes toward engineering as a field of study.

To explore the impact of Teaching by Learning method on students' content understanding, life-long learning skills, and engineering attitude, data were collected from both experimental and control group students about their CAD content knowledge, life-long learning skills, and engineering attitudes. In a previous work reported [12], the data collected in Fall 2015 semester were analyzed and discussed. In the present study the data collected from multiple sections of the same course over four semesters were analyzed. The data accumulated provide a more comprehensive exploration of the effect of the Learning by Teaching method in the learning of CAD. Both quantitative and qualitative data were collected and analyzed.

2 LITERATURE REVIEW

Teaching could be thought as having three phases: preparing to teach, teaching, and reflection and observation. Before interacting with students, teachers need to master the content to be taught and prepare a plan for delivering the content. Literature showed that people learn more from the preparation for teaching as compared to preparation for test [4]. When studying for the purpose of passing a test, the learners tend to memorize the material. When preparing for the purpose of teaching the content, the learners have to organize the content in a meaningful way. Consequently the process makes the content knowledge more accessible in the memory. The learner pays more attention to the materials to be learned, because he/she does not want to be embarrassed by not knowing the questions while teaching their peers [2]. When teachers interact with students, they need to give explanations and respond to students’ questions. Students who provide explanations learn more than who receive them. When teachers teach, they generate different explanations while observing students’ response. This process helps the teacher gain a deeper understanding of the content [10]. Teachers receive feedback from the students through the students' reactions including non-verbal reactions, student questions, and student assessments. Answering questions from the students can help the teachers be more aware of their misunderstandings or their own gaps in understanding [2].

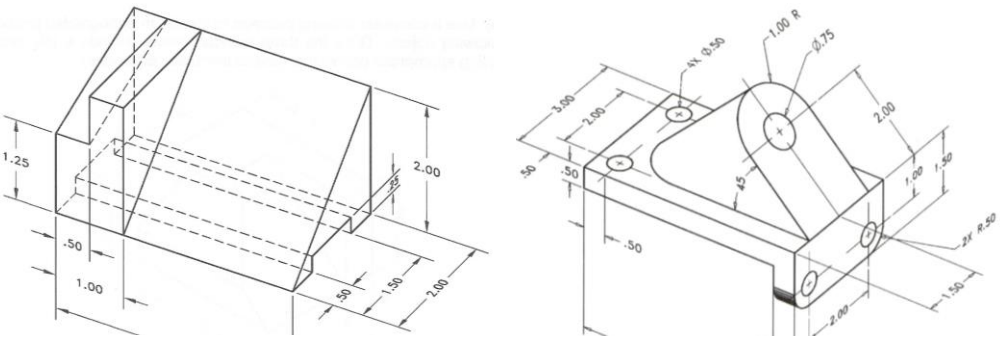
Many different Learning by Teaching pedagogical approaches have been designed, including peer tutoring, teaching assistantship, cooperative learning, community service learning, and teachable agents. Those approaches have also been applied in engineering education across various disciplines [5],[7],[8],[13],[14]. However, few research studies applying Learning by Teaching were conducted in CAD education. Most of the previous studies rely on student self-reported data. In our study, we collected both quantitative and qualitative data about the students’ achievements and their experiences.

3 METHODS

3.1 Study Method

The project has been implemented in a freshman "Mechanical Engineering Drawing" course sections offered in Mechanical Engineering Department since Fall 2015. The CAD software NX was used in the course. This course mainly teaches students the single solid modeling, drafting, and bottom-up assembly. The research study conducted was a quasi-experimental pre-and-post test design. Data were collected from seven different sections in four semesters between 2015 and 2018. Two of these seven sections were designated as control group. Five sections were designated as experimental group. The students in the experimental group were assigned into groups. Each group consisted of three or four students. Each group was asked to take the teacher’s role and teach a CAD modeling exercise to the rest of the students during the class meeting. The student teachers had one week to prepare for their teaching. Each student teaching session took 20 to 40 minutes of the class time. In the control group, students did not take an active role to teach and they received the traditional teacher-led instruction.

The CAD modeling exercises assigned to the student teachers included modeling features that the students needed to learn. The student teachers had one week to learn these features, practice the modeling problems as a group, and design their instruction to teach the other students in class. For example, the modeling exercise shown in Fig. 1(a) was to teach students how to use features such as block, pocket, and chamfer in NX. The modeling problem shown in Fig. 1(b) was to challenge the student teachers to select the best way to model the slanted part of the model.



(a) (b)

Figure 1: Examples of CAD modeling exercise assigned to student teachers.

The student teachers were encouraged to seek help from the course instructor or the teaching assistants when they had questions. The student teachers searched the Internet (including YouTube videos) and the literature at other times. The preparation the student teachers went through for teaching had the potential to help develop life-long learning skills. During the student teachers' teaching sessions, the student teachers had full control of the class. The course instructor participated in the class as a facilitator only. The students in class listened to the student teachers very carefully and followed their directions as shown in Fig. 2. The student teachers answered the students' questions individually and helped them learn the course content.

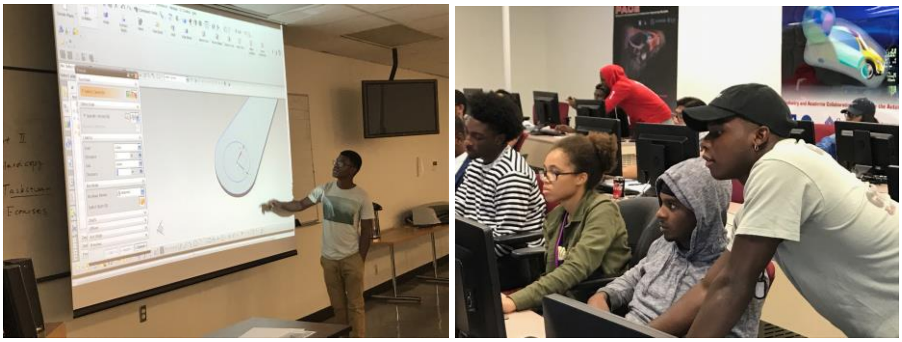


Figure 2: Students taking teacher's role in class.

3.2 Research Instruments

In order to evaluate the effect of the project activities on students' learning outcomes and experiences, five instruments were used: a demographic questionnaire, a life-long learning (LLL) scale, an engineering attitude (EA) survey, an exit project survey, and a CAD modeling exam. The demographic questionnaire designed by the researchers captured the students' demographic information including their ethnicity, gender, major, and whether or not they were first-generation-college students in their family. The LLL scale designed by Wielkiewicz et al. [16] was used to evaluate the students' life-long learning skills. The LLL scale is a 16-item, 5-point Likert-scale. Some sample items from the LLL scale were: "I see myself as a life-long learner," "I am curious about many things," and "I like to learn new things." The EA survey designed by Robinson et al. [15] was used to evaluate the students' attitudes towards engineering. The EA survey is a 25-item, 6-point Likert-scale. Sample items from the EA survey included: "Engineers spend most of their time doing complex mathematical calculations," "Engineering would be a highly interesting profession for me," and "Most of the skills learned in engineering would be useful in everyday life." More details of these two surveys were presented in our previous work [17]. The LLL scale and EA survey were administered at the beginning and the end of each semester in both experimental and control groups. An exit project survey was designed to explore the students' experiences with the teaching activities. Both open-ended and Likert-scale questions were included in the exit project survey. The exit project survey was not anonymous. The survey was administrated at the end of semester for the students in the experimental group only. For both control and experiment groups, a CAD modeling exam is given at the end of the semester to assess students' CAD knowledge and ability to use CAD software to create single models and drafting. The course instructor scored the students' CAD modeling exam and was aware of the control group and experimental group students.

4 RESULTS AND DISCUSSION

The data accumulated over four semesters since Fall 2015 are discussed in this paper. The analyses of the data collected in Fall 2015 were discussed in Peng et al. [12]. In Fall 2015 and Spring 2016 semesters, each student in the experimental group took the teacher role once. Analyses of the student exit survey responses from Fall 2015 revealed that students had preferred to have more than one time to teach in a given semester. Therefore, in Fall 2016 and Fall 2017 semesters, students in the experimental group were offered to teach two times during the semester.

4.1 Participants' Demographic

Students who did not complete any one of the research instruments were excluded from the analyses. A total of 140 data samples were collected up to date. There were 40 students in the control group and 100 students in the experimental group. The data presented in this section were collected through the demographics questionnaire. The questionnaire asked students to indicate their ethnicity, sex, major, and whether or not they were first-generation-college students in their family. Fig. 3. shows the distribution of the male and female students in both control and experimental groups. In the control group, there were 9 females (22%), while there were 17 females (17%) in the experimental group. In the demographic survey, students were asked to indicate whether they were first generation college student or not. If one or more of their parents were college graduates, then the student was not a first generation college student. Fig. 4. represents the distribution of the students who were first generation college students and the students who were not first generation college students in both groups. Sixteen participants in the control group (40%) were first generation college students, while 28 participants in the experimental group (28%) were first generation college students. The ethnicities of the participants as they reported in the survey are shown in Fig. 5. There were 28 African American students in the control group (70%) and 77 African American students in the experimental group (77%). The percentages of the Hispanic students in the control and experimental groups were 7% and 5%.

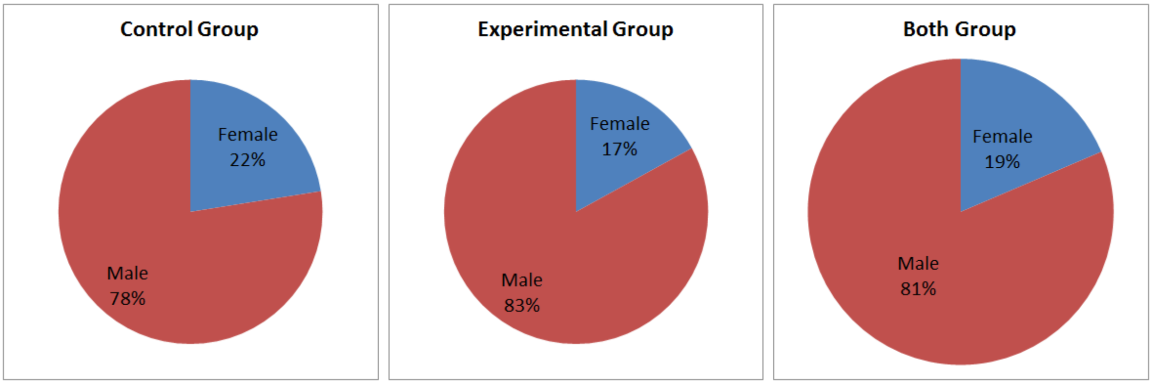


Figure 3: Participants' gender across the groups.

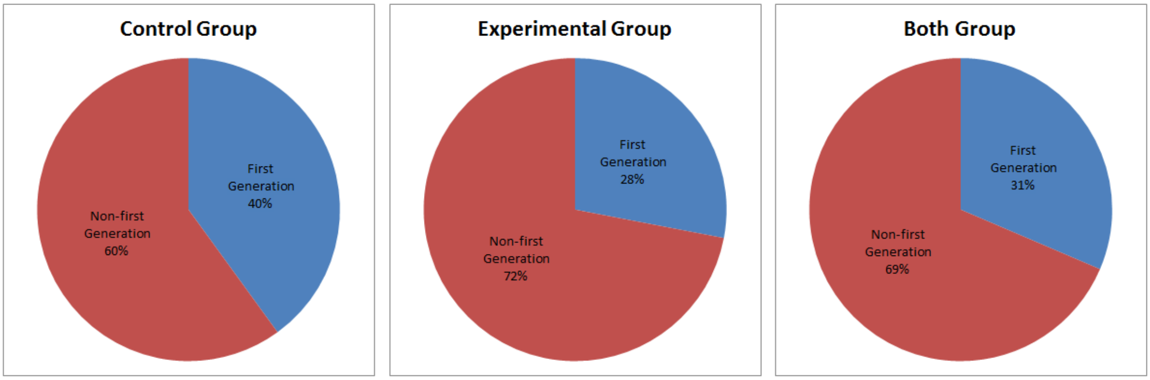


Figure 4: Participants' first generation college student status across the groups.

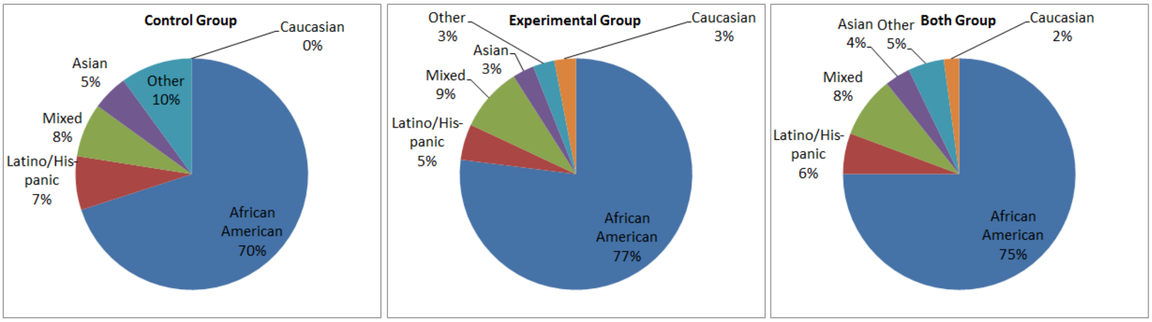


Figure 5: Participants' ethnicities across the groups.

4.2 Life-Long Learning (LLL) Scale and Engineering Attitude (EA) Survey

The students' mean scores in all pre and post surveys were calculated. Each student's gain scores for the life-long learning (LLL) survey and for the engineering attitude (EA) survey were computed by subtracting the pre score from the post score (i.e., gain LLL score = post LLL score - pre LLL score and gain EA score = post EA score - pre EA score). The control group and experimental group are denoted as the subscripts "Cnt" and "Exp," respectively. The standard deviation is denoted as "SD."

The mean scores of the students' responses to the LLL survey are presented in Tab. 1. The results showed that the post LLL scores are higher than pre LLL scores in all groups. T-test results found that post LLL scores of the male students (Mmale-post=3.67) were statistically significantly higher than their pre LLL scores (Mmale-pre=3.58) (t(113)=2.22, p=0.028) at the $p<0.05$ level. However, Post LLL scores of female students (Mfemale-post=3.72) were not significantly different from their pre LLL scores (Mfemale-pre=3.65) (t(25)=0.94, p=0.36). The post LLL mean scores of the students in the control group (Mcnt-post=3.75) were not significantly different from their pre LLL mean scores (Mcnt-pre=3.65) (t(39)=1.66, p=0.11). Similarly, the post LLL mean scores of students in experimental group (Mexp-post=3.65) were not significantly different from their pre LLL mean scores (Mexp-pre=3.58) (t(99)=1.82, p=0.07). For the first generation college students and not-first generation college students, no significant difference was found between their post LLL scores and pre LLL scores. When the gain scores were compared among the different groups (i.e., control group vs. experimental group, male students vs. female students, first generation college students vs. not-first generation college students), no statistically significant difference was found at $p<0.05$ level.

Groups	Number of Students	Pre LLL Score Means (SD)	Post LLL Score Means (SD)	Gain Score for the LLL Scale (SD)
Control Group	40	3.65 (0.56)	3.75 (0.58)	0.10 (0.37)
Experimental Group	100	3.58 (0.51)	3.65 (0.56)	0.07 (0.40)
Male	114	3.58 (0.51)*	3.67 (0.56)*	0.08 (0.39)
Female	26	3.65 (0.62)	3.72 (0.61)	0.07 (0.36)
First generation	44	3.49 (0.49)	3.60 (0.49)	0.10 (0.35)
Not-first generation	96	3.64 (0.54)	3.71 (0.60)	0.07 (0.40)

***Statistically significantly different at p<0.05 level.**

Table 1: Mean scores of students' responses to the life-long learning (LLL) scale.

The male and first generation college students' responses in two types of treatment groups were further analyzed. There were 22 male and first generation college students in experimental group and 8 male and first generation college students in control group. T-test results showed that post LLL scores of male and first generation college students in experimental group (Mmale-first generation-exp-post=3.49) were statistically significantly higher than their pre LLL scores ((Mmale-first generation-exp-pre=3.33) (t(21)=2.23, p=0.037). In contrast, post LLL scores of male and first generation college students in control group (Mmale-first generation-cnt-post=3.73) were not statistically significantly different from their pre LLL scores (Mmale-first generation-cnt-pre=3.55) ($t(7)=1.34$, $p=0.22$). This indicates that taking the teacher's role exercises were most impactful for the male and first generation college students on improving their life-long learning skills.

The mean scores of the students' responses to the EA survey are tabulated in Table 2. The results show that the post EA scores are lower than pre EA scores in all groups (i.e., treatment groups, gender groups, first generation college student status). However, t-test results revealed that the decreases of the EA scores are not statistically significant in all groups except the control group and the first generation college student group. The post EA mean scores of students in the control group (Mcnt-post=4.29) were statistically significantly lower that their pre EA mean scores (Mcnt-pre=4.48) ($t(39)=-2.23$, $p=0.032$). The post EA mean scores of students in first generation college student group (Mfirst generation-post=4.24) were statistically significantly lower than their pre EA mean scores (Mfirst generation-pre=4.42) ($t(43)=-2.43$, $p=0.019$). When the gain scores for the EA survey were compared between different groups (i.e., control group vs. experimental group, male students vs. female students, first generation students vs. not-first generation students), no significant differences were found at $p<0.05$ level. The findings implied that the teacher-centered instruction has negative impact for students especially for the first generation college students.

Groups	Number of Students	Pre EA Score Means (SD)	Post EA Score Means (SD)	Gain Score for the EA Survey (SD)
Control Group	40	4.48 (0.47)*	4.29 (0.56)*	-0.19 (0.54)
Experimental Group	100	4.39 (0.43)	4.35 (0.56)	-0.04 (0.49)
Male	114	4.39 (0.43)	4.30 (0.53)	-0.08 (0.49)
Female	26	4.52 (0.48)	4.45 (0.64)	-0.07 (0.56)
First generation	44	4.42 (0.44)*	4.24 (0.57)*	-0.18 (0.49)
Not-first generation	96	4.41 (0.44)	4.38 (0.54)	-0.03 (0.51)

***Statistically significantly different at p<0.05 level.**

Table 2: Mean scores of students' responses to the engineering attitude (EA) survey.

4.3 CAD Modeling Exam

Students in both experimental group and control group completed the CAD Modeling Exam. The students' exam scores in the CAD modeling exam were analyzed among the different groups including, the two different treatment type, students' gender, and their first generation college status. Tab. 3 lists the mean scores, standard deviations, and t-tests results. In all categories, students in the experimental group performed better than the students in the control group. For example, all experimental group students' average CAD exam scores (Mexp=72.70) was higher than all control group students' average CAD exam scores (Mcnt=67.03) ($t=1.17$, $p=.25$). The mean score of the male students in the experimental group (Mmale-exp=72.42) was also higher than the male students in the control group (Mmale-cnt=69.35) ($t=.57$, $p=.57$). The female students in the experimental group scored higher (Mfemale-exp=74.06) than the female students in the control group (Mfemale-cnt=59.00) ($t=1.36$, $p=.19$). Similarly, when the students' first generation college status was considered, the students in experimental group scored higher than the students in control group. However all independent two-sampled t-tests did not reveal any statistically significant difference at the $p<0.05$ level.

Groups	No. of Students	Exam Means	Exam (SD)	t-test	
				t value	p value
Control Group	40	67.03	26.26	-1.17	.25
Experimental Group	100	72.70	24.87		
Male in control	31	69.35	26.16	-.57	.57
Male in experimental	83	72.42	24.44		
Female in control	9	59.00	26.49	-1.36	.19

Female in experimental	17	74.06	27.66		
First generation in control	16	65.75	19.43	-.17	.87
First generation in experimental	28	67.11	28.21		
Not-first generation in control	24	67.88	30.34	-1.03	.31
Not-first generation in experimental	72	74.88	23.30		

Table 3: Data analyses of students' CAD modeling exam scores.

4.4 Exit Project Survey

Open-ended and Likert-type questions were designed in the exit project survey to capture students' opinions about the learning by teaching activities. This section presented the feedback responded by 100 students on the survey.

When students were asked "how many hours did you spend in average to prepare for your teaching sessions in class", the majority of the students (49%) responded as 'more than one hour and less than three hours.' The second most selected response was 'one hour' with thirty students (30%). While the remainder of the sixteen students indicated that they spend 'more than three hours and less than six' (16%), five students spend 'six hours or more' (5%).

The next question asked students "how difficult it was to locate the resources for their teaching role preparation". While 56 students (56%) found it 'not difficult at all', 34 of them (34%) found it 'slightly difficult.' Only eight students (8%) stated that it was 'difficult' to locate the resources for their teaching role (Figure 6). And two of them (2%) chose 'Very difficult'.

When students were asked what they "liked the most in taking the teacher role in class", 50% of the students reported that they liked to "present their knowledge to the class." They enjoyed "being in charge of their own learning" and developed "a deeper understanding by preparing and teaching other students." As one student stated: "to teach people to understand was a great feeling." Students also liked to teach other students "their way of solving a problem rather than hearing it from the professor or the required text." This helped them to "understand what they were doing better, and how to work with others." On the other hand, some students mentioned that the teaching experiences "gave them a perspective of what the professor and the student assistants do every week." Participants realized "how hard teaching students can be even in a university" and "teaching a lecture looks simple but it takes time and preparation."

Students were also asked what they "liked the least in taking the teacher role in class." The students mentioned that they felt "the pressure it takes to stand in front of a class" whether due to their "stage fright" or "feeling of letting their peers down." Participants found the teaching roles "quite stressful." Besides, some of them reported that it was "difficult to get everyone to follow directions" and challenging to "wait for everybody to be on the same page" as they took the teacher role. It was difficult "managing the students and keeping their focus on subject matter." Few students pointed out that it took "a lot their time to prepare for teaching" while two others did not like "to schedule to meet other students to teach" and "group coordination." One of the participants stated that "focusing on the teacher role as well as the project" was what s/he did not like.

The next question asked students about "the difficulties they came across as they prepared for their teaching role" and "how they addressed those difficulties." The most frequent response was about "scheduling a good meeting time for all the group members to meet and prepare". Group members were able to overcome this difficulty either by "making a group chat to agree on times that they could all meet and work on the assignment" or "having to sacrifice some of their spare time to meet up." The next most frequent responses were "explaining their reasoning to their peers" and "understanding the needs of their peers". Participants found it difficult "what exactly to say and how to say it" so that the students in class could understand. In order to make sure that their peers "understanding what they are trying to explain," they "talked to students to know about their way of learning in class." Few participants had "technical difficulties with the software used" and they "continued to teach using verbal demonstrations."

When the students were asked "what did they learn new as they prepared for their teaching role and in their teaching experiences," they responded that they learned "how to solve the problem in several ways" and their "peers provided insight on the easier, more efficient ways to do things." Some students emphasized how "difficult it was to be a teacher" and they "had to explain in depth what was needed to be done so everyone would understand." Besides, other students stated that their teaching role helped them to "communicate with others" and "be patient and more open to people." In addition, students indicated how they learned about the importance of "getting prepared for the class" so that they "know the work and process before they teach it to someone else." Preparing for the teaching role helped the students "to sketch better" and "to make the model that was given" by "learning new features." Few student participants reported that they learned to "work well with the group members."

Students were also asked "how helpful it was to learn the content of the course from their classmates in class." The results showed that 42 of the participants (42%) found learning the course content from their classmates 'very helpful' while 45 of them (45%) found it 'helpful.' Only 13 of them responded that it was 'slightly helpful' to learn the content of the course from their classmates in class (13%).

In another question students were asked "what they learned new or different from their peers teaching that they would not learn otherwise from their course instructor's or TAs' teaching." Most of the students used the terms "different" in their statements. They mentioned how they "learned different approaches to solve the problems" but "achieving the same objective." They also stated that "it was easier to learn from a peer rather than a teacher or TA" because "peers provided insight for easier ways to do the assignment" and "it was less intimidating to ask for help" to their peers. Furthermore, few of the participants indicated that they "learned shortcuts from other students to solve a problem" as well as learning "how to do more things through sketch."

The last question in the survey inquired students' responses pertaining their "recommendations to improve the teaching activity and what they would prefer to change in the teaching activity for future course offerings." Participants' most frequent responses were that they "would not change anything" and "like it the way it is." Some students suggested to "slow down, talk clear and loud and explain things better" so that "everyone in the class understands." Other students suggested "to make the teaching sessions a part of grading" as "it takes a lot of time to practice" for them. Also, participants suggested to "offer more teaching experiences" because the "teaching exercise brought them together" and "made them think together." While one participant wanted to see the "teacher takes his time to teach and explain the material," another participants suggested to have "more interactive class meetings rather than a traditional PowerPoint day to day class lectures." Moreover, students suggested to "spent more time working on the assignment" and "make sure everyone is prepared" for the assignment. Participants stated that they would prefer to see "the group members were all in the class to know when it's their turn and who each other were." The other suggestions included; "prepare the computers in the lab before hand," "give a problem they are going to teach in the next class session," "divide tasks between group members," "go over on the homework and project examples," and "make sure the activity is not too difficult or too easy."

4.5 Discussion

Our analyses revealed that the Learning by Teaching method had more positive impact on first generation college students. This finding is not surprising to us. First generation college students would have been more receptive to the student-centered learning activities because those activities actively engage the students in their learning regardless of their intrinsic motivation to learn or to engage in the course activities. Students are forced to participate when the instructional activities require their full engagement. In the present project, experimental group students were required to prepare for teaching the content and deliver the instruction to their peers in class. Researchers observed that all students in the experimental groups worked hard and tried to do their best in their preparation and delivery of the instruction. The course instructor and the student assistants did not lead the class meeting session during the students' teaching. Teaching the course content to the peers in class was an exemplary student-centered activity that fully engaged the students who were teaching the course content. First generation college students may easily loose their interest in learning the content when the traditional and teacher-centered instruction is delivered. Not first generation college students may be more resistant to loose their interest when the course instructor delivers a traditional teacher-centered instruction. Future research can investigate the impact of the student-centered instructional designs on first generation college students in comparison to not first generation college students. If similar findings are reported, then the use of student-centered instructional strategies will become significant because they also support to enhance equity in education. These findings will greatly contribute to the efforts to close the socio-economic gap between the college educated and not college educated individuals in the society.

It is possible that not first generation college student are more used to ask questions in a traditional and teacher-centered instruction and used to engage in conversations with their course instructor and the student assistants. The first generation college students may be shy to ask their questions and engage in conversations in teacher-centered traditional instruction. When the instruction is delivered with a peer, first generation college students may become more open to ask questions and engage in the course activities. When the first generation college students teach the class session, they may take these activities more seriously than the not first generation college students. There could be some psychological and/or sociological underpinnings why first generation college students are more receptive to the Learning by Teaching method than their not first generation college counterparts. Future research can investigate those psychological or sociological factors. Individual interviews with selected students can be conducted to explore those factor or underpinnings.

In the future studies, researchers can investigate to what extend Learning by Teaching method can help improve students' strategic versus procedural knowledge or positive versus negative knowledge development [3],[6],[9],[11]. Strategic knowledge in CAD is defined as the capability to design and apply the most suitable modeling strategy depending on the modeling context and objective. Strategic knowledge in CAD is often being developed through experience. Our student teachers learned and taught the CAD modeling techniques to their peers in class in relatively short time. Whether the student teachers were able to develop strategic knowledge or whether they were able to help their peers develop that strategic knowledge were not explored in this study. Negative knowledge is often defined as *knowing what not to do* in CAD [11].

A limitation of this study is that we did not ask students about their prior CAD knowledge or experience that they might have before taking the CAD course.

5 CONCLUSIONS AND FUTURE WORK

In this project, a student-centered instructional strategy, Learning by Teaching method, was implemented in a freshman computer-aided design class. The quantitative data and qualitative data were collected and analyzed to examine students' learning of CAD, life-long learning, and engineering attitude. The findings indicated that taking the teacher's role has positively affected the students' life-long learning skills and their CAD modeling knowledge. Among the participants, male and first generation college students have dramatically improved their life-long learning skills. The traditional teacher-centered instruction has negatively and significantly impacted students' engineering attitudes. When the Learning by Teaching method was applied in the CAD education, the negative changes in students' engineering attitude were not statistically significant.

The experimental group students might have spent more time in preparing for their teaching session than the students who did not teach and just studied the content for their own learning. The time students spent might not be even when the two treatment types are considered. In the future studies, Learning by Teaching method can be compared with other student-centered instructional methods in addition to a control group comparison. By doing so, the extent to which Learning by Teaching method is more impactful than the other student-centered instructional methods can be examined.

In the present study, authors studied the student participants' CAD knowledge, their life-long learning skills, and engineering attitudes. Future research can study the students' other skills and knowledge pertaining to 21st century skills, for example, adaptive expertise, self-regulation, communication, argumentation, and critical thinking, leadership, and creativity.

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Xiaobo Peng, https://orcid.org/0000-0002-0498-7194.
Diwei Zhang, https://orcid.org/0000-0001-6164-561X
Malcolm Jackson, https://orcid.org/0000-0001-9910-2645
Bugrahan Yalvac, https://orcid.org/0000-0002-3675-1936
Antonia Ketsetzi, https://orcid.org/0000-0002-8361-9305.
Deniz Eseryel, https://orcid.org/ 0000-0002-6274-4633.

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