2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #39115

A Qualitative Insight into User Experiences of an Intelligent Tutoring System to Learn Sketching Skills.

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An Insight into User Experiences of an Intelligent Tutoring System to Learn Sketching Skills

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Abstract

Sketching is a valuable skill for many engineering students to support the development of various auxiliary skills such as refined spatial visualization, problem-solving, idea generation, and communication. As the students engage in the engineering design process, sketching skills, along with the auxiliary skills, become valuable tools in future courses and continually in their careers. Explicitly teaching students to sketch is challenging given the instructor-to-student ratio. Hence, intelligent tutoring systems (ITS) are highly beneficial to students in this context to develop these skills actively rather than expect students to develop these skills independently through the needs of other courses. An ITS was introduced through this study to teach sketching skills to students in mechanical engineering courses. The basics of Two-point perspective sketching were the focus of the instruction material facilitated by this ITS. The tutoring platform provides individualized automatic feedback to students immediately after they complete a sketch to inform them of their performance and ultimately to enhance their sketching skill development. This study aims to understand the experiences of graduate and undergraduate mechanical engineering students from three institutions learning sketching through the ITS environment.Our study is guided by the following research questions: 1. What was the engineering student's experience in learning to sketch in an intelligent tutoring platform? 2. What are the strengths, weaknesses, and suggestions for improving the intelligent tutoring system? 3. What are the impacts of the intelligent tutoring System on the sketching self-efficacy of engineering students? In this study researchers collected data through surveys and semi-structured interviews. The participants were students enrolled in undergraduate and graduate Mechanical Engineering courses at three different institutions where they learned and practiced sketching using the ITS. This study helps us to understand the strengths and weaknesses of the ITS, along with suggestions for how to improve the software from an engineering student perspective. The user experiences of mechanical engineering students was valuable to understand if and how students are finding this particular ITS helpful in their academic lives. The results of the study will be useful to researchers and engineering education community working to develop educational software tools, to better understand the student expectations, and educators interested in identifying a way to incorporate sketching.

Background

Application of Artificial Intelligence in engineering education is achieved through intelligent tutoring systems(ITS); ITS have started to become more prevalent in engineering education to provide students with computer-based instruction in a personalized manner. ITS has the potential to play an essential role in the future of engineering education. ITS attempts to provide instruction and also necessary feedback through Artificial Intelligence. One of the main advantages of ITS is that it is capable of replicating one-on-one tutoring to students [1] without the need for a human tutor. It was shown that ITS increases the performance of students by improving their examination scores by about one standard deviation compared to students who received traditional instruction [2]. However, human tutors were found to be most effective and improve the examination scores by two standard deviations [2]. Human tutors are not affordable for most students, and significantly fewer students gain the benefits of one-on-one human tutoring. Teaching certain concepts to undergraduate engineering students through ITS, an application of Artificial Intelligence in education is a promising area that needs further exploration in terms of its benefits for diverse undergraduate engineering students.

A study that compared Computer-based learning methods such as Massive Open Online Courses found ITS to be more effective in fostering learning with its interactive and personalized interface [3]. Learning using ITS does not require students to be at a physical class location or university space at a specific time [4]. Another advantage of ITS cited by literature is that ITS helps in reducing the grading workload of instructors and, at the same time, mitigate unfair or inconsistent grading [5] It is also important to note that although ITS has many advantages, ITS is more valuable when it is used alongside a human instructor and not when a human instructor is completely replaced [6]. A recent meta-analysis review comprising 50 studies concluded that ITS was beneficial for student learning in 46 out of 50 studies [3]. A small number of studies that did not find any improvement in student performance after utilizing ITS, were weak in execution or were designed poorly [3]. Thus, ITS is a powerful tool that supports student learning in a unique and personalized manner similar to a human tutor.

Sketching is a useful skill for many engineering students to support the development of various auxiliary skills such as refined spatial visualization, problem-solving, idea generation, and idea communication, etc. As the students engage in the engineering design process, sketching skills, along with the auxiliary skills, become valuable tools in future courses and continually in their careers. Explicitly teaching students to sketch is challenging, given the instructor-to-student ratio. Hence, intelligent tutoring systems are highly beneficial to students in this context to develop these skills actively rather than expecting students to develop these skills independently through the needs of other courses. In the context of this study, an intelligent tutoring system named *SketchTivity* was introduced to teach sketching skills to students [7–11]. *SketchTivity* utilizes sketch-recognition algorithms, gives real-time automatic feedback to students, and aims to improve sketching skills along with students' sketching self-efficacy in sketching. *SketchTivity* currently includes modules on basics (lines, arcs, squares, circles), perspective (1 point, 2 point, planes, ellipses), primitives (cubes, cylinders, cones, spheres), combinations (additive), and perception (contours, symmetry). See Figure 1 for the software window with module names on the left. Each module consists of a tutorial video for students to watch, followed by eight practice exercises. At the time of study, once the students complete the eight exercises, they receive a score for precision, smoothness, and speed along with a tip for students (see Figure 2). *SketchTivity* was developed at Texas A&M university, and has been deployed to various universities and classrooms at the time of our study; we seek to make further improvements in the software.

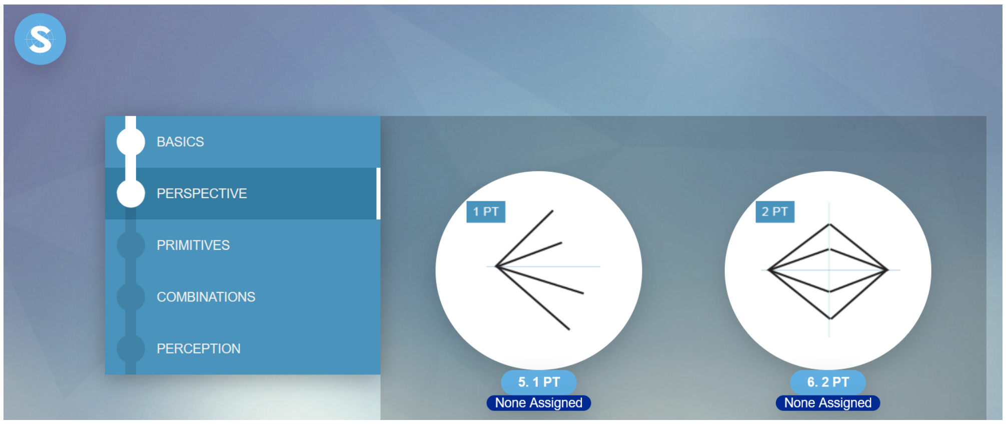

Figure 1: Modules

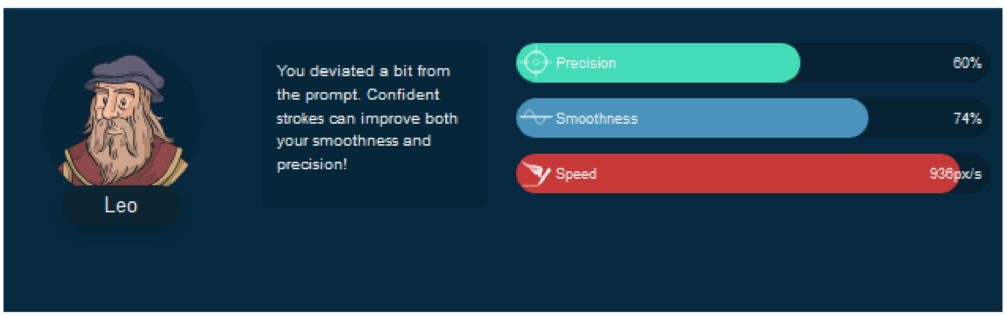

Figure 2: Feedback Screen

This study aims to understand the experiences of undergraduate and graduate engineering students learning of sketching through the ITS environment. Our study is guided by the following research questions:

- *What was the engineering student's experience in learning to sketch in an intelligent tutoring platform?*
- *What are the strengths, weaknesses, and suggestions for improving the intelligent tutoring system?*
- *What are the impacts of the intelligent tutoring System on the sketching self-efficacy of engineering students?*

Related Works

A. Intelligent tutoring systems for Sketching

ITS have been developed and tested for many different drawing and visualization learning settings. Inadome et al. [12] developed an intelligent sketching instruction system to provide step-by-step feedback on the differences between learners' sketch and an augmented reality image viewed with a headset. This system detected gaps between pen position and contour points on the AR image and made suggestions through both text and auditory messages [12]. A system to guide visual reasoning about 3D geometry was developed by Kim and Wang [13]. Students were asked to construct 3D solids piece by piece, accounting for adjacent sides and hidden shape faces. The ITS guided students towards correct 3D shape construction with shape piece selection hints and construction sorting process hints [13]. Mechanix was developed by Valentine et al. [14] to interpret mechanical engineering truss and free body diagrams using sketch recognition algorithms. Instructors create assignments, problems, and solution diagrams with labeling features, while students view problem instructions, a panel to record force equations, edit functions, and automated feedback from the system to inform them of any missing features [14]. GearSketch was an adaptive learning system developed by Leenaars et al. [15] to translate drawn answers to elementary science gears problems into diagrams on practice problems and challenge puzzles. It used student knowledge models to evaluate solutions to questions with multiple correct solutions. Each of these ITS for sketching begins with computer recognition and interpretation of user sketches, and expands it to structured lessons in learning contexts with practice and feedback.

B. Improving Self-Efficacy with intelligent tutoring Systems

Self-efficacy is the perceived confidence students have in their own abilities to carry out learning activities and achieve goals. It is derived from students' internal agency and their relationship to the learning environment, with self-beliefs defining their perceived abilities [16]. Self-efficacy informs students' interests in a subject area and determines their purposeful actions towards achieving learning goals [17]. Interests are also informed by outcome expectations of success or failure students have before and during pursuit of learning goals. Expected and actual outcomes both reinforce the actions students take to reach goals, becoming a part of their learning base ultimately determining their decisions and strategies to pursue goals [16, 17]. Self-efficacy depends on self-regulation and helps students evaluate goals, structure individual actions to reach them, and motivate them to pursue long-term goals while coping with challenges [18].

Few studies of ITS have directly examined their capacity to support student self-efficacy. In a computational approach to assessing self-efficacy in ITS, [19] used a variety of cognitive and physiological data to model learners' emotional and motivational states during an ITS educational genetics game. Similarly, [20] performed structural equation modeling of students' reported self-efficacy, test scores, and interaction data, such as hints requested and errors made with a math ITS to show the influence of multiple factors on goal achievement. Problem-solving actions and learning performance results were combined with students' frequent self-efficacy surveys during an ITS algebra unit, [21] demonstrating that self-efficacy dynamically influences self-regulating behavior. A study of ITS for dialogue in student pairs gave adaptive feedback based on students' individual and team self-efficacy levels, but more frequent prompts did not lead to greater participation by low self-efficacy students [22]. These studies have modeled students' self-efficacy when learning with an ITS, but none have directly surveyed students about their self-efficacy to achieve learning goals with the support of the ITS.

C. Student Evaluations of intelligent tutoring systems

ITS have increased in popularity with more advanced AI models informing their design. However, there are many issues students can face when learning with ITS. A recent systematic review of ITS learner characteristic evaluation criteria found that most literature examined (a) knowledge level, (b) learning performance, and (c) behavior in the learning path [23]. Learner performance alone, and learner performance plus experience, were most frequently used to evaluate the ITS [23]. A meta-analysis of ITS effectiveness criteria also used performance comparison as a common outcome indicator while also considering the quality of instruction [3]. A summary of fourteen ITS evaluation frameworks illustrated that, while a mix of objective and subjective metrics was used to evaluate ITS, system functionality or effectiveness and learning improvement or knowledge acquisition were the most commonly assessed outcomes [24]. The authors emphasized the need for both subjective and objective metrics in all areas of learning effectiveness and efficiency, system performance, user satisfaction and usability, and affective engagement [24].

Evaluations of ITS should consider not just whether it can support students' achievement of learning outcomes but also students' perceptions of the system and motivation to learn with ITS. First, students should feel the ITS effectively teaches the content it was designed to. Second, students should be motivated by the ITS to engage with content in ways that support learning. This study addresses the need to understand students' perceptions and experiences with ITS for sketching.

Methods

A. Survey Instrument

Surveys consisting of Likert-style and open-ended questions were administered to students. The following were the questions that were asked in the survey: Q1) What is your overall satisfaction with *SketchTivity*? Q2) Rank your level of agreement with the following four statements: a) *SketchTivity* was effective at teaching 2-point perspective sketching. b) *SketchTivity* was effective for practicing 2-point perspective sketching. c) *SketchTivity* was motivating for practicing and improving my sketching skills. d) I will sketch more after practicing with *SketchTivity*. Q3) What issues, if any, did you have with the software? Q4) What suggestions, if any, do you have for improvements to *SketchTivity*? Q5) Is there anything else you would like to say about *SketchTivity*?

A Drawing Self-Efficacy Instrument was used to measure the pre and post self-efficacy of students who practiced using SketchTivity[25]. The instrument consisted of 13 items and the average of drawing self-efficacy score was calculated for each student.

B. Participants

The participants in this study consisted of undergraduate and graduate students enrolled in four courses at three different institutions. Out of a total of 138 students enrolled in three courses at three institutions, 137 students responded to Q1 and Q2; 109, 88, and 65 participants responded

Table 1: Demographics of the participants

Participant demographcis	Percentage
Men	76.09%
Women	18.84%
First-generation	10.14%
Non-first generation	86.96%
Hispanic	9.42%
Non-hispanic	84.06%
White or Caucasian	39.13%
Asian	42.75%
Mixed	5.80%
Middle Eastern	2.90%
Black or African American	0.72%

to Q3, Q4, and Q5. Note that not everyone reported their demographic identity. In this study Institution I refers to Texas A&M University, Institution II refers to Georgia Institute of Technology and Institution III refers to San Jose State University. These institutions were located in Texas, Georgia, and California, respectively. Below are the percentage of participants in the respective demographic groups. Out of a total of 138 participants, 68.12% were from Institution I, 15.94% of were from Institution II, and 16.67% were from Institution III. The majority of the participants belonged to Mechanical Engineering majors. However, there were also a few students from other majors as well. 83.33% belonged to Mechanical Engineering, 4.35% were from Aerospace Engineering, 4.35% were from Material Science and Engineering, and 2.90% were from Industrial Engineering. There was one participant (0.72%) each from Biomedical, Chemical, and Nuclear engineering. The majority of the participants were males and graduate students; 76.09% were men, 18.84% were women, 84.06% were graduate students, and 16.67% of them were undergraduate students. 10.14% of the participants were First-generation students, 86.96% were Non-first generation students, 84.06% were Non-Hispanic students, and 9.42% were Hispanic students. 39.13% of the participants were White or Caucasian, 42.75% were Asians, 5.80% were Mixed race, 2.90% were Middle Eastern and 0.72% were Black or African American. See Table for a tabular breakdown.

A total of 11 students participated in student interviews out of which nine of them were men and two of them were women. Note that further demographic details were not collected from the interview participants.

C. Student Interviews

At Institution I in the Advanced Product Design course, towards the end of the semester, we recruited students for participating in individual interviews to get their detailed feedback regarding their experience with *SketchTivity* after receiving IRB approval at Institution I. 11 students were willing to participate and they were given a $10 Amazon gift card after their participation in the interview. A semi-structured interview protocol was followed and the interviews lasted for about 20-30 minutes each. The template of questions that the interviewers had with them is listed below.

However, note that each interview was unique and did not follow the exact order or the set of below questions.

- Overall, how would you describe your experience with learning about drawing?
- What did you like and dislike about the software?
- What are your thoughts regarding the way you learned about drawing?
- Do you have any ideas about how software could help better aid your learning?
- Was there anything missing from the software that you expected?
- Would you like to use a similar method for learning drawing the next time you do so?
- What other ideas/suggestions do you have?

D. Data Collection

Data were collected in Fall 2021 semester and Spring 2022 semesters. *SketchTivity* was deployed to students in three institutions enrolled in four different courses. At Institution I, *SketchTivity* was deployed to a graduate course named Advanced Product Design in Fall 2021, and Spring 2022 semesters. At Institution II, *SketchTivity* was deployed to a graduate course named Designing Open Engineering Systems (ME 6102) in Spring 2022 semester. At Institution III, *SketchTivity* was deployed to a freshman-level undergraduate course named Engineering Design and Graphics. In all these courses, the student survey was administered to students toward the end of the semester after they used *SketchTivity* to complete their assignments. Students got around 5 weeks to practice and learn to sketch using *SketchTivity*. All the students who did not own a personal tablet were given a tablet and a smart pen that they could keep with them until all the assignments were due where they needed to use *SketchTivity*.

Results

RQ 1. What was the engineering student's experience in learning to sketch in an Intelligent Tutoring platform?

In order to understand the impact of ITS, data was gathered on their overall satisfaction with the tool, effectiveness of the tool in teaching Two-point perspective sketching, effectiveness for practicing Two-point perspective sketching, and motivation for practicing and improving their sketching skills.

Student Satisfaction

Out of a total of 137 participants, 17 of them were very satisfied (12.41%) with the ITS, 40 of them were satisfied (29.20%), 37 of them were somewhat satisfied (27.01%), 22 were indifferent(16.06%), 13 were somewhat unsatisfied (9.49%), 4 were unsatisfied (2.92%), and 4 were very unsatisfied (2.92%). Thus, 41.61% of the participants were either very satisfied, or satisfied, while 31.39% were indifferent, somewhat unsatisfied, unsatisfied, or very unsatisfied. (see Figure 3)

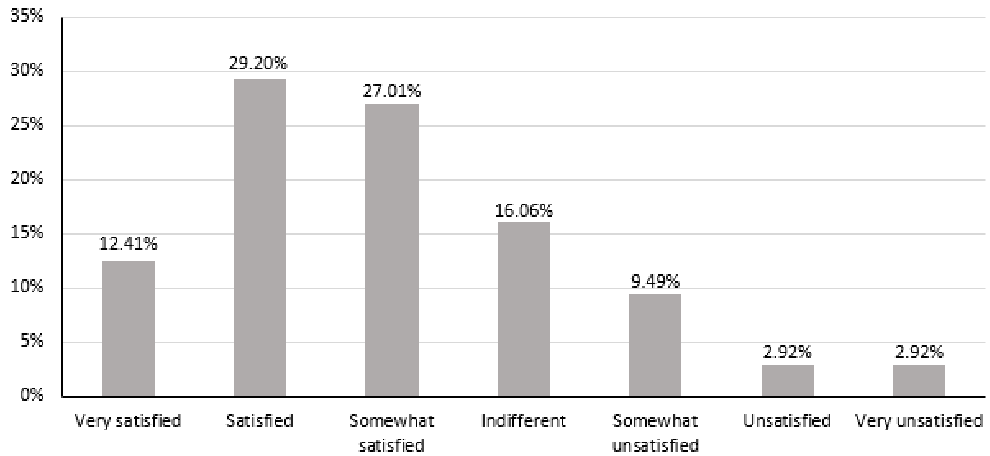

Figure 3: Overall student satisfaction

Effectiveness in Teaching Two-point perspective sketching

ITS was designed to teach the basics of Two-point perspective sketching to engineering students, and hence we gathered student perspectives on the effectiveness of ITS in teaching the users Two-point perspective sketching. Out of a total of 137 participants, 15 of them strongly agreed that ITS was effective in teaching Two-point perspective sketching (10.95%), 57 participants agreed (41.61%), 30 participants somewhat agreed (21.90%), 23 participants neither agreed nor disagreed (16.79%), 6 participants somewhat disagreed (4.38%), 3 participants disagreed (2.19%), and 3 participants strongly disagreed (2.19%). Thus, 52.55% of the participants, expressed either very strong or strong agreement, while 25.55% expressed indifference, somewhat disagreement, disagreement, or strong disagreement. (see Figure 4)

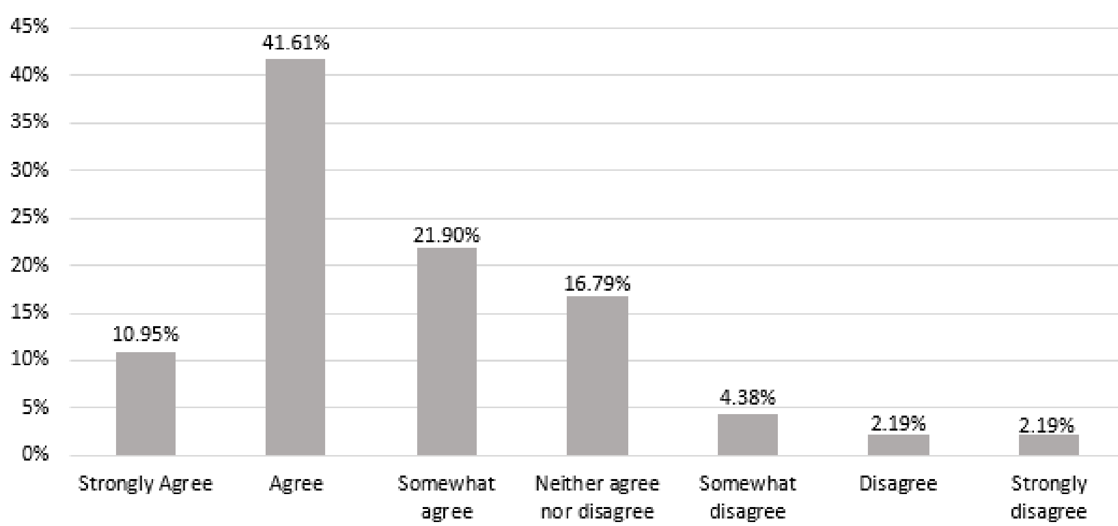

Figure 4: Effectiveness in Teaching Two-point perspective sketching

Effectiveness for practicing Two-point perspective sketching

Out of a total of 137 participants, 17 strongly agreed that the ITS provided an effective environment for practicing sketching (12.41%), 56 agreed (40.88%), 32 somewhat agreed (23.36%), 19 neither agreed nor disagreed (13.87%), 5 somewhat disagreed (3.65%), 3 disagreed (2.19%), and 5 strongly disagreed (3.65%). Thus, 53.28% of the participants expressed very strong or strong agreement, while 23.36% expressed either indifference somewhat disagreement, disagreement, or strong disagreement. (see Figure 5)

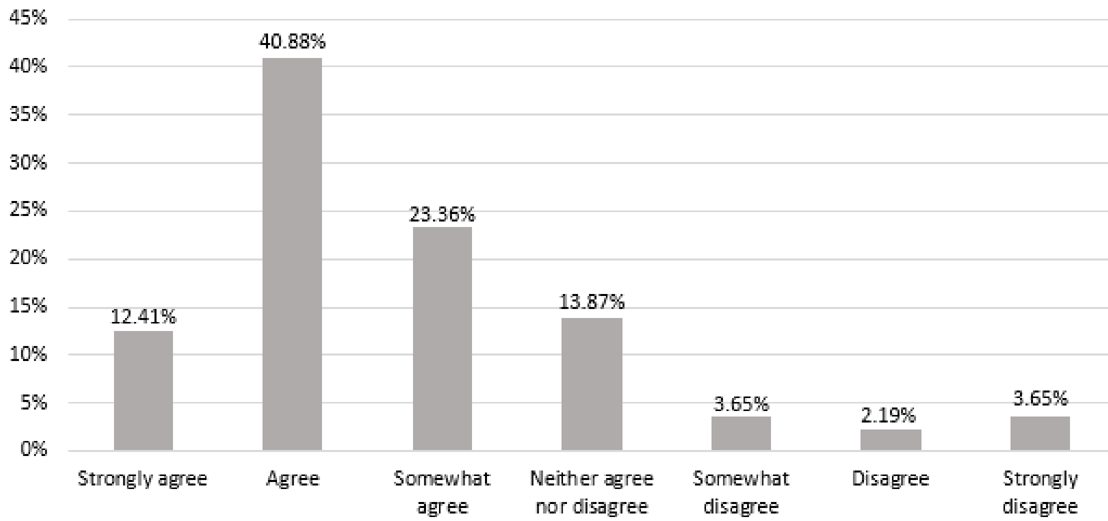

Figure 5: Effectiveness for practicing Two-point perspective sketching

Motivation for practicing and improving sketching skills

Out of a total of 137 participants, 14 strongly agreed that the ITS provided motivation for practicing and improving sketching (10.22%), 46 agreed (33.58%), 31 somewhat agreed (23.63%), 21 neither agreed nor disagreed (15.33%), 14 somewhat disagreed (10.22%), 6 disagreed (4.38%), and 5 strongly disagreed (3.65%). Thus, 43.80% of the participants expressed very strong or strong agreement, while 18.25% expressed either indifference somewhat disagreement, disagreement, or strong disagreement. (see Figure 6)

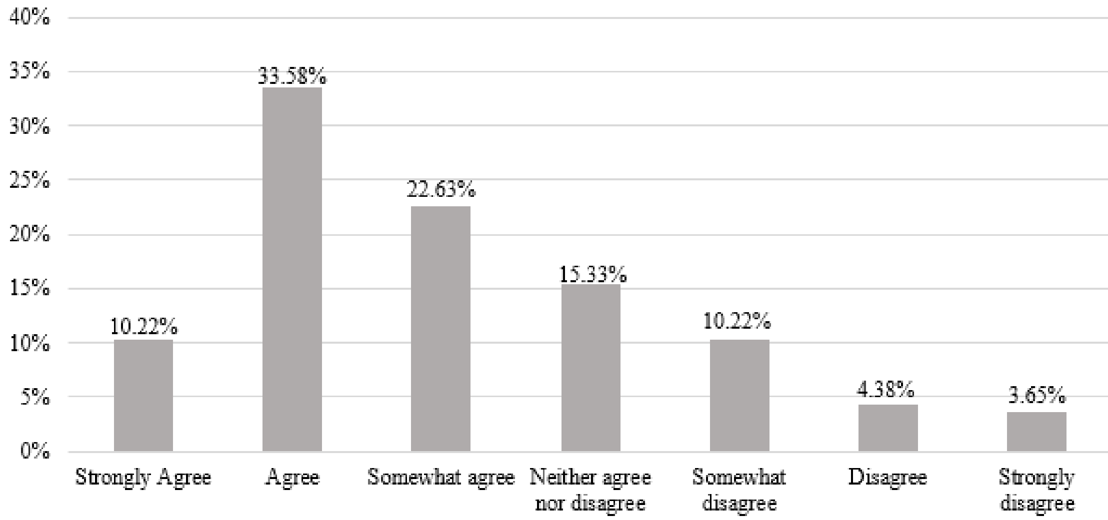

Figure 6: Motivation for practicing and improving sketching skills

Motivation for more frequent sketching

Out of a total of 137 participants, 10 strongly agreed that the ITS provided motivation for frequent sketching (7.30%), 28 agreed (20.44%), 38 somewhat agreed (27.74%), 36 neither agreed nor disagreed (26.28%), 14 somewhat disagreed (10.22%), 3 disagreed (2.19%), and 8 strongly disagreed (5.84%). Thus, 43.80% of the participants expressed very strong or strong agreement, while 18.25% expressed either indifference, somewhat disagreement, disagreement, or strong disagreement. (see Figure 7)

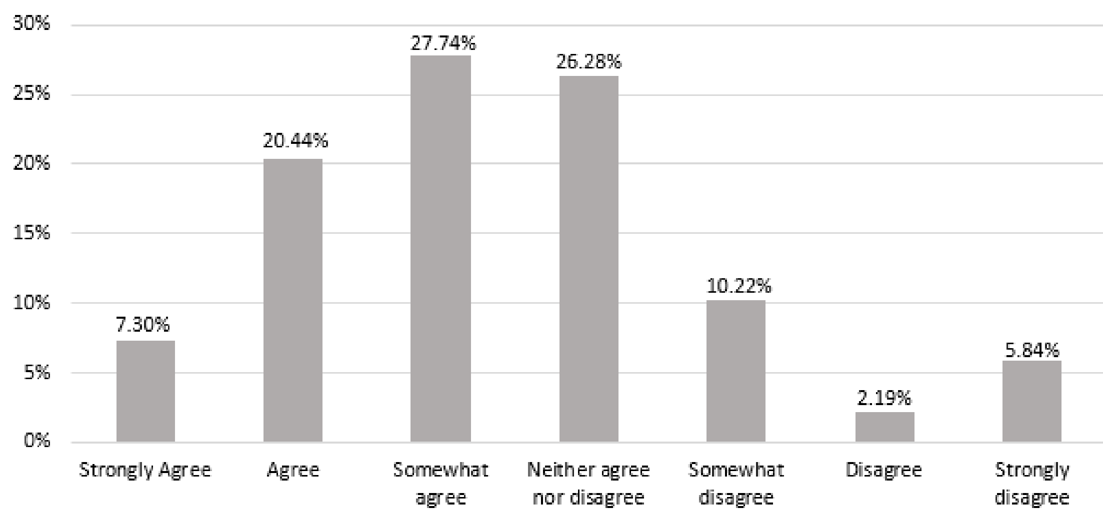

Figure 7: Motivation for more frequent sketching

RQ2. What are the strengths, weaknesses, and suggestions for improving the Intelligent tutoring system?

To get an insight into strengths, weaknesses, and suggestions about ITS, we gathered open-ended answers from students through a survey administered in all three institutions. Q3, Q4, and Q5 were answered by 109, 88, and 65 students, respectively.

Engineering students who used the software shared various positive comments about the software. *An amazing innovation*, *I'm impressed*, *I was amazed at my drawing ability after*, *Great software overall! Provides interactive learning exercises starting from very basics* were some of the positive comments shared by the participants. Majority of the responses about the software were positive.

Below is a collection of issues that were brought up by the participants.

One of the most frequent issue students faced was regarding sketch submission. Many students mentioned that the software would automatically submit the sketches before students finished sketching. A few participants specifically mentioned facing this issue while working on sketching the sphere; the software would move to the next after users drew a circle before the entire sphere was completed. The users were unable to return back, and finish the exercise they were working on. The software sometimes would also delay in recognizing sketch completion; students would then press the next button, and the software would skip two steps ahead. Several students mentioned detecting not just the stylus, but also the palm movements. Participants also mentioned not having the option to erase their mistakes, causing them to restart the exercises. Multiple participants mentioned issues they faced regarding the loaned tablets and pens indicating that the tablet was not responsive at times. A few participants brought up the issue of the software not saving the progress, causing them to redo the sketches all over again. The Sketching foundations tests had to be taken frequently, and students were unable to access anything else in the software when they were asked to take the test. The browser did not show the entire software window, and the users were sometimes instructed to sketch off-screen.

Below is a collection of suggestions brought up by the participants:

1) Remove the auto-submit and allow students to submit the sketches manually when they want to submit.

2) Allow the users to erase the mistakes they make while sketching in order to prevent the users from redoing the entire exercise. An erase button was mentioned by several students.

3) Reject palm and detect just the stylus.

4) Save progress.

5) Improve response time.

6) Add more complex exercises, and less repetition.

7) Fix bugs.

8) Reduce the frequency of Sketch Foundations Test.

9) Improve User Interface.

10) Interactive Tutorial sessions.

11) Password recovery option.

Further, we followed up with the graduate students enrolled in Advanced Product Design at Institution I. We conducted individual semi-structured student interviews to gain more detailed insights into their experience with ITS.

The transcribed interviews were loaded into NVivo and an open coding method was used to assess the content of those interviews. The initial coding process was focused on understanding key feedback from students and those codes were then sorted into four categories, strengths, weaknesses, and improvements/suggestions. Those findings are directly related to the ITS discussed in this paper and the graduate students' experiences when using that ITS for their required class and potentially beyond.

Strengths

The strengths of this platform mentioned by interviewees extend across the entirety of the ITS platform. Participants were satisfied with the intuitiveness associated with the user interface. It was very obvious that a pen was the ideal input device for the platform as it was originally intended to be. Participants with very little drawing experience felt they could engage with the software with few, if any, barriers stopping them from completing the assignments given in the course where this software was integrated into drawing course objectives. Experienced and completely new sketchers alike were happy with their experiences using the software, remarking that it was a good way for them to practice the basics of sketching in a repeatable and structured way. There were a set of exercises that particularly resonated with users that seemed to engage them more than others. Those exercises include circles, cylinders, cones, cubes, and squares.

Interviewees also felt that the scaffolding of the ITS was appropriate and useful for the development of their skills in sketching ellipses inside of a cuboid in particular. Multiple interviewees mentioned that they were spending a significant amount of time using the ITS when in the course and some outside of the course for their own enjoyment and benefit.

Weaknesses

The weaknesses discussed here range from particulars of the software design to reliability issues of the account management solution of the software but include some scaffolding issues within the lessons designed into the ITS.

There were significant bugs associated with saving of work for the users which was resolved during their experience using the ITS, this led to significant frustration with the users and in some cases could have had more impact on their perception of the ITS compared to their user experiences when it was operating as intended.

Palm rejection issues also plagued some of the users, although it is expected that this issue might be related to the hardware of the users or the hardware provided by the authors. While some users liked the scaffolding for ellipses in a cuboid, others found the scaffolding for perspective sketching to be lacking and abandoned learning that skill altogether.

Suggestions/Improvements

The authors had asked the interviewees what suggestions and improvements they might have for the ITS team, and some of this feedback was related to the stability of the system and the lack of features such as a history of sketches or a leader board for the course. Users who chose to use their own personal tablets, such as iPads, seemed to feel that their experience was better than their peers using devices provided by the ITS team. Some students using the provided tablets also felt that their experience in general with that device was subpar.

RQ3. What are the impacts of the intelligent tutoring system on the sketching self-efficacy of students?

The ITS was designed to promote mastery-based learning, and focus was given to improving the beliefs of students in their capability to sketch along with sketching skills. A 13-item modified DSEI instrument was used to measure the drawing self-efficacy of participants [26]. 138 students reported their drawing self-efficacy before they used the ITS. After they finished their practice with ITS, the drawing self-efficacy of the same set of students was measured again. According to Paired T-test, there was a statistically significant improvement in drawing self-efficacy before and after using ITS ($t(137) = -11.18$, $p \leq .01$).

Conclusion

In this study, we have explored the tremendous potential of ITS in providing a student-centered learning experience to undergraduate and graduate engineering students. Essentially, we intended to give the engineering students an experience of learning sketching at their own pace and timing and replicate the experience of having a human tutor. Sketching is a valuable skill for engineering students, and also difficult for instructors to teach and provide individual attention to students. Students receive real-time personalized feedback on the sketches they draw using the ITS. Through this study, we got an opportunity to gather details about user experiences from both graduate and undergraduate engineering students from three diverse institutions. A statistically significant improvement in sketching self-efficacy scores among the users present evidence on the impact of SketchTivity on participant's sketching self-efficacy. We intended not only in improving the sketching skills, but also students' beliefs in their sketching ability. Our initial findings indicate a mixed response from the students in terms of their experience with the ITS. We received an overwhelming amount of positive experiences from engineering students from all three institutions through surveys and individual semi-structured student interviews. At the same time, we were able to identify the areas students faced most difficulty while using the ITS; we obtained rich feedback in the form of suggestions and complaints which will help us tremendously in improving the software. We continuously work on improving the software to provide the students with the best sketching learning experience.

Acknowledgements

This research was supported by National Science Foundation, "Collaborative Research: Fostering Engineering Creativity and Communication through Immediate, Personalized Feedback on 2D-Perspective Drawing" : 2013612 (Texas A&M University), 2013504 (Georgia Tech), 2013575

(San Jose State University) and 2013554 (Purdue University).

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