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Sketching in Mechanical Engineering Curriculum – Students' Perspective*

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Prior literature has supported the use of sketching as a beneficial skill and communication tool for engineering students. Specifically in the mechanical engineering curriculum, sketching can be of vital importance in engineering design activities and can promote spatial visualization skills. Besides its benefits, in many universities, sketching is not part of the regular engineering curriculum, indicating the need to conduct studies to examine its importance and impact on engineering students' training. We hypothesize that sketching, with its ability to enhance students' visualization skills and critical thinking, will be able to minimize students' intellectual inhibition (i.e., a state where students count sketching as not valuable for their field). Thus, the purpose of this study is to understand students' perspectives on sketching if introduced in their mechanical engineering curriculum. Using a multi-method approach, we collected the data from 130 students belonging to three different universities in the United States. Students participated in surveys to share their perspectives towards sketching and their prior experiences; students also answered the open-ended questions to describe why they believed sketching should be taught to mechanical engineers. We used self-determination theory as an analytical lens to explain our findings. The quantitative data were analyzed using the Chi-Square test of independence, and the qualitative data were analyzed using an open coding mechanism. The results indicate that students showed a positive attitude towards sketching regardless of their demographic background and prior sketching experience. Also, students significantly advocated for including sketching training in the curriculum. Students indicated sketching as an engineering competency-enhancing and autonomy-enhancing skill that promotes relatedness within engineering. The results of this study are novel and help to share the importance of sketching instruction to the engineering education community, including educators, curriculum developers, and pedagogical experts, leading to the integration of sketching training in engineering.

Keywords: sketching; self-determination theory; mechanical engineering; students' perspectives

1. Introduction

Engineering drawings are an essential skill for engineering students for effective design and communication. In 2000, the Accreditation Board for Engineering and Technology, Inc. [1] (ABET), introduced "ability to communicate effectively" as a student outcome in the ABET Criteria 3 [1]. Along the lines, for engineering students, prior literature studies argued that graphical communication skills are a salient skill that engineering programs and faculty need to consider [2] for all engineering students. The importance of graphical communication skills, specifically for design ideas for engineering students, is evident from historical records of engineering drawings, where the first record of engineering drawing dates to early 2130 BC [2]. Over the years, researchers have argued that graphical or visual way of communication is favored compared to other modes of communication in engineering, where ideas and designs need to be shared frequently [2]. For graphical and visual communication, one noteworthy mechanism can be the use of free-hand sketching [3, 4]. These sketches, if done with precision, may closely match mechanical drawings where ideas are summarized into meaningful components or objects [5]. Also, the sketches can indicate representational competence – a needed skill for mechanical engineering students. Additionally, studies have described sketching as a beneficial skill for effective engineering design [3, 6, 7] and enhancing students' problem-solving skills [3].

Besides the benefits and importance of sketching as the first initial step in representational competence, the increased reliance on technology tools for design undermined its popularity [8]. Consequently, the current mechanical engineering students do not

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formally receive the necessary sketching instruction and hesitate to use it as a communication tool [9, 10]. Also, not making sketching a necessary component of engineering training resulted in students' intellectual inhibition, which is the inherent belief that sketching is not essential to engineering. [11].

In this paper, we argue that sketching is vital for all engineering students, specifically for mechanical engineering students. We hypothesize that it is a needed skill for enhancing students' ability to visualize, problem-solve, and think critically, and if introduced, students will find value in this training and will be willing to invest the requisite time and effort. Consequently, the purpose of this study is to understand mechanical students' perspectives on sketching if introduced into their curriculum. In this paper, we examined how diverse students described their perspectives and experiences with sketching while accounting for their prior sketching experiences. More specifically, we addressed the following research questions:

RQ1: What are mechanical engineering students' perspectives and prior experiences about sketching instruction?

RQ2: How do these perspectives vary across diverse student groups (academic classification, gender, first-generation, Hispanic, and the institute they belonged to)?

2. Literature Review

The drawings for the Mechanical design process can be made to scale using instruments or computer-aided design tools [12]; however, in this study, we refer to informal free-hand drawings by sketching. The free-hand drawings in this study are not drawn to scale and may or may not constitute notations to depict objects or their functions. Sketching captures how different aspects or components are related to each other without rigidizing the components by fixing their sizes and shapes [13, 14]. Solid modeling software attempts to capture how different components are related to each other and fix their size and shape, which hinders students' design ability [15].

Sketching is an essential communication tool that provides invaluable support in many disciplines, such as interior design, technology education, graphic design, visualization, and engineering [16]. For example, in a study conducted on 126 undergraduate student participants, the majority indicated the need to learn sketching skills and described it as a necessary tool for visualizing ideas [17].

Like other disciplines, in engineering, although limited literature exists on the effective uses and importance of sketching, it provides mixed results. While some literature highlights it as an important skill in engineering practice [16], others point to non-familiarity. For example, [18] compared differences between practicing engineers and undergraduate Mechanical engineering students about their perception of sketching as an essential design activity. The authors reported a statistically significant difference in the number of responses where practicing engineers perceived sketching as a design activity compared to undergraduate Mechanical engineering students. It is noteworthy that although engineers consider communication as a vital competency for engineering design, they often neglect sketching, which can be described as a tool for communication. For example, [19] investigated the importance of sketching in engineering design. Using the data from 19 practicing engineers from various disciplines, such as Mechanical, electrical, civil, industrial, and materials science, the study identified the most critical and least essential engineering design activities. The results indicated that communication is the most important activity. However, sketching, although it was among the list of activities, was not considered a vital trait.

Besides the unequivocal importance of sketching, in engineering, the perspective and attitude towards sketching varied based on multiple factors, such as the engineering discipline [20] or professional affiliation [15]. Researchers found that perspectives on the importance of sketching varied across disciplines. For example, [20] investigated the attitude of civil engineering students towards sketching and drawing compared to architecture students using a 32-item attitude questionnaire. The results of the study indicated that compared to architectural students, civil engineering students had a less positive view of the professional role of sketching and drawing; they were less likely to value sketching and drawing and less likely to use sketching and drawing [20]. In another study conducted on mechanical engineering students, [21] developed and used a Mechanical Engineering Visual Design Mediums Concept Inventory with 22 questions and explored various topics such as students' understanding of the usefulness of sketching, students' motivation for sketching, and students' misunderstandings in sketching [21]. The results from the data of 233 students indicated that Mechanical engineering students spent more time on computer-aided design (CAD) than on sketching. Also, the authors reported that students were unaware of the cognitive benefits of sketching as well as the role of sketching in creativity. Overall, this study found that students lacked an understanding of sketching and its value [10, 21].

Similar to discipline-based variations on the importance of sketching, a notable difference also exists between professionals. For example, a research study was conducted on industry professionals and educators and examined their attitudes on including free-hand technical drawing in the engineering curriculum [15]. Keeping the distinction between novice and experienced professionals, the results of the study indicated that the perspectives of novice educators were significantly different from those of novice professionals. While novice educators did not think it was essential to include sketching as part of the curriculum, novice professionals believed it would be beneficial to include sketching in the curriculum [15]. Further, the attitudes of experienced educators and experienced industry professionals were mixed, where most experienced educators believed that sketching skills were valuable [15].

Prior literature studies also examined the various ways in which sketching may be carried out in academic settings (e.g., [22]). Two prominent such ways were paper and pencil and digital applications, including computer-aided design (CAD) tools. For example, a large study consisting of 320 participants from the Landscape Architecture Department was conducted to investigate students' attitudes toward conventional and digital drawing tools in environmental design studios. Using a 23-statement questionnaire, the authors reported that students' attitudes toward digital drawing techniques were more positive compared to conventional drawing techniques [19]. In another study, mechanical engineering students' perceptions were collected to examine the usefulness of free-hand sketching compared to CAD tools during the engineering design ideation process [23]. The results indicated that more than 65% of the participants were in favor of introducing free-hand sketching into the Mechanical engineering curriculum before teaching CAD tools [23]. Also, students preferred using free-hand sketching as the first step during the design process. Besides the importance of sketching in either way (i.e., free-hand or using a digital application), the results of these studies highlight the importance of sketching in engineering, specifically in the mechanical engineering curriculum.

Overall, researchers have explored sketching attitudes within engineering. Previous findings indicate a wide range of perspectives regarding sketching, including disciplinary differences in attitude, lack of awareness of the importance of sketching, and mixed opinions regarding including sketching training in the curriculum. However, none of the studies have attempted to examine the differences in attitude based on the demographic background of students. We also see limited studies in the field of Mechanical engineering. Considering the literature gap, in this study, we are using a unique lens of student demographics such as gender, first-generation or non-first-generation status, undergraduate or graduate classification, institute/university, and Hispanic or non-Hispanic status, and prior sketching experiences to examine their perspectives (i.e., attitude and experience) about sketching instruction.

2.1 Analytical Framework

To characterize our findings, in this paper, we are using Self Determination Theory (SDT) [24] as our analytical lens. The use of an analytical framework will help us to analyze and identify the patterns in the data [24]. According to SDT, three innate psychological needs drive intrinsically motivated human behavior: competence, autonomy, and relatedness [24, 26].

Competence is not an achieved skill; instead, SDT describes competence as "a felt sense of belief and effectance in action." In other words, individuals have an innate psychological need to feel competent in the activity they are engaged in, control the outcome, and when they experience mastery, the need for competence is fulfilled [27]. Autonomy is supported to the extent to which the individuals experience interests, values, and choices [24]. Researchers have found that behaviors that satisfy autonomous needs promote well-being and positive outcomes such as self-regulation and persistence [28]. Relatedness is the need to feel connected to others within the social environment [24]. Collaborating with peers, connecting with materials, and relating with teachers contribute towards fulfilling the need for relatedness, promoting an individual's intrinsic motivation and engagement in the academic setting [29]. [27] Discuss these needs as universal necessities essential to human nature for optimal development. Additionally, the needs do not vary based on the age, gender, culture, or socioeconomic status of the individual [20]. An individual's motivation, engagement, growth, etc., are directly related to the extent to which the social context fulfills an individual's needs [26]. On the other hand, the extent to which the needs are not met, the individual will experience alienation, hardship, and fragmentation [27]. Thus, according to SDT, satisfying basic needs facilitates intrinsic motivation, pursuing intrinsic goals, and eventually leads to experiencing "well-being and optimal development" [27]. SDT explains the unfolding of an individual's development, including academic development, as an interaction between the individual student and their respective social context [30].

In this paper, we used SDT and its characteristics to organize and explain our findings related to Mechanical engineering students' perspectives and experiences in sketching. SDT has not previously been applied in engineering to understand free-hand sketching behavior. Thus, using it as the analytical framework will help in understanding students' behaviors and experiences.

3. Design and Methods

This multi-institute study is part of a larger project that investigates the importance of sketching for mechanical engineering students. In this study, we designed and conducted a survey to understand students' perspectives and experiences about sketching. Following a multi-method approach, we analyzed the data using quantitative and qualitative analysis. For quantitative analysis, we followed a cross-sectional research design and examined the variations across students in different institutes and varying demographics. For the qualitative study, we used a content analysis approach.

3.1 Site and Participants

The data were collected from three different institutes: Institute 1 is a large R1 university in the south-central region of the United States, Institute 2 is a large technical university located in the southeastern region of the United States, and Institute 3 is located in the western region of the United States; both Institute 1 and Institute 2 are top engineering universities. The participants in this study are graduate and undergraduate engineering students. The participants were recruited from various courses in mechanical engineering during regular sessions between 2021 and 2022. Participation in the study was voluntary. A total of 572 students participated in the study. However, not all students answered each question. In addition to gender and ethnicity, we also collected data on other demographic variables such as graduate/undergraduate status, first-generation status, and Hispanic status. The available details of students' demographics are provided in Table 1

Table 1. Student demographics in all three institutes

	Institute 1 N = 67,133	**Institute 2 N = 43,844**	**Institute 3 N = 37,133**
Gender			
Male	35,787	30,031	17,656
Female	31,346	13,813	19,428
Ethnicity			
White	36,304	15,654	6,337
Asian	6,307	9,541	12,626
Degree classification			
Graduate students	13,257	26,397	8,921
Undergraduate students	53,876	17,447	28,212

3.2 Instrument

We designed a survey consisting of nine questions, with four questions for students' perspectives toward sketching and four questions for their prior or current experience. Out of 8 questions, 6 were Likert scale questions, and two were open-ended. The survey was administered approximately one month after the beginning of the semester. Demographic information such as major, gender, race/ethnicity, age, and educational level of parents was collected along with their consent to participate in the study. We gathered students' self-reported responses towards sketching by asking the following eight questions, as seen in Table 2. It is noteworthy that varying numbers of responses were received for open-ended questions. The sample size for each question is also described in Table 2.

The questions were designed to gain insight into

Table 2. Survey instrument

No	**Question**	**Response options**	**No of Respondents**
1	Do you think sketching skill is important?	7 Likert Scale: very important; important; somewhat important; indifferent; somewhat unimportant; unimportant; very unimportant	130
2	Do you think sketching is enjoyable?	very enjoyable, enjoyable, somewhat enjoyable, indifferent, somewhat annoying, annoying, and very annoying	130
3	Do you think engineers should be taught to sketch?	Yes, No, and indifferent	130
4	Why or why not engineers should be taught to sketch? (optional)	Open-ended response	71
5	Rank your level of sketching experience	Not a sketcher, Beginner, Novice, Intermediate, Proficient, Advanced, and Expert	130
6	Do you have any experience with digital sketching with a tablet and stylus?	I have sketched on a tablet before, I have only sketched on paper, and I have never even used a tablet and stylus before	130
7	When was the last time you sketched?	Today, Within a week, Within the last month, Within the last year, More than a year ago, and I have never sketched	130

students' existing experiences and perspectives towards sketching. Additionally, we also collected qualitative open-ended responses from participants to explore the reasons behind their respective perspectives towards including sketching instruction. We asked students to self-report their level of sketching experience, their experience with digital sketching, and their frequency of sketching. Additionally, we allowed students to describe their past sketching experience in an open-ended form.

3.3 Data Analysis

For research question 1, we used both qualitative and quantitative analysis. For qualitative analysis, we coded the data using an open coding mechanism and identified themes. The data was analyzed using NVivo, and categories were formed using an inductive approach. The categories and themes within each category were finalized after a few iterations of careful reading of codes. For quantitative analysis, we used descriptive statistics.

For research question 2, we performed the chi-square test of independence and determined if there were statistically significant differences between the respective demographic categories. Before running the analysis, we tested the data for assumptions and ensured that all the assumptions of the Chi-Square test were met. If the Chi-square test statistic is statistically significant, it is to be accompanied by a strength statistic such as Cramer's V to determine the strength of association if the Chi-square test outcome was significant [31]. We have computed Cramer's V for all the cases where statistically significant differences were identified among various demographic identities [31]. Additionally, we have also included the odds ratio to interpret the results.

4. Results

4.1 RQ1: What are Mechanical Engineering Students' Perspectives and prior experiences about Sketching Instruction?

To answer research question 1, we examined students' responses and classified them according to perspectives and experiences.

4.1.1 Perspectives towards Sketching

We used descriptive statistics and examined how students classified their perspectives based on three perspectives: (1) importance of sketching, (2) enjoyment with sketching, and (3) teaching sketching to engineers. Tables 3, 4, and 5, respectively, provide these results.

The results of this descriptive analysis indicate that Mechanical engineering students overwhelmingly agreed that sketching is an important skill (93.8%), is enjoyable (81.54%) and should be taught to engineers (90.0%).

Table 3. Participants' attitude about the importance of Sketching skill

Participant Response	**Count**	**Percentage**
Very important	25	19.23%
Important	58	44.62%
Somewhat important	38	29.23%
Indifferent	6	4.62%
Somewhat unimportant	2	1.54%
Unimportant	1	0.77%
Very unimportant	0	0.00%

n = 130

Table 4. Participants' attitude about the enjoyability of Sketching skill

Participant Response	**Count**	**Percentage**
Very Enjoyable	28	21.54%
Enjoyable	49	37.69%
Somewhat enjoyable	29	22.31%
Indifferent	15	11.54%
Somewhat annoying	7	5.38%
Annoying	2	1.54%
very annoying	0	0.00%

n = 130

Table 5. Participants' attitude towards teaching engineers to sketch

Participant Response	**Count**	**Percentage**
Yes	117	90.00%
No	0	0.00%
Indifferent	13	10.00%

n = 130

In addition to descriptive analysis, we conducted a qualitative content analysis of the responses of 71 Mechanical engineering students on why they think sketching should be taught to them. We identified four themes: Communication, Engineering design, Idea representation, and Timesaving.

The first theme was identified as Communication, and it was the most frequently occurring theme among all the responses. There was a total of 30 codes altogether that mentioned sketching's utility as a communication tool in engineering. According to the responses, sketching is beneficial when it comes to conveying ideas, thoughts, designs, and concepts to others that includes not only teammates and colleagues but also to clients, customers, and bosses at the workplace. A few examples of participant responses under the theme communication are given below: (1) It *is useful in trying to communicate ideas, concepts, and designs in the workplace;* (2) *It allows us to explain and demonstrate our ideas/concepts to other engineers, customers, team members, more effectively.* (3) *Engineers* *should be taught to sketch in order to become better communicators.* (4) *Communication in engineering is important. Sketching is a way to communicate your ideas to another person.*

The second most frequently occurring theme within the responses was Idea representation. A total of 23 codes mentioned sketching's utility for representing ideas in engineering. Although this is very closely related to communicating with others and sometimes inseparable, it was grouped under a separate theme in order to distinguish the student responses that were primarily about depicting one's ideas for the purpose of getting them out of one's head, examining the best possible idea and for simply representing ideas. A few example participant responses within the Idea representation theme are given below (1) *represent an idea*, (2) *benefit all engineers to see how their idea might look like.* (3) *Helps illustrate your ideas, and you can see if something will generally work before making the CAD model.* (4) *Helps bring out ideas in easy ways.* (5) *ideas can be transformed into a visual representation, and* (6) *To illustrate basic ideas.*

The third most frequently occurring theme was Engineering Design. There were 16 codes that fell under the theme. Our findings indicate that our participants find sketching skills to be a valuable asset when it comes to the engineering design process. Below example codes within the theme are an indication of the value of sketching in engineering design. (1) *For designing and manufacturing,* (2) *It is important to have the experience for design aspect,* (3) *sketching is a good first step before creating an actual design, and* (4) *I believe sketching can be a useful tool during the introductory stages of design.*

The fourth most frequently occurring theme was Time-saving. There were 13 codes that fell under the theme. The example codes within the theme were (1) *It saves time,* (2) *Quick visualization tool,* (3) *It is the quickest way to convey thoughts,* (4) *Quicker and more handy (easier to get a pen/pencil and paper than it is a computer) than using CAD, and* (5) *It is the one of the fastest way to illustrate the idea.*

4.1.2 Experiences with Sketching

We used descriptive statistics and examined students' prior experiences based on: (1) level of sketching experience, (2) digital sketching experience, and (3) frequency of sketching. Tables 6, 7, and 8, respectively, provide these results. We also used qualitative content analysis to investigate the source of engineering students' prior sketching experience.

The results of these descriptive analyses indicate that the majority of the Mechanical engineering students were not experienced in sketching,

Table 6. Participants' Sketching Experience

Participant Response	Count	Percentage
Not a sketcher	15	11.54%
Beginner	38	29.23%
Novice	28	21.54%
Intermediate	33	25.38%
Proficient	12	9.23%
Advanced	0	0.00%
Expert	0	0.00%

n = 130

Table 7. Participants' digital sketching experience

Participant Response	Count	Percentage
I have sketched on a tablet before	33	25.38%
I have only sketched on paper	78	60.00%
I have never even used a tablet and stylus before	19	14.62%

n = 130

Table 8. Participants' Sketching frequency

Participant Response	Count	Percentage
Today	37	28.46%
Within a week	29	22.31%
Within the last month	21	16.15%
Within the last year	19	14.62%
More than a year ago	22	16.92%
I have never sketched	2	1.54%
Today	37	28.46%

n = 130

although the majority of them perceived sketching as an important skill and an enjoyable activity. Half of the Mechanical engineering student participants were either Beginners or Novices, while none of the students reported being Advanced or Experts in sketching (See Table 6). Table 7 indicates that the majority of the Mechanical engineering students reported that they did not have digital sketching experience. As seen in Table 8, the majority of the Mechanical engineering students utilized sketching frequently.

In addition to descriptive analysis, we conducted a qualitative content analysis; 193 undergraduate students recorded their prior drawing or sketching experiences. Six different themes emerged from the qualitative responses. The themes were: *No experience, K-12 experiences, Recreational drawing, college courses, software*, and *work experiences.*

The first theme was *No experience*, and there were 81 codes within the theme. It is to be noted that *No experience* was also the most frequently occurring theme, implying that the majority of the undergraduate Mechanical engineering students came with no prior drawing or sketching experience or training.

The second most frequently occurring theme was

K-12 experiences. There were 72 codes within the theme. The codes were a combination of both middle school and high school courses, and the names that were mentioned by the participants included art or drawing courses, engineering courses, graphics design courses, robotic courses, digital art courses, high school architecture, high school engineering design, AP studio art, Intro to drafting, Survey of Engineering, Intro to engineering, Foundation of engineering, Visual Arts Comprehensive, and painting. Participants also repeatedly mentioned their experience with the Robotics team in high school as contributing to their drawing or sketching prior experience. There were a few mentions of elementary school drawing experiences, and those students have no other experiences beyond that.

The third most frequently occurring theme was *Recreational drawing*, and there were 34 codes within this theme. These participants reported that their prior experience in drawing or sketching came primarily through a hobby or as a recreational activity. A few example codes from the participant responses were (1) *Sketching is a hobby of mine,* (2) *Recreational drawing for my entire life (19 years),* (3) *Draw for fun, and* (4) *I like to doodle a lot.*

The fourth most frequently occurring theme was *College Courses*, and there were 9 codes within this theme. These undergraduate participants mentioned the names of college courses such as Introduction to CAD, 2D and 3D Design Studio, Engineering Design, and Capstone course.

The fifth most frequently occurring theme was *software*, and there were 7 codes within this theme. CAD and SolidWorks were the two software participants named, and for these participants, their only prior experience was through the use of CAD or SolidWorks. This also seemed to be closely linked with the previous theme, where some participants mentioned certain college courses where they might have used CAD or SolidWorks.

The sixth and final theme was *work experiences*, and there were 5 codes within the theme. The participants mentioned that they gained experience in drawing or sketching during their internships in companies during the course of their undergraduate period.

Overall, it is to be noted that most of the participants did not have any drawing training or experience prior to when the survey was conducted in the course. Other participants, on the other hand, did have prior experience from K-12 coursework, through their personal hobby or recreational activity, college courses, the software they had to use, and also from workplaces. Note that all the participants in the survey were taught sketching and given ample opportunities to practice sketching on paper and digital tools in this course after the survey data was collected.

80 graduate student participants recorded their prior drawing or sketching experiences. Seven different themes emerged from the qualitative responses. Again, the themes we found previously for undergraduate students, such as *No experience, K-12 experiences, Recreational drawing, software*, and *work experiences*, emerged for the graduate students although the number of codes within the themes was different. *Engineering drawing or graphics courses* the participants took during their undergraduate career emerged as a separate theme. Also, *College courses* were added as another theme where all the participant responses other than Engineering drawing or graphics courses were coded.

Engineering drawing or graphics was one of the courses the participants repeatedly mentioned; hence, *Engineering drawing or graphics* was identified as a theme of its own, with 16 mentions within the data. In most of Mechanical engineering undergraduate programs, Engineering drawing or graphics is a mandatory course, and our findings indicate that a lot of graduate students received training in drawing and/or sketching through Engineering drawing or graphics courses. Further, the next theme was identified as *College courses*, and it included all the courses participants mentioned other than Engineering drawing or graphics. *College courses* were also the most frequently occurring theme, and there were 24 codes within the theme. The courses the graduate student participants mentioned included Technical Drafting, Machine Drawing, Industrial Design Drawing, Intro to Engineering Design in undergrad, Art Appreciation, and Capstone Design. Thus, various undergraduate courses that students took were a significant source through which graduate students received drawing training. *K-12 experiences* were yet another theme, and there were 14 codes within the theme. It is to be noted that, for these students, their main source of training in drawing or sketching came from high school.

No experience was identified as a theme for graduate students as well, and there were 19 codes within this theme. Although a lot of graduate students mentioned the names of various courses, there was a group of students who indicated that they had no prior drawing or sketching experience. Further, *Recreational drawing, software*, and *work experiences* were also identified as themes with 17, 5, and 3 codes, respectively. Note that these were also themes identified in the undergraduate student sample. There were several graduate students who spent their spare time drawing for recreational purposes. AutoCAD, SolidWorks, and Revit were the software that were mentioned by the students. Internship was the code that was found within the theme of *Work Experiences.*

4.2 RQ2: How do these perspectives vary across diverse student groups (academic classification, gender, first-generation, Hispanic, and the institute they belonged to)?

To answer research question 2, we conducted a chi-square test of independence and examined how students' perspectives and experiences varied across demographic variables

4.2.1 Variations in Perspectives

To investigate variations in students' perspectives towards the importance of sketching, we conducted the chi-square analysis after combining the two categories: the first category was very important, important, and somewhat important, and the second category comprised indifferent, somewhat unimportant, unimportant, and very unimportant. Chi-square analyses illustrated that students' attitude towards the importance of sketching are similar across graduate student status ($\chi2$ (1, N = 130) = 0.57, p = 0.45), gender ($\chi2$ (1, N = 123) = 0.29, p = 0.59), first-generation status ($\chi2$ (1, N = 128) = 0.96, p = 0.32), Hispanic status ($\chi2$ (1, N = 121) = 1.82, p =0.18), and institute ($\chi2$ (2, N = 260) = 1.92, p = 0.38). Therefore, regardless of their demographic identity, students reported sketching skills as important.

Similarly, for variations in students' perspectives towards enjoyment, we conducted the chi-square analysis after combining the two categories, where the first category comprised very enjoyable, enjoyable, and somewhat enjoyable, and the second category comprised indifferent, somewhat annoying, annoying, and very annoying. The results of the chi-square analyses illustrated that these perceptions were similar across graduate student status ($\chi2$ (1, N = 130) = 0.06, p = 0.80), gender ($\chi2$ (1, N = 123) = 0.33, p = 0.57), first-generation status ($\chi2$ (1, N = 128) = 0.26, p = 0.61), Hispanic status ($\chi2$ (1, N = 121) = 1.08, p = 0.30), and institute ($\chi2$ (2, N = 260) = 6.11, p = 0.05) Therefore, regardless of their demographic identity, students reported sketching skill is an enjoyable activity.

Additionally, Chi-square analyses illustrated that students' perceptions about teaching students to sketch were similar across graduate student status ($\chi2$ (1, N = 130) = 0.48, p = 0.49), gender ($\chi2$ (1, N = 123) = 0.83, p = 0.36), first-generation status ($\chi2$ (1, N = 128) = 0.62, p = 0.43), Hispanic status ($\chi2$ (1, N = 121) = 0.49, p = 0.49), and institute ($\chi2$ (2, N = 260) = 6.11, p = 0.05). Therefore, regardless of their demographic identity, most Mechanical engineering students reported that engineers should be taught to sketch.

4.2.2 Variations in Experiences

To investigate variations in students' level of sketching experience, we conducted the chi-square analysis after combining the two categories: the first category comprised not a sketcher, Beginners, and Novices, and the second category comprised Intermediate and Proficient, chi-square analyses illustrated that sketching experiences were similar across gender ($\chi2$ (1, N = 119) = 0.08, p = 0.77), first-generation status ($\chi2$ (1, N = 124) = 1.08, p = 0.30), institute ($\chi2$ (1, N = 112) = 165, p = 0.20) and Hispanic status ($\chi2$ (1, N = 117) = 0.08, p = 0.78).

Results of the chi-square analyses indicated that sketching experience was statistically significantly related to students' academic classification (undergraduate or graduate student); ($\chi2$ (1, N = 126) = 11.34, $p < 0.001$; Cramer's V = 0.3, indicating a medium effect). It is worth noting that the actual count of undergraduate students who reported being experienced in sketching was much less than the expected count; the actual count of undergraduate students reporting being inexperienced in sketching was higher than the expected count. Specifically, undergraduate students were approximately 7 times more likely than graduate students to be in the inexperienced group compared to the experienced group ($[Undergrad_{inexp}/ Undergrad_{exp}]/ [Grad_{inexp}/Grad_{exp}]= [27/3]/[54/42]= 7.00$). Therefore, demographic identities such as gender, first-generation status, the institute they belonged to, and the Hispanic status of Mechanical engineering students did not influence their sketching experience, while their graduate status influenced their sketching experience.

Chi-square analyses illustrated that digital sketching experiences were similar across graduate student status ($\chi2$ (1, N = 130) = 0.44, p = 0.51), gender ($\chi2$ (1, N = 123) = 0.15, p =.70), first-generation status ($\chi2$ (1, N = 128) = 0.03, p = 0.87), and institute ($\chi2$ (2, N = 260) = 0.16, p = 0.92). Results of the chi-square analyses indicated that sketching experience was statistically significantly related to Hispanic status (Hispanic vs. non-Hispanic student); ($\chi2$ (1, N = 121) = 6.09, $p < 0.05$; Cramer's V = 0.22, indicating a small effect). It is worth noting that the actual count of Hispanic students who reported being experienced in digital sketching was much higher than the expected count, and the actual count of Hispanic students reporting being inexperienced in digital sketching was lower than the expected count. Specifically, non-Hispanic students were approximately 4 times more likely than Hispanic students to be in the inexperienced group compared to the experienced group ([non-

$Hispanic_{inexp}$/non-$Hispanic_{exp}$]/[$Hispanic_{inexp}$/$Hispanic_{exp}$])= [84/24]/[6/7]= 4.08). Therefore, demographic identities such as gender, graduate status, first-generation status, and college of Mechanical Engineering students did not influence their sketching experience, while their Hispanic status influenced their digital sketching experience.

To investigate variations in students' frequency of sketching, we conducted the chi-square analysis after combining the two categories: the first category comprised today, within a week, within the past month, and the second category comprised more than a year ago, and I have never sketched. Chi-square analyses illustrated that sketching frequency was similar across graduate student status ($\chi2$ (1, N = 130) = 0.08, p = 0.77), gender ($\chi2$ (1, N = 123) = 1.41, p = 0.23), first-generation status ($\chi2$ (1, N = 128) = 0.07, p = 0.80), Hispanic status ($\chi2$ (1, N = 121) = 203.07, p = 0.07), and institute ($\chi2$ (2, N = 260) = 0.48, p = 0.79).

5. Discussion

Our study findings indicate that Mechanical engineering students, regardless of gender, first-generation or non-first-generation status, undergraduate or graduate classification, Hispanic or non-Hispanic status, and the institute they belonged to, had positive perspectives toward sketching. Mechanical engineering students from diverse demographic backgrounds believe sketching is important and enjoyable. Our findings did not indicate that Mechanical engineering students have negative perspectives or beliefs regarding sketching. These results were aligned with the conclusions of [10, 32, 33], where the study participants reported positive views toward sketching; however, our results were not aligned with the conclusions of [11, 34, 6, 20], where the participants reported unfavorable views on sketching.

We have applied the Self-Determination Theory (SDT) to organize and explain our findings related to Mechanical engineering students' sketching behavior and development. Our study investigated mechanical students' perceptions of free-hand sketching and prior experiences. The needs of competence, autonomy, and relatedness in individuals must be fulfilled for them to be intrinsically motivated, according to SDT [35]. We have discussed below how Mechanical engineering students' needs for competence, autonomy, and relatedness drive their sketching behavior and perspectives.

According to self-determination theory, individuals have an inherent need for competence. The participants' view that sketching skills are important indicates that sketching skills have the potential to satisfy Mechanical engineering students' need for competency. Training in sketching can improve the sketching skills of future engineers and their sense of competency as engineers. Students' attitude that sketching should be taught emphasizes how sketching skills attempt to fulfill the need for Mechanical engineering students to be competent engineers. Our qualitative survey results indicated that students believe sketching should be taught to them due to the benefits of communication, engineering design, and idea representation. As students gain a strong tool to communicate ideas and aspects of design to peers and supervisors, sketching skills fulfill their need for competency in engineering. Within engineering design, sketching enables students to enhance their problem-solving skills, idea generation, and creativity, making them competent in professional and work settings. Students believe that sketching skills are important and should be taught because sketching skills can potentially make students experience a sense of competency as engineers.

According to self-determination theory, individuals have an inherent need for autonomy. Our findings show that sketching is enjoyable to the majority of Mechanical engineering students. Since the universal need for autonomy in individuals involves choosing behaviors aligned with individual interests, sketching behavior is aligned with Mechanical engineering students' interests. Although our sample size is limited, results show that regardless of gender, first-generation or non-first-generation status, undergraduate or graduate classification, Hispanic or non-Hispanic status, and the institute our participants belonged to, most of our study participants rated sketching skills as enjoyable. Thus, Mechanical engineering students' engagement in sketching behavior is not out of compulsion by instructors or because they have no other options, but out of personal interest for most students. Here, as students find sketching to be an enjoyable undertaking, it shows that most students are intrinsically motivated to learn sketching, which is very promising when CAD tools are increasingly popular among students and in the curriculum. As communicating ideas and idea representation were recurring themes of why students believed sketching skills should be taught, students perceived sketching instruction to provide a tool to represent and communicate their unique ideas and fulfill the need for autonomy and relatedness within engineering. While educators design sketching activities, activities that support learner agency and autonomy will benefit students.

Relatedness is another need, as outlined in the Self-determination theory. Graphical communication is an effective way for engineers to share and brainstorm engineering design ideas and engage in collaborative problem-solving. Within college and workplace settings, an effective communication tool fosters better collaboration with peers, instructors, and supervisors. Improved collaboration and shared understanding can foster a sense of belonging and relatedness among peers, instructors, and supervisors, making a positive impact on the profession while fulfilling the need for relatedness and connectedness. Educators, while designing sketch activities, must keep in mind to include opportunities for the development of relatedness, such as collaborative activities, peer sharing, etc.

Our study findings indicate that Mechanical engineering students have varying levels of experience in sketching, with the majority falling into the beginner to intermediate categories, and this shows the need for including sketching instruction. Although students have positive perspectives towards sketching, none of the participants identified themselves as 'Advanced' or 'Expert' sketchers. Gender, Hispanic or non-Hispanic status, and first-generation or non-first-generation status did not significantly influence the participants' sketching experience. However, graduate and undergraduate students had statistically significant differences in sketching experiences. As graduate students have spent longer in Mechanical engineering, it's not surprising that they have more experience in sketching. The additional coursework, complex design projects, and industry work experiences graduate students experienced have given them more opportunities to engage in sketching behavior. Furthermore, there was a difference in sketching experience based on the college from which the participants were. Different academic programs, departments, instructors, and curricula place different levels of emphasis on sketching, and hence, based on the specific institute, it's not surprising that sketching experiences vary. Our findings on the varying levels of sketching experience highlight the need for developing competency in sketching, and this can be achieved through sketching instruction by experts.

Our findings regarding digital sketching experience indicate that the majority of the participants still use paper and pen for sketching activities and not digital tools such as tablets. Around one-fourth of the participants mentioned that they had prior digital sketching experience. It is possible that students were not aware of the digital options available for sketching and lacked the necessary resources required to engage in digital sketching; at the same time, it is also possible that students prefer the traditional way of sketching on paper using pencil or pen. Engaging in digital sketching requires practice using digital tools; providing learning support by using digital technology can promote autonomy by letting them choose between traditional or digital platforms for engaging in sketching activity. In case of digital sketching experience, gender, first-generation or non-first-generation status, undergraduate or graduate classification, and institute did not have any statistically significant impact. However, there was a statistically significant difference between the digital sketching experience of Hispanic and non-Hispanic participants, where Hispanic students' engagement in digital sketching was higher than that of non-Hispanic students. Overall, our findings suggest a lack of experience with digital sketching among most of the Mechanical engineering student samples we collected. We suggest that digital sketching competency needs to be developed in all students to better prepare them for the changing modern industry standards, digital collaborations among peers, and for utilizing enhanced visualization possibilities offered by digital tools.

Our findings related to Mechanical engineering students' sketching frequency indicate that sketching is an activity most students engage in regularly or periodically as part of their academic work. It is to be noted that there were no statistically significant differences among the sketching frequency based on gender, first-generation or non-first-generation status, undergraduate or graduate classification, Hispanic or non-Hispanic status, and the institute they belonged to. Regular engagement in sketching activities suggests the need for instructional interventions to develop and further enhance students' sketching skills. It is also likely that students are engaging in sketching activities out of their own choice, fulfilling the need for autonomy. Regular engagement in sketching activities could improve their competency in sketching. In order to promote relatedness and connectedness among students, instructors can encourage collaborative sketching activities.

One of the most frequently occurring themes of qualitative responses indicated that most Mechanical engineering students do not have prior experience in sketching. Several studies [3, 36, 37, 34] have directly or indirectly examined the mechanical engineering students' experience with sketching and also reported that students are lacking in sketching experience, aligned with our results. It indicates that sketching instruction needs to occur to enhance their sketching skills and transform students into engineers who are competent in communicating visually.

We recommend that engineering programs incorporate free-hand sketching lessons into the Mechanical engineering curriculum, along with the CAD tool training they currently receive. We also recommend integrating the principles of SDT into sketching instruction. A sense of competence in engineering can be cultivated in Mechanical engineering students by giving them opportunities to practice and become experts in sketching. Sketching self-efficacy can be improved by training them to gain mastery and providing constructive feedback. We recommend using digital AI-based sketching tools that offer immediate personalized feedback to students. Allowing students to choose sketching projects can cultivate a sense of autonomy, which is linked to intrinsic motivation and can lead to better performance. A supportive classroom environment where collaboration and peer engagement in sketching activities are present can enhance students' sense of relatedness. Sharing the value of sketching within Mechanical engineering with students can also cultivate a sense of relatedness among them as they gain sketching training. Providing a supportive environment and opportunities to practice sketching will be valuable to Mechanical engineering students to develop them into tomorrow's competent engineers.

6. Conclusion

In this study, we explored the perspectives of Mechanical engineering undergraduate and graduate students on free-hand sketching at three different universities belonging to Texas, California, and Georgia, respectively, within the United States of America. Our results indicate that most Mechanical engineering students, irrespective of their demographic background at the time this study was conducted, believed sketching skills to be valuable and enjoyable, and that they should be taught to engineering students. Sketching skills fulfill the need for competency, autonomy, and relatedness in Mechanical engineering students, leading them to become professionally competent engineers of tomorrow. Our study results also indicate that the majority of students are aware of the benefits of sketching skills. Thus, our findings supported our hypothesis that students view sketching as a valuable tool due to the benefits of enhancing spatial visualization skills, critical thinking, etc. However, none of the participants self-reported themselves as Advanced or Expert sketchers. Most of our Mechanical engineering study participants did not have prior digital sketching experience, although they engaged in sketching either regularly or infrequently.

The main takeaway from the results is that the Mechanical engineering students who participated in our study advocate for sketching skills to be taught to them. It is to be noted that most mechanical engineering students have no prior knowledge of sketching, while they also recognize the value of sketching; hence, through our study, we would like to share the importance of providing sketching instruction to the engineering education community, including educators, curriculum developers, and pedagogical experts, leading to the integration of sketching training in engineering.

Literature suggests that intellectual inhibition occurs when students fail to recognize the value of sketching, whereas our results indicate an overall positive attitude towards sketching. Further research could investigate the factors influencing students' perspectives on sketching. We found that gender, first-generation status, and the institute they belonged to did not have a statistically significant influence on their perspectives (attitude and experiences) towards sketching. One limitation of our study is that we do not prove why Mechanical engineering students, whom we surveyed, see the value of sketching. However, we acknowledge that the participants in our study were enrolled in mandatory classes that have to be taken by all Mechanical engineering students as part of the curriculum and not elective courses. If the participants in our study were enrolled in elective classes, it could be possible that only those students who had a positive attitude towards sketching were enrolled in elective courses. Sketching was explicitly taught to survey participants later in the semester, after they had completed the survey. It could be possible that students recognized the importance of sketching because they knew it was something they were going to learn as part of this course. We believe that explicitly teaching sketching to students increases the likelihood of them recognizing its value, as evidenced by our survey of students.

Further, sketching is more valuable to some engineering majors than others; hence, further research aims to include other engineering majors as well. Through future studies, we also strive to explore sketching perspectives beyond students, examining faculty perspectives and those of industry experts in the field of engineering, where sketching skills are particularly beneficial. In the future, we also aim to understand the learning objectives of sketching instruction in the engineering curriculum and how it could look different based on the engineering major.

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