



The Evolution of Tactile and Digital Learning Preferences in Undergraduate Engineering Education

Dr. Conrad Tucker, Pennsylvania State University, University Park

Dr. Kathy Schmidt Jackson, Pennsylvania State University, University Park

Dr. Kathy Jackson is a senior research associate at Pennsylvania State University's Schreyer Institute for Teaching Excellence. In this position, she promotes Penn State's commitment to enriching teaching and learning. Dr. Jackson works in all aspects of education including faculty development, instructional design, engineering education, learner support, and evaluation.

Dr. Linda C. Schmidt, University of Maryland, College Park

Dr. Gul E. Okudan Kremer, Pennsylvania State University, University Park

Mr. Peifeng Yin

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The objective of this research is to investigate how student preferences towards *digital/virtual* and *hands-on/tactile* learning evolve at different stages of undergraduate engineering education. Within the context of this research, *digital* learning techniques refer to the use of virtual environments to communicate educational concepts and activities; and *hands-on* learning relates to the physical handling of objects. Inevitably, certain characteristics of *hands-on* interactions (e.g., experiencing texture or weight of objects) are difficult to translate to the digital space. Certain characteristics of *digital* interactions (e.g., digital augmentation of objects) are difficult or infeasible to accomplish during *hands-on* interactions. While research findings have determined that both digital and hands-on learning are relevant in shaping student experiences in engineering courses, deeper insight into the magnitude of these preferences across grade levels remains limited. Outstanding research questions include, for example: do freshmen students prefer a different learning style compared to senior students? Are senior students equipped to utilize the industry techniques that are heavily digital or tactile oriented? Understanding the evolution of student preferences towards these learning styles would provide valuable insights to instructors and researchers aiming to enhance engineering education by determining when/where to emphasize a certain pedagogy during the undergraduate engineering experience.

This research is a multi-institutional collaboration between Penn State University and the University of Maryland. Freshmen and senior engineering students are included in this study in order to quantify the differences between digital and hands-on learning: 1) across engineering grade levels, and 2) across different engineering course types. This paper will provide preliminary evidence on how student preferences evolve as they progress through their engineering curricula. Such insights will inform researchers and industry about the preparedness level of the next generation work force in their ability to design physical systems for the real world, while concurrently taking into account the rapidly evolving shift towards digital simulation models and online collaborative environments.

1. Introduction

The objective of this research is to investigate students' learning preferences relating to *digital* and *tactile* experiences at different stages of their undergraduate engineering experiences. Unlike freshmen students who may/may not have had substantial exposure to digital/tactile activities, upper level engineering students actively engaged in several project based courses during the course of their undergraduate engineering experiences that might have provided insights about their learning preferences, as it relates to *digital* and *tactile* experiences. This research stems from a multi-institutional collaboration between Penn State University and the University of Maryland, where we aim to gain a deeper insight into the preferences of the next generation

work force prior to their graduation and highlight the professional work environment that may/may not align with students' existing preferences towards digital/tactile activities. In the following sections of the paper, we first present a summary of the relevant literature to shed light onto the relevance of the type of input for further processing during the cognitive processes. Then, we present quantitative and qualitative results of the differences in student perceptions after providing information on the course context as part of which data was collected.

2. Summary of the Relevant Literature

Learning requires cognition, a process “by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used.”¹ The use stage is manifested in understanding information, problem solving and decision-making. Experimental psychology championed the development of studies in learning, thinking, and reaction time². Below, we summarize some of the relevant works on cognition relating to our research based on the extended summary of cognition, value and decision-making research by Sprehn¹⁸.

Earlier studies on cognition began in 1940s, where laboratory studies aimed at identifying groups of people with significant differences in their cognitive processes. Some of the predominant theories of this epoch are: 1) Perceptual versus Conceptual Groupers³, 2) Sharpeners and Levelers⁴, 3) Field Dependency/Independency⁵, and 4) Impulsive versus Reflective Thinkers^{6,7}. We refer the readers to Kozhevnikov⁸ for an in depth review in this area. One salient criticism of these early theories, as voiced by Walker⁹, Kogan and Saarni¹⁰, and Sternberg and Grigorenko¹¹, is the lack of statistical separation between groups, especially when multiple studies are considered.

More recently, neuroscience focused studies have appeared to understand cognition at the physiological level. Cognition starts with the information perception (vision). Perception begins as light enters the eye and activates photoreceptive cells on the retina. The retina acts as a transducer, turning light into neural signals. The photoreceptors in the retina communicate with bipolar cells, which relay to ganglion cells. The ganglion cells are the connection to the brain, turning chemical signals into action potentials. Ganglion cells are specialized; five unique types have been identified and function to perceive depth, color and shape, color only, react with photosensitivity, and function to move the eye. The ganglion signals transmit to the optic nerve and from there, signals are sent to the thalamus¹².

Signals are then processed by the hippocampus, the regulatory structure of memory. Within this structure, signals are processed and encoded. There are four primary types of encoding based on the signals that are received: acoustic, tactile, semantic, and visual. Acoustic encoding deals with auditory sensations. Tactile encoding happens from the somatosensory cortex and involves how something feels. Semantic encoding focuses on meaning. Visual encoding involves the amygdala

and processes images between short- and long-term memory¹³. Encoding persists even after the stimulus disappears¹⁴.

Given the fact that visual and tactile encoding engage different parts of the brain, we hypothesize that students with hands-on and digital preferences to learning might have different performances in such settings. In order to study this hypothesis, we designed a data collection instrument and collected data from engineering students in a course setting. Below, provide information about the course setting followed by a discussion of the preliminary results.

3. Course and the Data Collection Context

Data was collected in two separate courses. An overview of the projects students worked on during these courses is provided in Table 1. The first course, *Introduction to Engineering Design* (EDSGN 100) is an undergraduate level course taken by most students in their first year of undergraduate education. The course introduces students to the “design process” in the context of engineering, where students work in teams of 4-5 on two 8 weeklong projects to explore existing solutions (emphasis on both virtual and tactile learning), generate design concepts (primary emphasis on virtual learning such as Computer Aided Design (CAD)) and build physical prototypes (primary emphasis on tactile learning using 3D printing techniques or traditional assembly using low cost components).

The second course, *Concurrent Engineering* (IE 466) is an undergraduate level engineering course mostly taken by students completing their senior year. The course introduces students to the concept of concurrent engineering; and through a series of case studies, investigates how different management, product, process, and service decisions impact company success. Student teams are made up of 4-5 students per team. Each team works on a semester-long project focused on investigating the engineering and management decisions that lead to a particular design solution, and how concurrent engineering concepts could have yielded more successful designs. The project has both virtual (e.g., digital design tools) and tactile (e.g., product dissection) components, hereby serving as a suitable data collection context, similar to the *Introduction to Engineering Design* (EDSGN 100) course.

Table 1: Overview of the Project Assigned in EDSGN 100 and IE 466

	Introduction to Engineering Design (EDSGN 100)	Concurrent Engineering (IE 466)
Primary Grade Level	Freshmen	Seniors
Design Artifact	Sustainable Electronic Toothbrush	Home Coffee Maker
Project Data	Fall 2012	Fall 2013
Project Summary	Student teams (~ 4-5 students/team) are assigned the task of developing a concept for a new niche market for a sustainable consumer electronics product. Each student team is to develop new concepts for a sustainable	The objective of the coffee maker project is to investigate the engineering design process and the concepts of concurrent engineering that could help yield more efficient design solutions. The project is partitioned into four components that

	consumer electronics product. Each team is to analyze the current offerings in the market and design a product that will better meet needs of the targeted environmentally conscious/green population.	include both digital and tactile modes of student learning.
Project Components	i) Analysis of Customer Needs including surveys, online search, etc. ii) Product Dissection (Component and Assembly Process, Literature Review, Patent Search), iii) Concept Generation (Conceptualization and Virtual Representation), Concept Selection and Materials and Manufacturing Analysis	i) Analysis of Customer Needs including surveys, online search, etc. ii) Product Dissection (Component and Assembly Process, Literature Review, Patent Search), iii) Concept Generation (Conceptualization and Virtual Representation), Concept Selection and Materials and Manufacturing Analysis
Virtual Learning	i) Visual inspection of the product, ii) Online internet search, iii) Digital sketches/design	i) Visual inspection of the product, ii) Online internet search, iii) Digital sketches/design
Tactile Learning	i) Product physical inspection, ii) Product dissection, iii) Product redesign	i) Product physical inspection, ii) Product dissection, iii) Product redesign

3.1 Description of Team Base Activities

In both the *Introduction to Engineering Design* (EDSGN 100) and *Concurrent Engineering* (IE 466), students work in teams to complete activities relating to both virtual and tactile learning. In the context of the EDSGN 100 course, customer needs analysis and product benchmarking were performed using the Analytical Hierarchy Process (AHP) and Pugh Charts. With senior students in IE 466 (who had more exposure to the engineering design process throughout the course of their academic careers), more advanced customer-engineering methods such as the House of Quality (HOQ) were employed to analyze the design of the coffee maker. For the QFD component of the project, students in IE 466 had to:

1. Identify *at least* 7 customer requirements (“Whats”).
2. Identify *at least* 7 engineering characteristics (“Hows”).
3. Assign a degree of importance to each customer requirement.
4. Perform a competitive assessment of the coffee maker against two other coffee makers (i.e., competitors) using the customer requirements identified earlier.
5. Find the relative importance of each customer requirement.
6. Identify strong, moderate, and weak relationships between whats and hows.
7. Compute the importance rating of each engineering characteristic, compare the technical aspects of your product to the competitors and identify the target values and the direction of movement to achieve each target value.

During the product analysis steps of the projects, students had to visually inspect their product (i.e., electronic toothbrush for EDSGN 100 and coffee maker for IE 466), followed by a product dissection and subsequent reassembly. For EDSGN 100, students:

1. Disassembled, measured, and analyzed the function of each component of the electronic toothbrush and recorded their measurements in a Bill of Materials (BOM) table.
2. Hand-sketched each component of the electronic toothbrush and identified their relationship to other components/subassemblies and recorded their findings.
3. Determined the features of their electronic toothbrush that made it easy or hard to assemble as well as the features that should be changed in order to improve the ease of use.

As part of their product dissection activity, students in IE 466 performed a Failure Mode and Effects Analysis (FMEA) of their coffee makers to analyze potential failure modes at the (i) System, and (ii) Design levels. Students had to:

1. Clearly define *all* of the System and Design FMEA failure modes, causes, and effects.
2. Identify the primary functions for a coffee maker, and subsequently identify potential failure modes for each function.
3. Discuss the rank ordering of design failure effects based on the Design FMEA.

The final component of each project involved investigating the global, societal, economic, and environmental impacts of their product.

1. *Global*: Where does the product come from? Investigate the global supply chain for the product and its use/popularity across different regions.
2. *Societal*: What impact has proper dental hygiene (for the EDSGN 100 project) or drinking coffee (for the IE 466 project) had on the society?
3. *Economic*: How much does a toothpaste/toothbrush or a cup of coffee cost? Perform an economic analysis on the feasibility of your design.
4. *Environmental*: What is the environmental impact of your design? How much water, electricity, etc. is utilized per use? How does this compare to alternatives in the market?

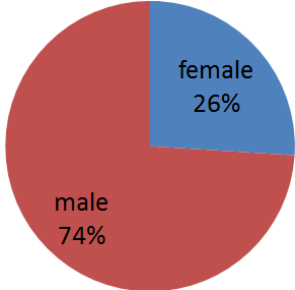
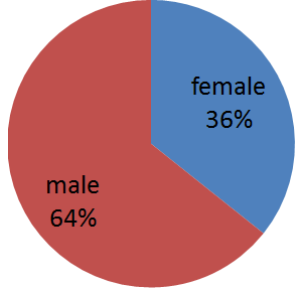
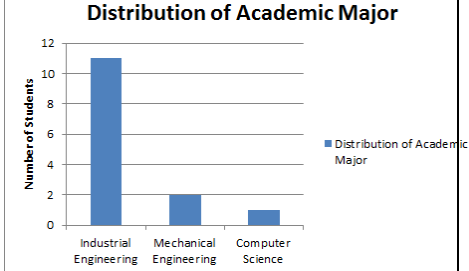
4. Description of Research Methodology

4.1 Study subjects

The researchers obtained IRB approval (IRB Protocol ID #41251, "Student Perceptions of Tactile and Virtual Learning Approaches: What Can We Learn from their Viewpoint?") prior to the start of this research study. The research study in the course, *Introduction to Engineering Design* (EDSGN 100) was conducted in the Fall 2012 semester (sample of 62 students), while the research study in the course *Concurrent Engineering* (IE 466) was conducted in the Fall 2013 semester (a sample of 14 students). For EDSGN 100, 74% of respondents were male, while 26% were female (Table 2). For the IE 466 course, 64% were male, and 36% were female (Table 2). Gender differences have been found to be relevant when investigating web-based information¹⁵. On a larger spectrum involving digital and tactile interactions, investigating gender differences could inform educators of the biases that exist in STEM education and the curricula enhancement that are needed to mitigate these biases and increase the participation of women in engineering.

In addition to gender data, students in IE 466 also provided academic major information. This is very valuable as it sheds insights into students' preferences towards virtual/digital preferences and their preferred professional career aspirations (based on their academic major). For students in EDSGN 100, academic major information was not available for all students since many students do not choose their majors until the start of their Sophomore year or later.

Table 2: Demographic Information of Student Participants

	Introduction to Engineering Design (EDSGN 100)	Concurrent Engineering (IE 466)
Gender Distribution		
Academic Majors	Unavailable because many students have yet to declare their engineering majors	

The distribution of student academic majors in IE 466 should not be surprising as the course is housed within the Industrial Engineering department. Future research will expand on the course offerings to investigate the differences in digital/tactile preferences across different engineering disciplines and offer a large sample size for engineering disciplines.

4.2 Data collection instrument

As part of the data collection, in addition to providing demographic data, students were asked specific questions pertaining to their future academic aspirations and their preferences towards digital/tactile learning. We present the specific questions in Table 3 for EDSGN 100 and Table 4 for IE 466.

Table 3: EDSGN 100 Survey Questions Pertaining to Virtual/Tactile Preferences

Q#	Introduction to Engineering Design (EDSGN 100)
1	My knowledge about the environmental impact of a product.
2	I find it useful to be able to virtually manipulate products (using tools like Solid Works/CAD, HTML/Google, etc.) when I am doing engineering design.
3	I find learning easier when I am virtually manipulating products.

4	I find it useful to be able to physically touch and manipulate products when I am doing engineering design.
5	Manipulating something physically helps me make connections between what I know and new intangible material that I am learning.
6	Seeing a visual helps me make connections between what I know and new intangible material that I am learning.
7	In this class, it is beneficial to have alternative ways of understanding the ideas or skills - Agreement Level Prior to Enrolling in Course.

Table 4: IE 466 Survey Questions Pertaining to Virtual/Tactile Preferences

Q#	Concurrent Engineering (IE 466)
1	Please describe your career aspirations.
2	Please rate your interest in learning concepts digitally (e.g., through visual inspection, digital interaction such as SolidWorks/CAD, etc.). On a scale of 1 to 5, 5 being the highest.
3	Please discuss what you learned from the coffee maker today, BEFORE opening the box and physically touching/interacting with it. (i.e., please discuss visual inspection, digital learning through internet searches, etc.).
4	Please rate your interest in learning concepts through tactile/physical interaction (e.g., touching/holding an object, taking an object apart, etc.). On a scale of 1 to 5, 5 being the highest
5	Please discuss what you learned from the coffee maker today, AFTER opening the box and physically touching/interacting with it. (i.e., please discuss your observations when physically interacting with the product).
6	Which activity did you enjoy the most? Visual Observation, Physical/Tactile Observation, Both equally
7	Please explain your response (Why did you like the above activity the most?)

5. Results

5.1. Quantitative survey results

The results in Tables 5 and 7 are revealing. They begin to shed light on the evolution of student preferences relating to virtual/tactile learning styles, as they progress during their academic careers. During each of the projects (i.e., electric toothbrush project in the EDSGN 100 course and the coffee maker project in the IE 466 course), students were exposed to both virtual and tactile aspects of learning. A direct statistical comparison between EDSGN 100 and IE 466 is currently not preformed due to differences in project types, data collection timelines, etc. However, the feedback provided by EDSGN 100 students after the completion of their project highlights a preference towards both virtual and tactile modes of interacting with design artifacts.

Table 5: Quantitative Results from EDSGN 100 Course Pertaining to Virtual/Tactile Preferences

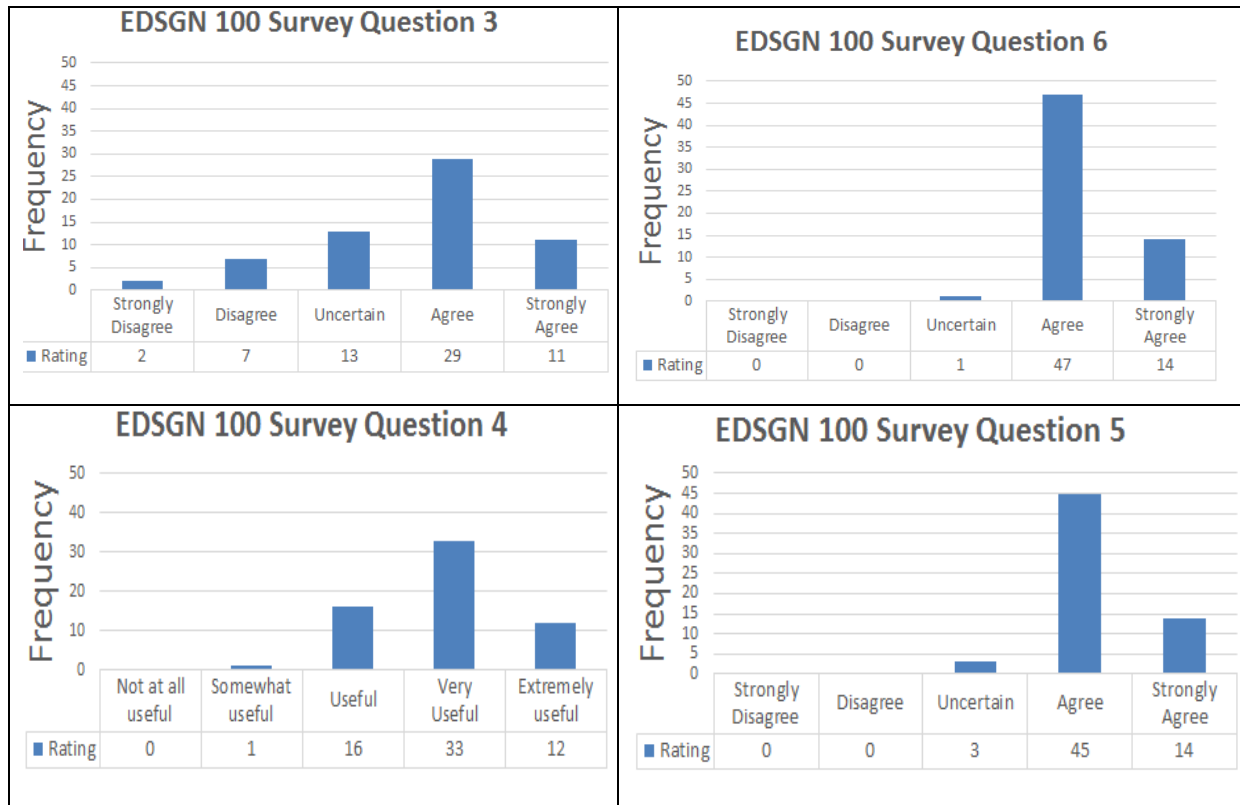


Table 6 presents a statistical analysis of the survey results from the EDSGN 100 course. Table 6 presents the pre- and post-course means for each of the questions asked. The null hypothesis is that the means of the pre- and post-test are equal; relevant t-statistic values presented in Table 6. If the p-value in Table 6 is less than the significance level (in this case 0.05), the null hypothesis is rejected. Table 6 reveals that students in EDSGN 100 seem to have a preference towards both digital and tactile preferences, as indicated by the t-statistic and p-values below the 0.05 significance levels. Such insights may help guide instructors teaching introductory engineering courses to include both digital and tactile modes of education delivery.

Table 6: Statistical Analysis of EDSGN 100 Survey

Q#	Pre-course Mean	Post-course Mean	t-Statistic	p-Value
1	2.468	3.532	-7.78	0.000
2	3.339	4.194	-5.22	0.000
3	2.952	3.65	-4.12	0.000
4	3.339	3.903	-3.63	0.000
5	3.806	4.177	-3.99	0.000
6	3.855	4.21	-3.64	0.000

7	3.645	4.268	-5.44	0.000
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In Table 7, quantitative analysis is performed on question 2 (digital interactions) and question 4 (tactile interactions) due to the numeric nature of these two survey response questions. Based on the t-statistic and p-values in Table 8, there is not a statistically significant difference in pre- (before students partook in the IE 466 coffee maker project) and post- (after students partook in the IE 466 coffee maker project) survey response means relating to digital preferences (question 2) and tactile preferences (question 4). It is important to note that a larger sample size beyond n=14 will better represent the student population pertaining to preferences towards digital and tactile preferences. While further research is needed to investigate why there is no statistically significant difference in the means of both digital and tactile preferences, such insights begin to spark the intellectual curiosity of researchers aiming to understand how student preferences towards digital and tactile preferences evolve during their academic careers. Such insights would inform educators of how well-aligned student preferences are with the professional workforce.

Table 7: Quantitative Results from IE 466 Course Pertaining to Virtual/Tactile Preferences

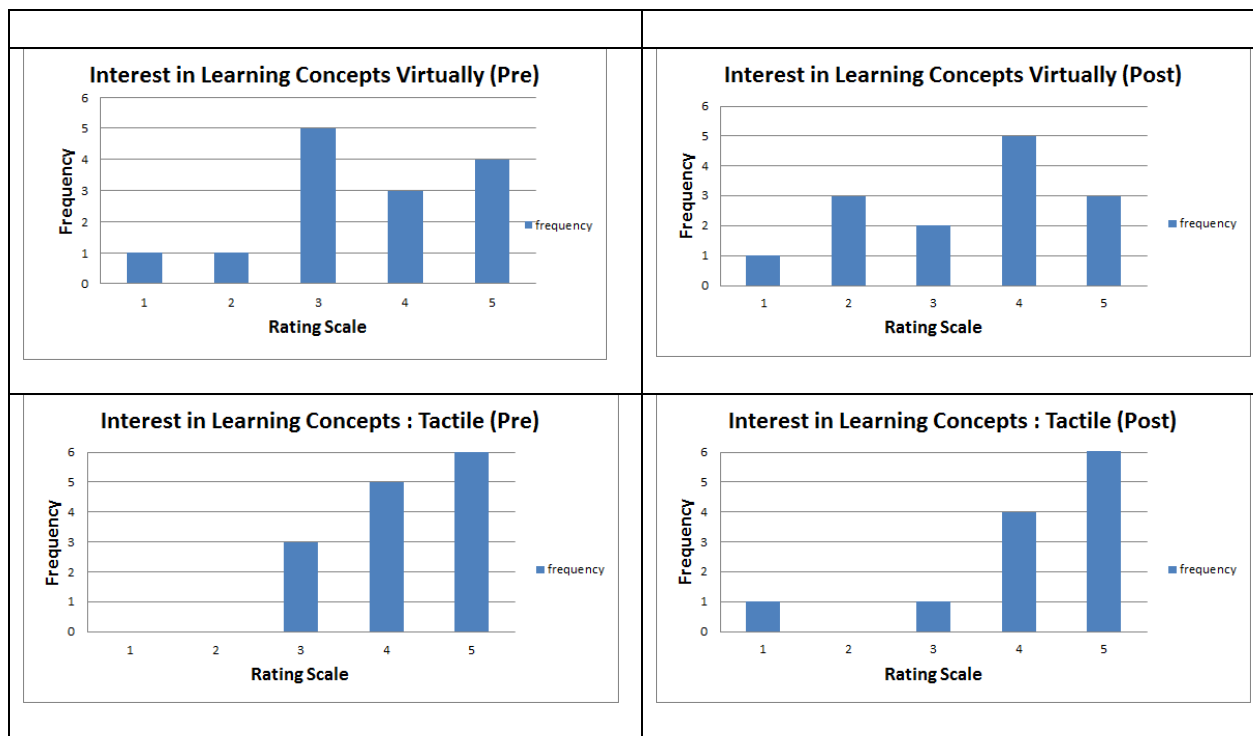


Table 8: Statistical Analysis of IE 466 Survey

Q#	Pre-course Mean	Post-course Mean	t-Statistic	p-Value
2	3.571	3.428	0.618	0.547
4	4.214	4.285	-0.234	0.818

Questions 1, 3, 5, 6 and 7 included textual responses from students and were analyzed using text mining and sentiment analysis techniques. Therefore, a statistical test of significance for the text mining results was not performed due to conversion biases that may be inherent in the text to numeric conversion algorithms employed by the text mining techniques. While it is interesting to know that our engineering students' preferences did not seem to change, given the exposure to both digital and tactile aspects of their project, this preliminary study sheds light on how this knowledge may be translated to industries recruiting students straight from undergraduate engineering programs.

5.2. Qualitative analysis of textual data

Qualitative data, in the form of textual feedback from students, provides a rich source of knowledge, beyond structured survey response where students are simply asked to rate preferences on a scale of 1-5. However, gaining significant insight using textual data has often been challenging due to time required to analyze it. To mitigate this challenge, we employ text mining algorithms to quantify student sentiment as it relates to their preferences towards virtual/tactile modes of learning. We use a lexicon-based method to analyze the survey answers provided by the students. It is assumed that each non-stop adjective or noun has some a sentiment score, either positive or negative. For example, the word “happy” indicates the positive emotion while “sad” suggests a negative one. Moreover, some adverbs and adjective also have an effect of strengthening or weakening effect of the original emotion. For instance, “very happy” has a stronger positive emotion than the sole word “happy.” Finally, the negation word, such as “don’t”, “aren’t”, “isn’t”, etc., will negate the emotion.

The algorithm begins by splitting a sentence into unique words. After removing the stop words, it will check the type and corresponding sentiment score of each word. The final emotion score is the sum of the scores of these words. The key issue for lexicon-based text mining techniques is the sentiment dictionary, i.e., the mapping between the specific word and an accurate sentiment score. In this work, we employ a merged dictionary from Taboada et al.¹⁶ and Thelwall et al.¹⁷

By employing the above explained lexicon-based qualitative assessment, we have analyzed the students' open-ended survey responses. Before converting these answers into analyzed data using the methodology, we provide the raw responses received. We note that student responses were not edited other than minor typographic errors.

Table 9: Pre-Dissection: Please discuss what you learned from the coffee maker today, BEFORE opening the box and physically touching/interacting with it

The importance of how the customer views a product and how engineers build off these descriptions to make it better.

I learned the technical aspects of the product like how much it weights, the dimensions, electricity requirements, etc. When I went on Walmart's website I was able to see the retail price and the customer reviews about the product. I believe the price and the customer reviews have significant importance on customers' decision making. Our product's rating was 4 out of 5 and the price was \$20, which, I believe, is a good deal.

I learned that the packaging of a product is actually quite important. A potential customer could be visually turned off just through poor advertising on the packaging.

I also learned that the digital information is quite extensive. Now, a potential customer can look online and find reviews of products before even having to go to the store.

By visual inspection of the box, I figured that the coffee maker was cheap as it was a no name brand and it did not have any "fancy" functions. The illustrations on the box were simple and therefore I presumed it was cheap. After looking the price online, we found out that the coffee maker costs \$8.69, thus confirming our suspicions of a cheap coffee maker.

We didn't do any internet research other than the price. The box explained all the features it had that they considered relevant, like how many cups of coffee it made and other extras like the option of programming it to brew coffee at a certain time.

I learned today that the appearance of the box plays the most important role in attracting customers to buy the product. The features of the coffee maker are the second section that customers view in order to buy the coffee maker. If the color of the box is not related with the product, customers would not observe the features of that product.

The team learned about the functionalities that made the product better than others. The usability such as size of the decanter, what added features it had to use, button types and settings, etc. The cost was also seen as well as color and the general look of the coffee maker.

Before opening the box, my group learned about the size, weight, and expected features of the coffee maker (removable filter, 5 cup, water window, etc.). We also looked up the price online. This gave us some expectations of how well it would work. The features were expected, but we couldn't entirely trust anything until we saw it. We could also infer things from the packaging design. Ours looked more classical with brown packaging which connects with coffee.

By reading the box you can understand what the company feels is important or special about their product from a more literal sense, the size of the packaging also told me how about how large the product would be. It also seems that the design of the box helps to determine if it is a higher quality product or lower level (even if this is judging a book (coffee maker) by its cover (box)).

I use the internet to search the coffee maker with other brands, the measurement, and the customer review. This gives me an imagination of the coffee maker before I open it.

I think one of the most interesting aspects of today's class was the discussion of customer requirements. When asked about a cell phone, a student simply stated "it's too small." It was interesting to me that often, customers don't even know what they want. It was such a vague statement, and companies are often playing a guessing game trying to determine what people want. This class reinforced the importance of marketers and customer forecasting.

What I learned is that the box visually says it all. I got the Rival and right away you can tell that the box was very simple and plain. You could tell who it was aimed for without even looking at the price. You can tell it was something that would get the job done (making coffee) in a quick and easily accessible manner.

Advertising on a box is both informational as well as to sell the product. We were able to do a comparative analysis without even opening the boxes, based off the outside information and pictures alone.

We learned:

- The cost of the product through the internet.
- The color and style of the product through the picture.
- The size of the product through the size of the box.

- Many features by the advertising on the box.
- Some important safety warnings by looking at warnings on the bottom.

Table 10: Post-dissection: Please discuss what you learned from the coffee maker today, AFTER opening the box and physically touching/interacting with it.

I learned how that functionality of the product is often not always the top priority. Aesthetics and side features can also sell a product.
After opening the box I was satisfied with the quality of the coffee maker. The plastic material that is used by the company was good quality. It wasn't a bendable, cheap plastic instead it was really solid which made me think that it's a durable product. Also the stainless steel plate gave a "classy look" to the coffee maker. After all I believe it's a good quality product from my first impression.
After opening the box, I was able to see more of the details of the product. I could tell if the product was un-sturdy or seemed "cheap", I could also see the tolerances of the product and see if the moving parts were easy to work with. I was able to see how intuitive the design was and get a better feel as to the good and bad qualities of the product.
I managed to see the construction of the coffee maker and confirm that it was built to be cheap. By comparing it to the other models, I could feel the difference in quality between models.
We saw the actual size of the coffee maker as well as how the different parts of it could be separated.
The attributes marked and the picture of the object on the box, do not always shows how the real product looks like. Some pieces appear to be larger in the picture than in real life. However, the quality of the product only is determined after customer opens the box and has a physical observation of the product.
There was a more hands on approach to it at that point. You could feel the quality of the material as well as how well it was put together. It was easy to see if it was functional or if there was a possibility it would break easily after heavy use.
The main difference about our coffee maker from many others in the class was how sturdy the plastic of the body was. That's not something any group could tell from the box. All of the moving parts worked well, and everything the box described as easy to remove, was. The product seemed to live up to the packaging (as best of our knowledge without using it).
By feeling and playing with the product you can again determine the quality or robustness of the product. The top of the coffee maker felt cheap and seemed to be lacking quality seen elsewhere in the product.
I already have the imagination in my mind about the coffee maker. After I open the box, I could physically touch it, and observe every part.
It was interesting to me to really dissect all of the different features. I had never really thought of all of the minute details of products. However, the different handles of the pots really stuck out as a predominant aspect that was worth examining. The ergonomics of a coffee pot may seem trivial to the average individual, but our team took a significant amount of time analyzing this feature across different coffee pots. I think the most predominant lesson learned from today was the amount of effort and engineering that goes into every part of a coffee pot (and other products as well).
To little surprise, the product was very cheap and had very cheap material. The box showed who it was aimed for and by physically touching it, you can tell that it was very cheap and easily replaceable. There was nothing to the coffee maker. After seeing other boxes from other brands, their boxes looked more visually appealing and you could tell that the coffee maker was more expensive just by the look of the box.
Once the box was opened you could feel the tangible quality of the item and the durability. Even though they looked similar in the pictures on the box, they were clearly very different quality once they were opened and held.
We learned: - The instructions are important; they were laying on top when we opened the box.

- The movable parts had cardboard between them for protection.
- Most of the plastic is cheap and would break easily.
- Our power cord is longer than some competitors.
- There was some safety plastic on the power cord so that a child couldn't plug it in.

5.3. Quantifying textual data

The results below are a summary of students' sentiments as they relate to the open-ended questions that were asked relating to virtual/tactile feedback. For each question, student textual responses were quantified based on the sentiment algorithms using the merged dictionary from Taboada et al.¹⁵ and Thelwall et al.¹⁶. As can be seen from Figure 1, sentiment scores are relatively positive across the questions asked in Table 3 (please note that Figure 1 contains only textual responses from IE 466 since this project contained more open-ended questions for senior students to address). In addition, each corresponding question number in Figure 1 directly relates to the question asked in Table 3). Questions 3 and 5 in Figure 1 are the most closely related questions regarding virtual/tactile experiences. While sentiment analysis presents an aggregate perspective of the preferences of virtual/tactile experiences, it provides additional information to support the findings of the quantitative data analysis presented in the previous step.

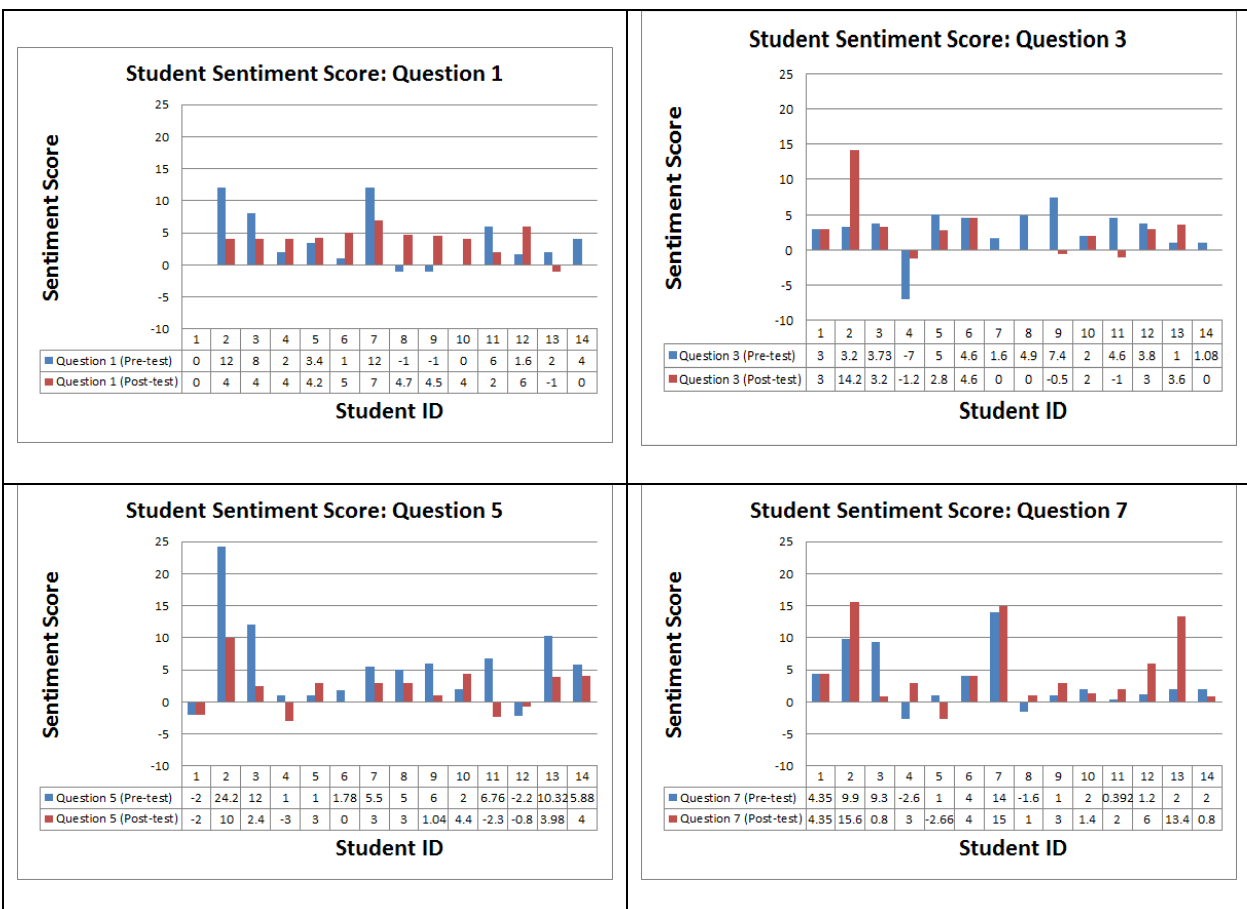


Figure 1: Sentiment Analysis of Student Responses Pertaining to Virtual/Tactile Learning

6. Conclusions and Future Work

The authors of this paper have presented preliminary insights into how the preferences towards digital/tactile preferences differ as students progress during their academic careers. Within the context of this research, *digital* learning techniques refer to the use of virtual environments to communicate educational concepts and activities. *Tactile* learning relates to the physical handling of objects. As the world moves towards a digitally connected, global workplace, it is interesting to know that freshmen students seem to prefer both digital and tactile modes of learning. With upperclassmen in the IE 466 course, there did not seem to be a significant difference in their preferences towards digital/tactile modes of design, after their semester long project. However, additional data is needed to generalize beyond the research findings of these two course offerings (especially in the IE 466 course, given the smaller sample size of 14). There are more than 25 sections of E Design 100 taught each semester, with approximately 32 students/section. Future research aims to expand on this research study to include a larger sample size and a control group so that researchers can investigate how the research findings from this preliminary study generalize across different sections and course offerings.

Future work will also include additional upper-level courses in a wide range of engineering disciplines so that researchers can determine the differences in student preferences and how those preferences differ across different engineering disciplines. Ideally, researchers would like to conduct a temporal research study that tracks individual students as they progress through their undergraduate careers to quantify the evolution of their preferences from freshman to seniors.

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