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Exploring Trends in First-Year Student Responses on Asynchronous Design Modules

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1. Introduction

With the COVID-19 pandemic restricting in-person instruction, content delivery and the monitoring of content comprehension is limited to online, asynchronous methods. While an increased emphasis on these remote methods is recent, literature related to engineering problem framing skills established the comprehension students see via in-person approaches [1-9]. These expectations serve as the basis of expectations and subsequent exploration as to how they operate via online, asynchronous delivery.

The motivation for this work is to determine how effective online, asynchronous and interactive modules are in supporting student comprehension of the engineering problem-framing process. To achieve this end, two asynchronous activity modules (Module 1 and Module 2) were completed by students enrolled in a Foundations of Design course. Basic statistics were carried out to establish preliminary performance standards on such modules. Note that student comprehension of the skills in this process is interpreted to be commensurate with student ability to carry out the process itself.

2. Literature Review

Fundamentally, engineering problem framing, also known as problem scoping, is a stage in the design process where designers define the nature of the design problem and the space in which they will search for design solutions [9]. Broadly speaking, this is conducted by gathering information, establishing constraints the design solution must adhere to, and ensuring the solution meets the needs of the stakeholders involved [9]. Embedded in this process, namely in the second step previously noted, is design specification analysis in which all facts related to the design solution are established and particularly adhere to the set constraints previously mentioned [10]. This typically occurs once the user needs and wants are established, prioritized and cast into a technical framework such that development of a design solution can begin [10]. Given the various parts that formulate the engineering problem framing process, adequate application of it in this manner is critical to avoid committing Errors of the Third Kind or a Type III Error in which a solution is designed for a problem not at hand or a suboptimal problem [6]. The likelihood of such occurring increases as the energy and time devoted to the problem framing process decreases [4]. As such, it is imperative engineering students are adequately taught the engineering problem framing process and how to properly apply it.

While there is an apt reason to become well-versed in engineering problem framing, literature thus far established the state of these skills in first-year undergraduate engineering students and the subsequent room for improvement upon them. Studies conducted by Kilgore et. al. found first-year engineering students to have an ability and inclination to situate a design problem in context more readily that is not an artifact of a particular design problem itself nor the student's knowledge of or interest in the specific task domain [7]. In other words, first-year engineering students readily supply a framework for a design problem in a broad manner. However, framing the problem with finer details as noted in the design thinking process does not occur to the same degree as students may feel unqualified to discuss technical and logistical details related to the design solution itself

[7]. Moreover, these novice designers may not recognize when problem framing is needed and may proceed to frame such as well-structured problems typically encountered in coursework [11]. Upon framing the problem in this manner, they tend to quickly formulate solutions to this well-defined problem [12] and ultimately commit Type III Errors.

Wholistic mastery of engineering problem framing skills is vital to engineering students such that they can apply them to scenarios with poorly defined problems as practicing engineers. Sole exposure to well-defined problems in engineering courses leads students to develop untenable habits such as little reflection on what could be done or the scenario as a whole and subsequent lack of proactive behavior to find the information needed [13]. While these students may be able to solve well-defined problems upon graduation, they may be unable to do such when the problem is in a realistic context as design problems do not arrive as tidy, rational, deterministic problems the way they tend to in courses [14] [15]. Successful application of engineering problem framing ensures deep comprehension of the content within which engineering students and engineers are solving problems [7].

3. Research Methods

3.1 Design of Asynchronous Design Modules

Two interactive, asynchronous design modules, Module 1 and Module 2, were created to facilitate the teaching and exposure of first-year undergraduate engineering students to the ideas and application of engineering problem-framing. Both modules were developed and subsequently deployed to students through Articulate 360. This program is entirely online and is ideal for interactive, distance learning where instructors can utilize a range of applications to design and implement online lessons with their students.

In particular, Module 1 was intended to define problem scoping. This module began by establishing the fundamental concepts behind engineering, science and design thinking as these operate in tandem to frame and, subsequently, solve an engineering problem. The module then took these ideas and applied them to an example scenario known for successful application of this process: MRI redesign for younger patients [16]. The engineering problem-framing process was then applied to the example scenario in a step-by-step process. Note the specific steps applied were developing a needs statement based on the underlying problem, identifying stakeholders, stakeholder need-finding, and information gathering. The step-by-step process was done such that the participating student received background information regarding what was needed and why for a given step and was then prompted to supply the necessary input to proceed to the next step.

Input requested from students included creating a needs statement, self-assessment of this needs statement, developing a list of stakeholders in the scenario, matching a list of needs to the corresponding stakeholder (known as a “needs sort” later in this work), providing a list of questions to use when gathering information for the design solution, and determining which sources of a provided set should be consulted to answer two questions: “How Do MRI Machines Work?” and “What Scares Young Children?”. Note these provided sources were Psychiatrists, Young Patients, Conduct Survey, Patents, Doctors, Medical Technicians, Experimentation, and Scholarly Journals. The self-assessment students gave for their needs statement was intended to assess their engineering self-efficacy and was conducted via a Likert scale from 1-10 where 1 was the least confident in their answer while 10 was the most confident.

While Module 1 focused on the problem-framing process, Module 2 focused on design specifications, namely, what typical design specifications are, determining which are relevant to a scenario, and how to quantify them. To do such, Module 2 begins by defining what design specifications are and broadly noting how they amalgamate in the final design solution to an engineering problem.

Similar to Module 1, Module 2 was executed via an example (a common non-mechanical pencil) that students worked through in a step-by-step process. After sufficient information was supplied in each step, the students were required to provide input which consisted of the work needed to complete each step. The necessary input included developing a list of initial attributes for the common pencil, their confidence in the accuracy of this list before and after receiving an example list, creating a list of ways to quantify the size of a common pencil, utilizing a tool known as the Specification Source Model (SSM) in which questions and justification are posed to assess how critical design attributes (Size, Accuracy and Capacity in this example) are to the overall design solution, and a final self-rating with respect to their confidence in using this tool for design specification analysis [17]. The relevancy thresholds available when assessing the relevancy of these attributes were Definitely, Probably, Maybe, Probably Not, and Definitely Not and translated to a 1-5 Likert scale with 1 corresponding to Definitely and 5 corresponding to Definitely Not. With respect to the three student confidence checks, students completed these via a Likert scale from 1-4 with 1 being the least confident and 4 being the most confident in their performance on a particular step of the module. Note that Figure 1 of the Appendix provides the SSM table integrated in this module.

3.2 Deployment of Design Modules 1 and 2 and Data Collection

Modules 1 and 2 were deployed as assignments in Autumn 2020 of a first-year undergraduate engineering course at a small, private, midwestern university. The course is required for all six undergraduate programs – Mechanical, Civil, Electrical, and Computer Engineering, Computer Science, and Engineering Education. Note that while these modules were expected to be completed by every student enrolled, not every student did. As such, a total of 147 students responded to Module 1 and 152 students responded to Module 2 out of 182 students enrolled in the class.

4. Results

4.1 Basic Statistical Analysis of Modules 1 and 2

4.1.1 Module 1

To begin establishing preliminary performance standards for first-year undergraduate students in the engineering problem-framing and design specification processes, descriptive statistics and distribution trends were identified for numerous inputs in both modules. It is important to note before moving forward that no data with respect to student comprehension and performance of the skills documented in Modules 1 and 2 from in-person instruction is being compared to this data as none is readily available for such work.

With respect to the first input of Module 1, identifying the needs statement, students were asked to assess how well they believed their needs statement addressed the underlying problem upon learning the true problem on the 1-10 Likert scale previously noted. For reference, 1 conveyed little student confidence while 10 conveyed the most confidence. The needs statements provided by the students were then reviewed by an experienced engineering designer and evaluated on the same Likert scale. The distribution of both assessments is presented in Figure 2 below.

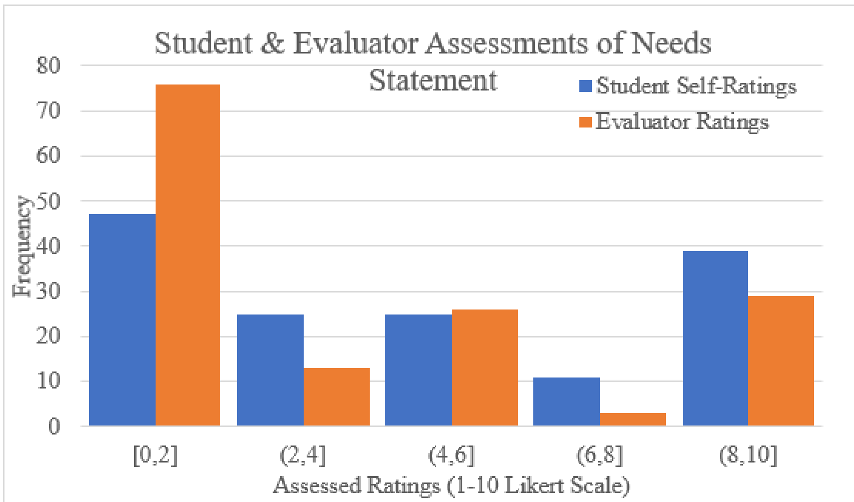

Figure 2: Distribution of Needs Statement Assessment by Students vs. Evaluator

As illustrated, student ratings of their needs statement consistently spanned values as small as zero and as large as ten with the first and last bins housing the majority of the 147 students who completed Module 1. Generally, the distribution of the evaluator ratings is skewed right as opposed to the fairly even distribution seen with the student ratings. Moreover, the first bin of the evaluator ratings is larger than that of the student ratings and the last bin of the evaluator ratings is smaller than that of the student ratings. The effects of this on the average and standard deviation of the evaluator ratings are presented in Table 1 along with those of the student ratings.

Table 1: Comparative Statistics Between Student and Evaluator Ratings of Needs Statements

Observed Statistic	Student Ratings	Evaluator Ratings	Difference in Ratings (Student – Evaluator)	p-value
Average (St.Dev.)	4.850 (3.612)	3.585 (3.794)	-1.265 (-0.182)	0.004**

*Note: a significance level of 0.10 was set where * p<.10, ** p<0.05*

As one can infer by the graphical representation in Figure 2, the average rating as given by students is greater than that of the evaluator. On average, the evaluator gave each statement over a point less to the statement than the students. The standard deviation of ratings given by the evaluator is also greater than that of the student ratings, indicating a slightly wider spread. Moreover, the difference between needs statement ratings is significant as indicated by a p-value of 0.004.

The next input requested from students involved listing all stakeholders in the scenario. Figure 3 below illustrates the distribution of the total number of stakeholders listed by the students.

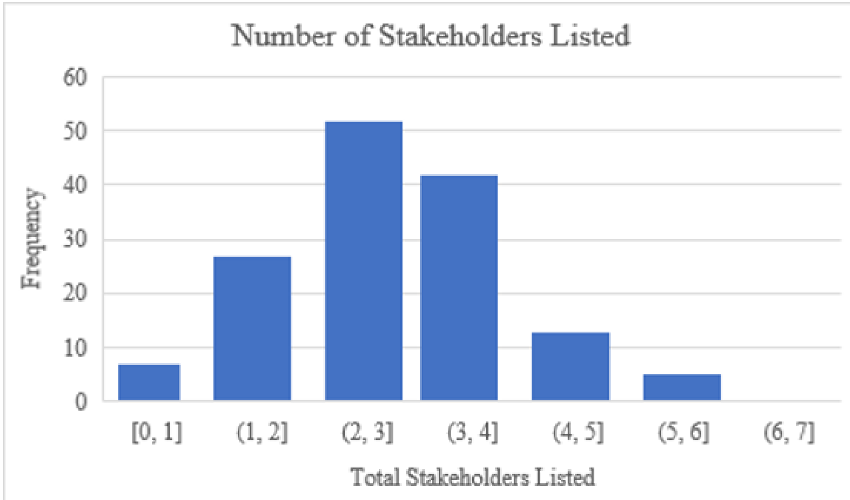

Figure 3: Distribution of Stakeholders Listed by Students to Engineering Problem

As depicted, the distribution of stakeholders provided by the students generally follows a normal distribution with most students giving two to four stakeholders in the engineering problem. The experienced engineering designer that ranked student needs statements identified seven stakeholders for this scenario: patients, doctors, nurses, MRI technicians, parents, the MRI company and the hospital. Table 2 provides the average and standard deviation for the number of stakeholders listed.

Table 2: Comparative Statistics for Module 1 Student Inputs

Observed Statistic	Number of Stakeholders Provided	Number of Questions Posed	Number of Sources: How do MRI Machines Work?	Number of Sources: What Scares Young Children?
Average (St.Dev.)	3.306 (1.174)	2.102 (1.084)	2.789 (1.273)	2.912 (1.097)

As noted in Table 2, the average number of stakeholders listed is slightly above 3, indicating the average aligns with the largest bin. The standard deviation is also slightly above 1, indicating a fairly narrow spread. Figure 4 below displays the number of questions asked in the information gathering portion of Module 1 by each student.

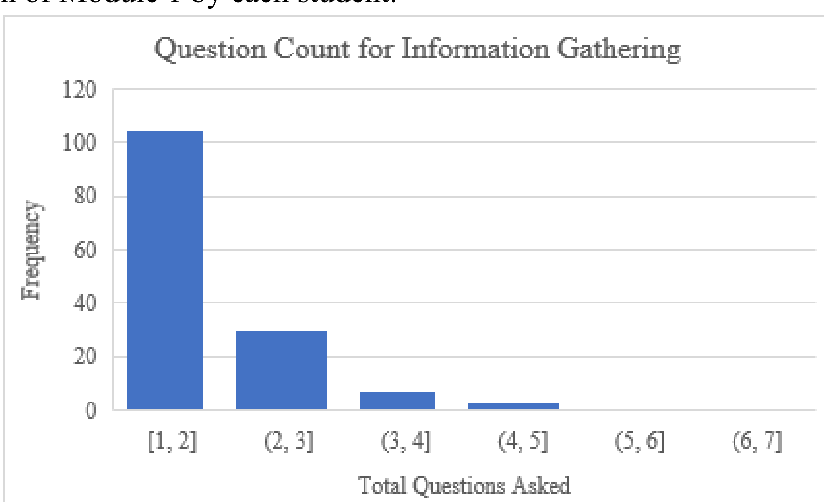

Figure 4: Distribution of Questions Asked by Students in Module 1

For comparison, the experienced engineering designer identified four potential questions to ask. Given by the right-skewed distribution, most students posed one to three questions to gather information while few provided more. The average and small standard deviation in Table 2 corroborate this and that the distribution's spread is concentrated around this point. From the provided eight sources to aid in answering the question "How do MRI Machines Work?" students selected a combination of possible sources as presented in Figure 5.

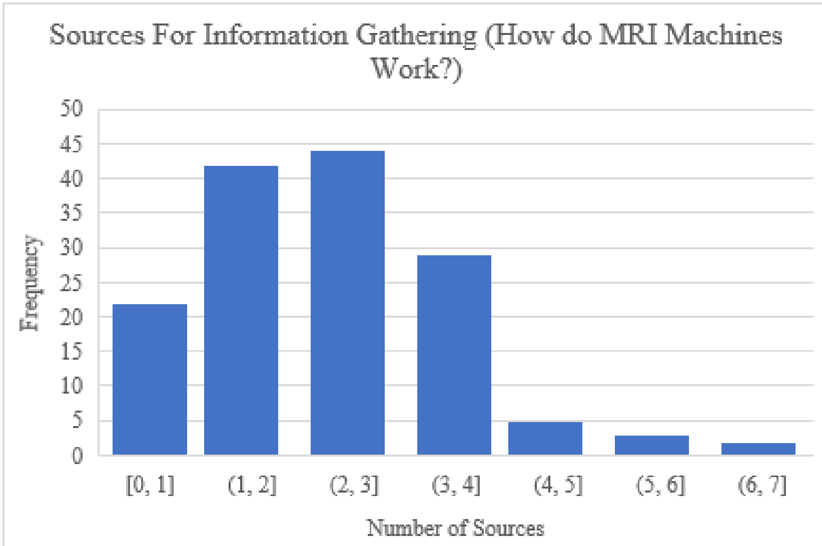

Figure 5: Distribution of Sources to Answer Question "How do MRI Machines Work?"

This figure illustrates another right-skewed distribution with most of the total sources to consult ranging from zero to four as indicated by the first four bins of the histogram. Figure 6 depicts a similar trend with respect to the sources needed to answer the question "What Scares Young Children?".

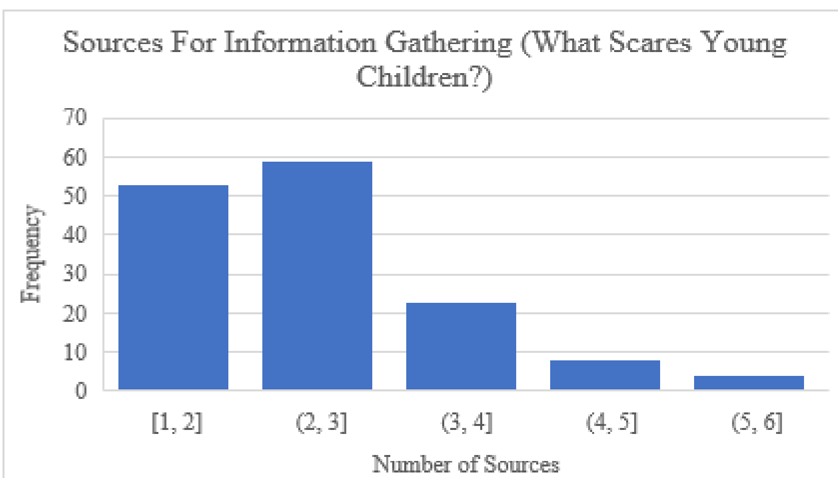

Figure 6: Distribution of Sources to Answer Question "What Scares Young Children?"

Figure 6 provides a right-skewed distribution with most students choosing to consult one to four sources. From Table 2, most students found two to three sources helpful to answer "How do MRI Machines Work?" and just under three sources helpful to answer "What Scares Young Children?" which is also in agreement with the small standard deviation of Figure 6's distribution.

While students selected a variety of possible sources to consult for both of questions “How do MRI Machines Work?” and “What Scares Young Children?”, it is important to highlight the evaluator determined a total of two sources (Medical Techs and Patents) were necessary to answer the former while six (Scholarly Journals, Experimentation, Medical Technicians, Conducting Surveys, Young Patients, and Psychiatrists) were necessary to answer the latter. Of those students who completed Module 1, 13 correctly identified the two necessary sources and only those sources for the first question. Figure 7 below illustrates the number of students who correctly identified zero, one, or both sources. Note that in Figure 7, students who identified the two correct sources, but also selected other sources to answer the question were counted as correctly identifying the two sources, giving a greater count than 13 students.

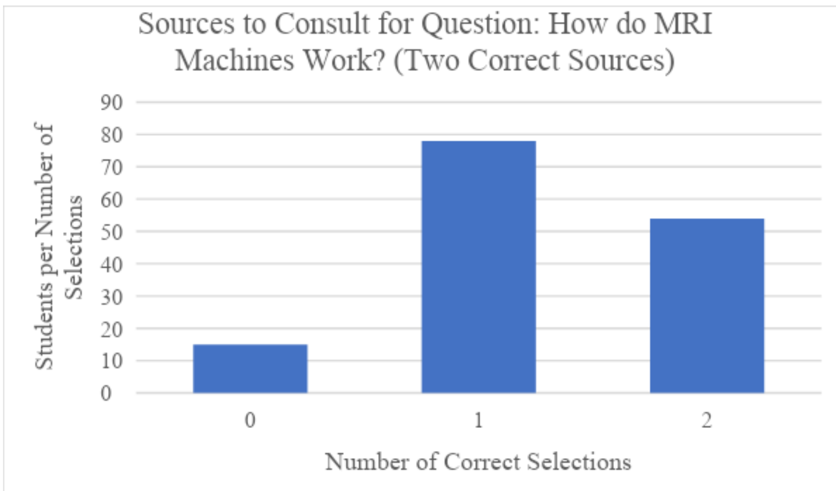

Figure 7: Number of Correctly Identified Sources per Student “How do MRI Machines Work?”

Here, many students were able to identify at least one correct source, followed by the two correct sources (but also some of the less than helpful sources), and few were unable to identify any correct sources. Much like Figure 7, Figure 8 presents the total number of students who identified the needed sources to answer the questions “What Scares Young Children?”.

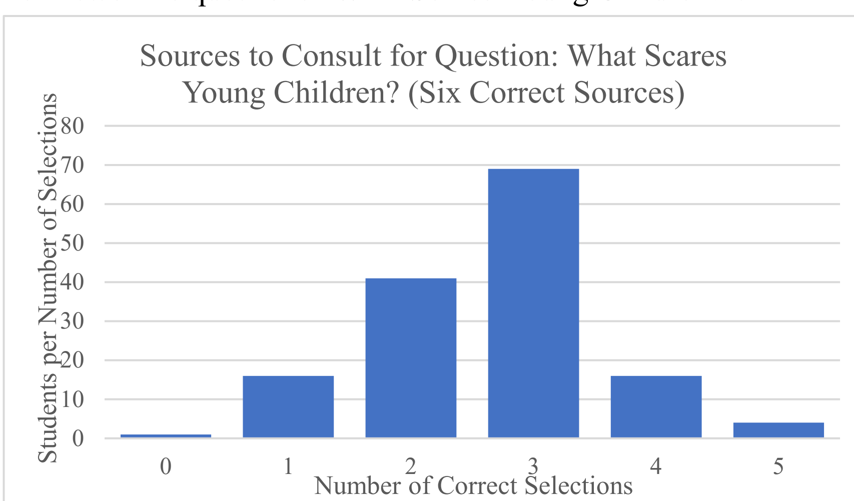

Figure 8: Number of Correctly Identified Sources per Student “What Scares Young Children?”

Note that zero students who completed the module were able to correctly identify all six sources. Rather, many students identified two or three of the needed six, with the remaining students selecting a different number such that an approximately normal distribution resulted.

4.1.2 Module 2

As previously noted, Module 2 reviewed design specification analysis and applied it to an example product: the common, non-mechanical pencil. The first step in this process and the first step that requested student input was a list of initial attributes one could supply a pencil. The distribution of total initial attributes given per student is depicted in Figure 9 below. In a similar comparative fashion to Module 1, the experienced engineering designer identified 16 attributes.

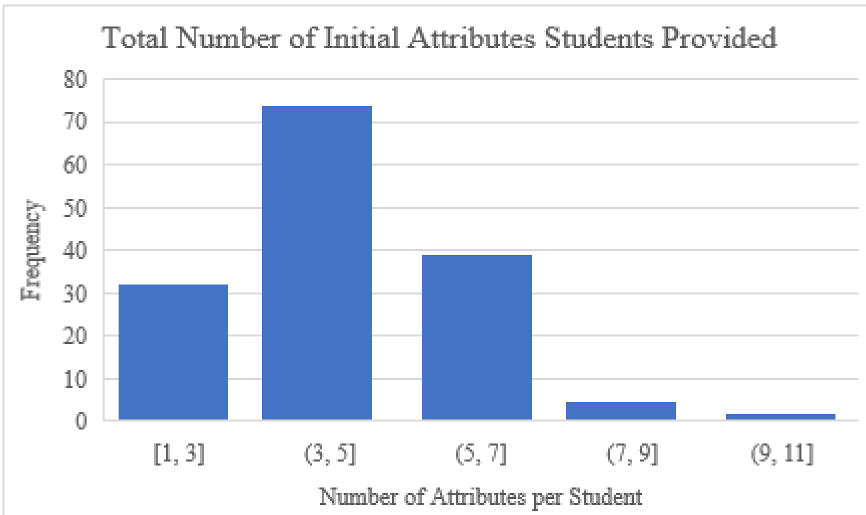

Figure 9: Number of Initial Attributes of a Pencil Given by each Student

Here, the distribution of initial attributes provided is slightly skewed right with many students providing three to five attributes. Table 3 provides the supplementing average and standard deviation for this distribution.

Table 3: Comparative Statistics for Module 2 Student Inputs

Observed Statistic	**Initial Attributes Provided**	**Confidence Rating Pre-Example Attributes**	**Confidence Rating Post-Example Attributes**	**p-value**	**Accuracy Attribute Relevancy (SSM)**	**Capacity Attribute Relevancy (SSM)**	**Size Attribute Relevancy (SSM)**	**Student Confidence in Applying SSM**
Average (St.Dev)	4.789 (1.630)	2.375 (0.796)	2.711 (0.827)	0.0004**	2.395 (1.056)	2.618 (1.218)	1.645 (0.864)	2.467 (0.829)

*Note: a significance level of 0.10 was set where * p<.10, ** p<0.05*

The average listed in Table 3 confirms most students listing between three to five initial attributes as that is the largest bin in Figure 9. This average works in tandem with the standard deviation of 1.630 to convey the number of initial attributes given is concentrated in the second and third bins of Figure 9 as well.

Upon creating their list of initial attributes, students were asked to assess their confidence in listing all that were possible via the 1-4 Likert scale previously noted where 1 is not very confident and 4 is very confident. They were then given the opportunity to compare their lists to one created by an experienced engineering designer and reflect again on the confidence they had in their initial list. The distribution of these student assessments before and after the "answer" is illustrated in Figure 10.

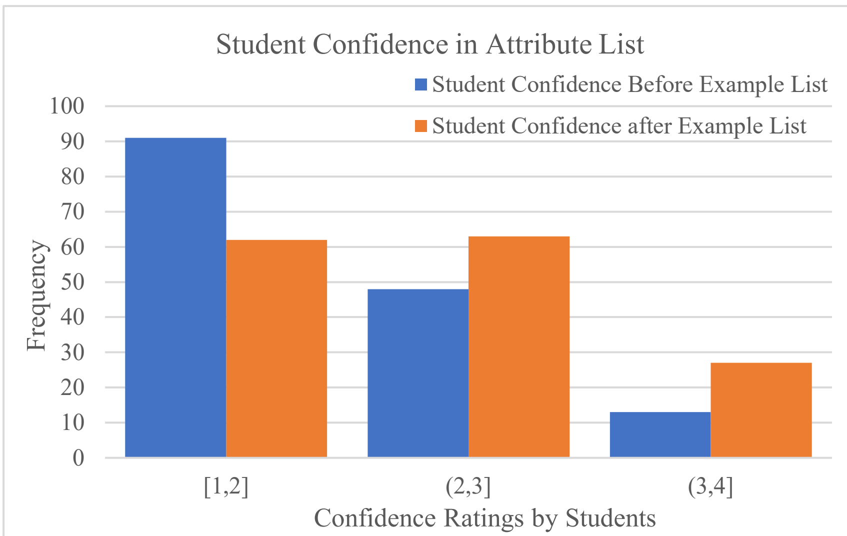

Figure 10: Student Confidence Assessment in Listing Attributes Before and After Viewing List Created by Experienced Engineering Designer

Both confidence distributions are skewed right with many students having no confidence or little confidence in the lists they supplied before the module addressed potential attributes. However, it is important to note that more students became confident in their attribute list upon reviewing these potential attributes as depicted by the secondary histogram in this Figure. The average and standard deviation of these distributions supplement this result in Table 3 as well. In particular, the average confidence in students' attribute list increased from 2.375 to 2.711 upon learning potential attributes from the module. The standard deviation exhibited a very minor change, illustrating a small spread between possible Likert scores. Moreover, a very small p-value (0.0004) was calculated as well, indicating the significance of this difference in student confidence ratings.

To complete the SSM for the pencil example in Module 2 (see Figure 1 of the Appendix), students were provided the three attributes previously noted (Accuracy, Capacity, Size) and to address their relevancy, one question was posed for each. The distribution for the relevancy of each attribute as determined by the students is presented in Figure 11. Recall a 1-5 Likert scale was used in this portion of the analysis to rank attribute relevancy where 1 corresponded to high importance and 5 corresponded to little importance.

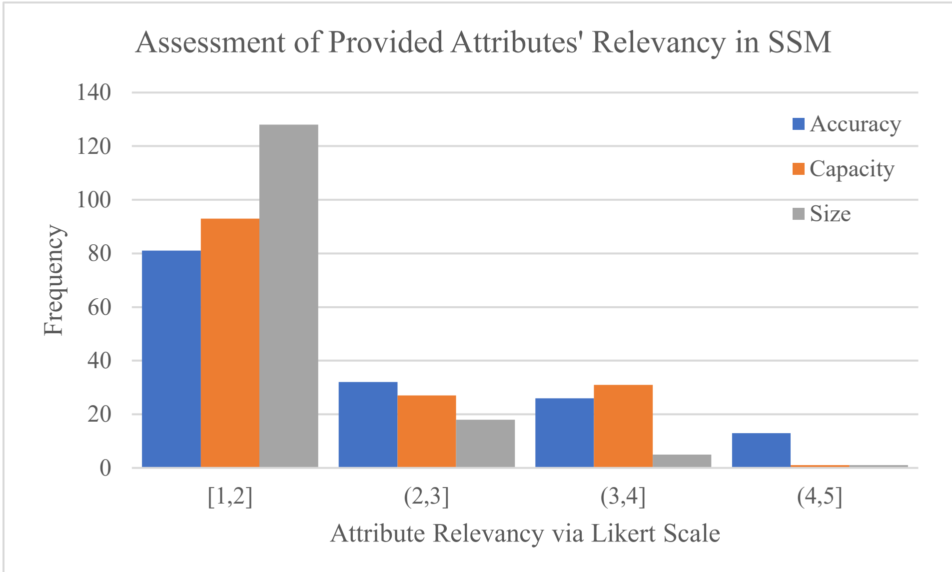

Figure 11: SSM Student Assessment of Attribute Relevancy

Overall, the three attributes followed right-skewed distributions with most students finding all of them to have great importance, especially the Size attribute. Table 3 presents the average and standard deviation of attribute relevancy for the three. As it can be seen, the average and standard deviation for the Size attribute corroborate the expectations from Figure 11. Note although the remaining two attributes have larger averages, they also have larger spreads as indicated by their standard deviations, giving them slightly less-concentrated distributions. Unlike the students, the experienced engineering designer deemed the Accuracy and Capacity attributes to be of little importance (4 and 5 respectively via the Likert Scale), but agreed with them when addressing the relevancy of Size and awarded it a score of 1.

Upon completion of the SSM in Module 2, students were again asked to assess their confidence in using the SSM in design specification analysis via the 1-4 Likert scale. The distribution of ratings is presented in Figure 12 below.

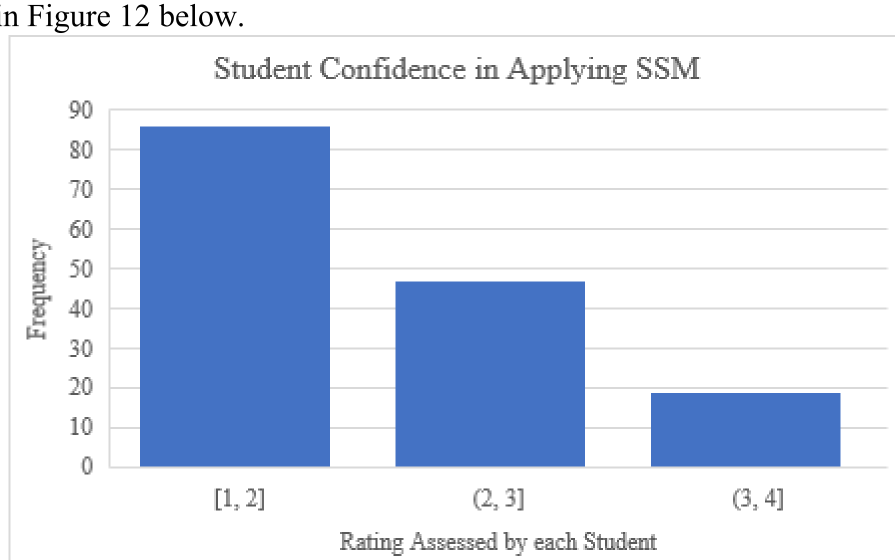

Figure 12: Confidence Assessment by Students in SSM

Again, the distribution is skewed right, with many students having little to no confidence in applying the SSM for design specifications in engineering problem framing. The quantified information from this distribution is presented in Table 3 as well. Generally, students have little to some confidence in applying the SSM as indicated by the average. The standard deviation also conveys a smaller spread and that most values are concentrated near the average.

5. Discussion

5.1 Preliminary Standards for Student Performance in Modules 1 and 2

5.1.1 Module 1 Standards

As previously highlighted, the first and last bins of that distribution convey most students had very little or very high confidence in the needs statement they produced while the remaining students were divided in a fairly consistent manner among the three bins between these two extremes. This illustrates an undefined trend in student efficacy of this portion of the engineering problem framing process. Given this, the preliminary standard of student performance for developing needs statements does not have a concrete focal point, rather, student efficacy in this is very widespread. Note that since no prior work referenced established baseline student performance in the development of engineering problem framing skills via distance learning, such baseline performance is established here and is highlighted as "preliminary standards" for the specific skills being discussed in both modules.

The experienced engineering designer that assessed these needs statements found many of them to be unsuccessful in addressing the true engineering problem at hand. Although most students could improve upon their needs statement, a fair portion of them did well with it, thereby giving the standard deviations of both distributions in Figure 2 comparable magnitudes. Typically, one would expect higher self-ratings in student needs statements to convey higher student performance in creating such, but the data for this portion of the work does not corroborate this. This indicates the need for educators to implement teaching practices that dive deeply into the fundamental concepts of a needs statement and the subsequent desire to develop such in a manner that adequately addresses the engineering problem at hand.

Unlike Figure 2, Figure 3, which displays the total number of stakeholders students provided for the scenario, exhibits a defined normal distribution. This, coupled with the average and standard deviation of 3.306 and 1.174 stakeholders respectively, conveys that students typically list few people or groups of people affected in such scenarios, thereby establishing the preliminary standard for students in this portion of the engineering problem framing process as such.

The next student input requested in Module 1, questions posed for information gathering, resulted in a different distribution from Figure 3. Specifically, Figure 4 exhibits a right-skewed distribution, with most students providing one to two questions. As a result, the average number of questions is 2.102 with a standard deviation of 1.084 questions. Therefore, the preliminary standard number of questions asked by students in the problem framing process is set at one to three questions.

The remaining two inputs requested of students in this module were the correct sources to consult to answer critical questions before creating a design solution: "How do MRI Machines Work?"

and “What Scares Young Children?”. With respect to both questions, many students selected one to four of the eight sources to consult as indicated in Figures 5 and 6 and as verified by Table 2. Thus, the preliminary standard for the number of sources students are expected to select from a supplied list of eight sources can be set as this range. As previously highlighted, a small proportion of students identified the correct sources needed to answer the first question while most of the remaining students selected at least one of the correct sources. In terms of the second question, many students accurately recognized several of the correct sources to answer the second question, however no students correctly identified all the sources needed. This implies students are more likely to recognize the correct number of sources needed from a given set to answer a design question if that number is small and not extensive.

5.1.2 Module 2 Standards

The first input requested of students in Module 2 was to supply a list of attributes to describe a common, non-mechanical pencil. With the right-skewed distribution in Figure 9 and the statistics provided in Table 3, most students identified one to seven attributes. Thus, the preliminary or baseline range of attributes expected from students for common items may be set as such.

As previously mentioned, student confidence in the attribute list submitted was assessed before and after an example list was provided. Upon learning this example list, student efficacy in their lists grew as indicated in Figure 10 and the average given in Table 3. Therefore, students can be expected to provide adequate attribute lists, but may need more exposure to such lists to verify for themselves they can create such on their own.

When applying the SSM, students typically found all three attributes to be of great importance to the overall design of a non-mechanical pencil and, therefore, critical design constraints to consider. While the experienced engineering designer found the Size attribute to be a crucially important design parameter to adhere to as well, they diverged from the students when considering the remaining two attributes and observed them to be of little importance to pencil design. Given the stark difference in attribute relevance from student to professional, it is possible that the eliciting questions in the SSM did not offer a clear enough explanation as to what kind of parameters exist and should be considered for the Accuracy and Capacity attributes. To remedy this and prevent such from occurring when analyzing any attribute, the eliciting questions can offer a brief example regarding how to evaluate the importance of a specific attribute to the design at hand.

After applying design specification analysis to the example item via the SSM, students again assessed their efficacy in using this tool. By the right-skewed display seen in Figure 12, students primarily ranked their confidence with lower values, indicating a lack thereof. These efficacy scores are justified when considering two of the three attributes students analyzed with the SSM were rated in an antithetical manner from the experienced engineering designer. Thus, the preliminary standard is fairly low for this aspect of engineering problem solving and can be highlighted in more in-class activities with students to further develop their skills and confidence in applying the tool.

6. Conclusions and Future Work

Throughout this work, the comprehension of the various steps in the engineering problem framing process were observed with first-year undergraduate engineering students enrolled in a Foundations of Design course. Given the restrictions imposed on in-person teaching and activities currently seen, these concepts were delivered to students via remote learning activities, namely, two online, interactive modules to determine their effectiveness and subsequent student comprehension of these concepts.

Preliminary standards for student performance on the engineering problem framing process in the first of these interactive modules were determined. Student confidence in developing a needs statement that addresses what is needed in the design solution ranged fairly evenly from high confidence to low confidence. They also tended to supply fewer stakeholders, fewer questions to gather the necessary information for a design solution and identify fewer sources to consult for answers to such questions.

With respect to the second module deployed, student performance on design specification analysis was determined. Specifically, students were able to supply a sufficient list of attributes for a design solution but were not always confident in them until receiving background as to how such a list is typically recognized. Moreover, a tool used to carry out this analysis, the SSM, was also observed and students were found to be less confident in using such tools without more guidance.

While this work provides a substantial basis for remote learning of the engineering problem framing process, more rigorous work must be done with these online activities to determine if these results arise repeatedly and ultimately, how to move forward and enhance student learning. In this work, the completion of these online activities was the first exposure students had in the Foundations of Design course to engineering problem framing and the supporting components. To establish if students need more repetition of engineering problem framing and its components in a remote setting for adequate retainment of these ideas, the online modules may be administered with new design scenarios at the beginning and end of the semester. Both sets of activities should undergo identical statistical analysis and allow educators to determine if these methods of remote learning are effective over time or if different activities must be developed and employed.

With the changes imposed on educators and students due to COVID-19, it is vital to ensure the delivery of course content and subsequent retention of this knowledge maintains the caliber previously seen with in-person activities. Through activity development, testing and analysis, successful methods can be created and ultimately become widespread in first-year engineering courses.

7. Appendix

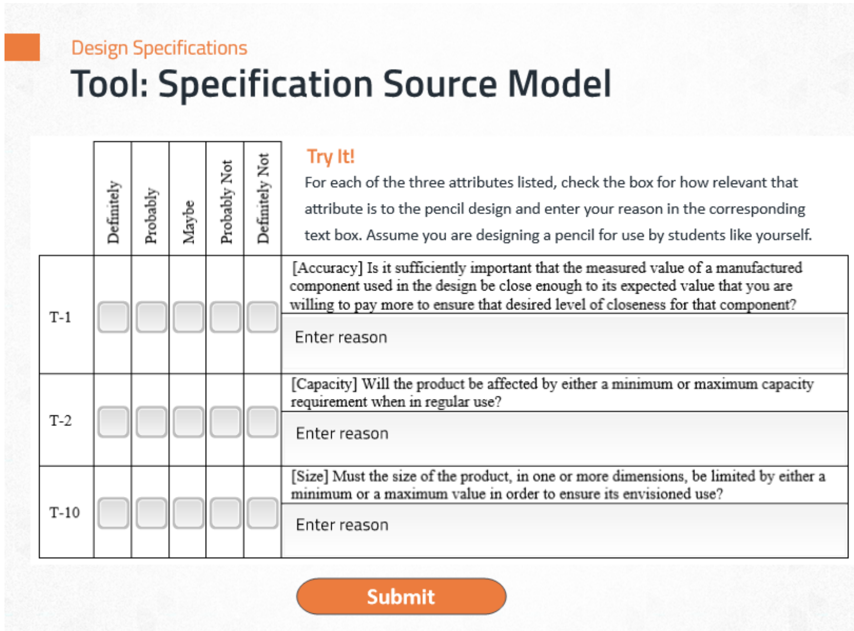

Figure 1: SSM Tool as Employed in Module 2

8. Reference

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