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Correlation between Asynchronous Module Comprehension and Traditional Comprehension Assessments

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While at university, Dr. Herak had several jobs including as a lab assistant (in Science Education, Mechanical Engineering and Entomology) as well as a GTA (in Science Education and the first-year Engineering Program). He also worked for 4-summers on the show staff for the Columbus Zoo, training various species of birds and other animals.

Dr. Herak was a secondary science teacher for 18-years, primarily for Westerville City Schools. However, he did take a leave of absence to teach at Aldenham School near London (UK). Dr. Herak has served as an adjunct professor at Central Ohio Technical College (Environmental Science) and adjunct professor position at Ashland University - Columbus Branch (Science Education), a position he still currently holds. Dr. Herak currently serves as a Senior Lecturer in the College of Engineering at The Ohio State University.

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Correlation Between Asynchronous Module Comprehension and Traditional Comprehension Assessments

1. Introduction

Over the past year, the COVID-19 pandemic has restricted in-person instruction and created a high demand for distance learning methods to be employed. Unfortunately, previous work analyzing student development of engineering problem framing skills has largely been completed with respect to in-person instruction methods and cannot be readily extended to the online learning environment [1-9]. As such, these results serve as the basis of expectations for student comprehension of such skills and investigation into how they operate via distant and asynchronous delivery may be pursued.

The motivation for this work is to determine if student comprehension and subsequent performance on online, asynchronous and interactive modules can readily be correlated to their performance on a traditional comprehension assessment: an individual homework assignment. To achieve this end, two asynchronous activity modules (Module 1 and Module 2) were completed by students enrolled in a Foundations of Design course and basic statistics were carried out to establish preliminary performance standards on such modules in a previous work completed by S. Youssef et. al. [10]. Upon completion of these modules, students were assigned the individual homework assignment and their responses to various questions were analyzed for correlation with their responses in the online modules via Spearman’s rank correlation coefficient, p-values and Cohen’s d effect size.

2. Literature Review

Engineering problem framing or problem scoping is a portion of the design process where designers define the structure of the design problem at hand and the scope they will employ to create design solutions [9]. In a broad sense, this occurs by obtaining information, identifying the bounds or constraints of the design solution, and ensuring stakeholder needs are satisfied in the developed solution [9]. The second step, identifying constraints to adhere to, is design specification analysis where facts relevant to the design solution are set [11]. Note that these aspects of the design solution will also adhere to the bounds previously determined [11]. Design specification analysis will take place once user needs are identified and will largely shape the constraints at hand [11]. These components of the engineering problem framing process must be followed and adequately applied to avoid Errors of the Third Kind or Type III Errors where the solution designed does not satisfy the problem at hand or satisfies a suboptimal problem [6]. As the energy and time spent on the problem framing process decreases, the likelihood of committing such an error increases [4]. As such, it is crucial to ensure engineering students have a deep comprehension of the engineering problem framing process and how to employ it themselves.

While it is vital to ensure this process is applied correctly, literature thus far established the degree to which first-year undergraduate engineering students harness these skills and implies how they may improve upon them. Studies conducted by Kilgore et. al. found first-year engineering students to have the desire and capability of setting the context of a design problem more readily so long as it is not a component of the design problem itself nor the student’s knowledge of or interest in the specific task domain [7]. In other words, first-year undergraduate engineering students can readily provide a broad framework for the design problem at hand. The framework does not typically have commensurate details as highlighted in the design thinking process because students may feel unqualified to discuss technical and logistical details of the design solution [7]. Furthermore, these novice designers largely encounter well-structured problems in their coursework and may not realize when proper problem framing is needed [12]. By extension, they become more likely to codify solutions to this well-defined problem [13] and ultimately perpetrate Type III Errors.

The comprehension of engineering problem framing skills and harnessing such is imperative to engineering students to ensure they can apply them when encountering poorly framed problems as practicing engineers. While exposure to well-defined problems in engineering courses allows for the foundation of these skills to be set, it can rapidly lead students to foster flawed habits such as little reflection on the scenario in a broad manner and subsequent lack of dynamic behavior to determine and obtain the necessary information [14]. The ramifications of this are evinced when students encounter problems in a realistic context and are unable to solve them since they were not presented in clean and rational problems the way they tend to in courses [15] [16]. It is ideal to avoid this and encourage cognizance and successful application of the engineering problem framing process as it also insinuates engineering students and practicing engineers comprehend the scope they are within and solving the problem(s) at hand [7].

3. Research Methods

3.1 Design and Deployment of Modules 1 and 2 [10]

The primary work of this paper serves as an extension of a previous work in which two online, asynchronous modules, Modules 1 and 2, were developed for and completed by first-year undergraduate engineering students. These modules served as foundational exposure to the engineering problem framing process and subsequent building of the skills needed to complete it.

In particular, Module 1 defined the various aspects of problem scoping and then applied each step of the process to an example scenario: redesigning an MRI for younger patients [17]. Module 2 defined design specification analysis in a similar manner and employed these foundational concepts in a second example: design specification of a standard non-mechanical pencil. Student input was required periodically in both modules and was then compiled to create graphical representations of the data. Basic statistics were computed to establish baseline student comprehension of these processes when learning them via distance learning methods.

Note that content delivery of engineering design in this course prior to the development of these modules has evolved considerably. Before the development and use of any modules, students received their engineering design knowledge in a traditional, lecture-style manner followed by in-class activities to reinforce the ideas presented. This was modified in the 2019-2020 school year where a less-interactive iteration of these modules was developed and deployed to students to serve as their primary exposure to engineering design concepts via an inverted-classroom setting. As such, all class time previously used for lecturing and active learning was shifted to solely facilitate student comprehension of engineering design via active learning.

3.2 Design of Engineering Design Homework Assignment

Upon completion of the assigned asynchronous modules, students were assigned an individual homework assignment that synthesized the content covered in both modules. Specifically, the homework served as a final assessment of student comprehension of the concepts covered in engineering problem framing by employing general application of engineering problem-framing to a given scenario (prosthetic arm development [18]) and design specification analysis in another (design product for ease of access into attic).

Much like Modules 1 and 2, students were guided in a step-by-step process with the necessary background information to complete each step and provide a preliminary design solution. With respect to the prosthetic arm scenario, students first watched a short video that supplied general information on who would benefit from the project and how the project came to be created. Upon watching this video, students observed the project from the perspective of those originally involved in tandem with the supplied background information in the assignment itself to not only complete the given step of the process, but also to begin formulating the typical thought process one must follow for successful engineering problem framing. With respect to the product design for attic access scenario, students were supplied broad background on the scenario and why a new product was being designed. The homework consisted of five parts (Problem Identification, Research, Design Specs, Specification Source Model, and Site Plan Bubble Drawing) with 11 steps comprising the five parts: listing stakeholders, creating a needs statement, identifying broader impacts of design solution, consulting experts, reviewing publications, asking stakeholders questions, assumptions to make, classifying constraints and evaluation metrics in the design specifications, applying the Specification Source Model (second scenario), establishing new constraints and evaluation metrics, and creating a preliminary site plan of the solution to the scenario. The Specification Source Model used here and in Module 2 were modified versions of the Constraint Source Model originally developed by J. Estell et. al. [19-20]. A total of 50 points were possible for the homework where each step was worth a certain number of points, depending upon how critical it was to develop a design solution. Note that the last section of the homework, the Site Plan Bubble Drawing, was not related nor relevant to the work completed in Modules 1 and 2 and therefore was not part of the analysis of this work.

3.3 Deployment of the Engineering Design Homework Assignment

The 182 students enrolled in a first-year undergraduate Foundations of Design course completed the homework assignment. A step-by-step breakdown and the corresponding point totals comprised a rubric used to grade the assignment by the course instructor and teaching assistants. This rubric and the points per step are provided in Figure 1 of the Appendix. The total points awarded and point breakdown per student for the assignment were stored in an Excel workbook and the results were used for correlation analysis with the results obtained from the modules.

As previously noted, teaching practices for engineering design in this course underwent several iterations to create the asynchronous modules as they are today. While such is the case, the individual homework assignment students completed was administered in each iteration and highlighted engineering design in the same broad manner. As opposed to the significant changes observed in the engineering design teaching methods employed, this assignment solely received changes in terminology and presentation of the homework scenarios themselves.

4. Results

4.1 Module 1 to Individual Homework Assignment Correlation Analysis

Student inputs in Module 1 were analyzed in a pairwise manner with various questions on the individual homework assignment students completed after both modules. Spearman's coefficient, the resultant p-value and Cohen's d effect size were found for each pair. Those deemed statistically significant are presented in Table 1 while those that did not meet this criterion were omitted.

Table 1: Correlation Values and p-values across Module 1 Inputs and Homework Questions

Module 1 Input	Homework Question	Spearman's Coefficient	p-value	Cohen's d Effect Size
Stakeholder Needs Sort	Developing Needs Statement	-0.137	0.099*	2.969

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

As indicated, only one pairwise comparison was statistically significant which resulted in a negative Spearman's coefficient and an effect size value greater than one.

4.2 Module 2 to Individual Homework Assignment Correlation Analysis

Student inputs from Module 2 were subsequently analyzed in the same pairwise manner with questions on their individual homework assignment and the same statistics were generated for those comparisons. Statistically significant results are presented in Table 2. Note that the "First Scenario" and the "Second Scenario" in this table are the prosthetic arm development and designed product for attic access scenarios respectively.

Table 2: Correlation Values and p-values across Module 2 Inputs and Homework Questions

Module 2 Input	Homework Question	Spearman's Coefficient	p-value	Cohen's d Effect Size
Quantify Size	Broader Impacts of First Scenario	0.143	0.078*	1.704
Quantify Size	Constraints & Evaluation Metrics of Second Scenario	0.191	0.018*	0.078
Initial Attributes	Broader Impacts of First Scenario	0.128	0.116	2.310

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

Note that the final entry in Table 2 is supplied to illustrate the proximity of this p-value to the significance level set. Of the two statistically significant comparisons found, both have positive Spearman coefficients. However, the second of these comparisons has an effect size greater than one while the while the first has a very small effect size.

5. Discussion

5.1 Individual Homework Assignment to Module 1

Module-to-homework assignment correlation analysis was completed to determine if performance on one can predict performance on the other. As depicted in Table 1, one comparison was statistically significant and resulted in a negative Spearman's coefficient. Based on this value, the comparison is subsequently translated as such: students that identified the needs of each stakeholder in the module more efficiently are more likely to have earned a higher score on the needs statement they created in their homework assignment. Moreover, this comparison has an effect size value greater than one, indicating a higher strength in this relationship.

While the interpretation of the Spearman's coefficient explains the relationship of these two variables, the implication can be extended to another degree. Since Module 1 was the first activity students completed and the homework assignment was the last activity students completed in this content unit, it can be inferred that after multiple instances of exposure to these ideas in the engineering problem framing process, students obtained a more concrete understanding of them, what they may need in a given scenario, and how to collectively capture it in a statement that allows one to begin outlining what will constitute the design solution. This encourages one to believe that although restrictions to in-person activities may inhibit some growth, repetition of the concepts that formulate these design processes with students will help them learn and eventually master them.

5.2 Individual Homework Assignment to Module 2

The correlation analysis between the homework assignment and Module 2 was applied to determine if performance on aspects of one could predict performance on aspects of the other. To this end, two statistically significant comparisons were found. The first of which was between the number of ways students would quantify size in a design on Module 2 and their score on identifying the broader impacts of design solutions in their homework assignment while the second considers the number of ways students quantify size on Module 2 and their score on recognizing the constraints and methods of evaluating such on a design. The Spearman's coefficient for both comparisons were positive and, for the first comparison, indicated that students who found more ways to quantify size were more likely to correctly determine the broader impacts of the design solution in their homework and receive a higher score on that portion of the assignment. In terms of the second comparison, students who found more ways to quantify size on a design were more likely to identify constraints on a design and the quantity-based metrics that allow for evaluation of each. With respect to calculated effect size values, the first comparison has a stronger correlation than the second since the former is larger than one while the latter is much smaller than one.

The relationship exhibited between the variables of the first comparison can be extended to infer other implications they have on students and these design processes. Students identifying a more extensive list of ways to quantify the size of a design imply they are thinking about such from numerous angles and considering the full range of its functionality. If they are considering a design's scope in this well-rounded manner, then this well-rounded thought process may be more readily applied to a larger scope such as how broad a design's impact may be.

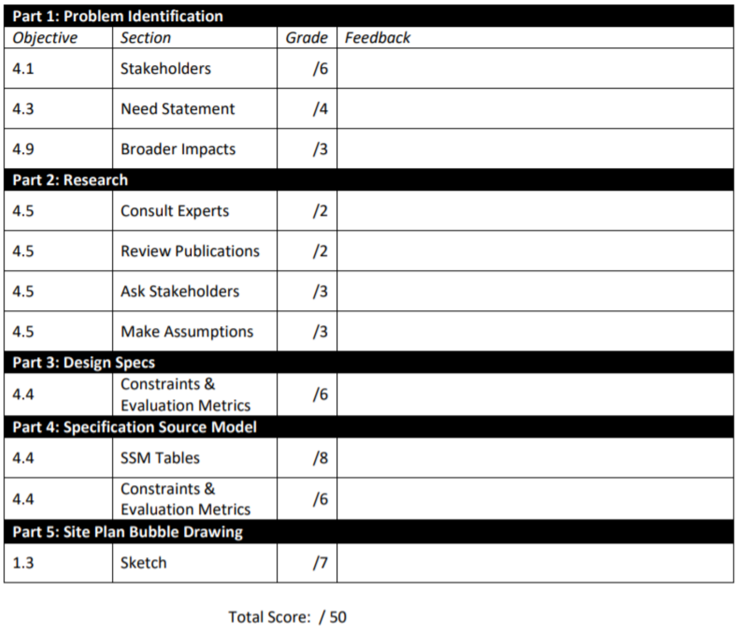
In terms of the second comparison, a more extensive list of ways to quantify aspects of a design gives students a broader scope to think about the design itself and what may be constraining it to its current state. Doing this also supplies them with various metrics they can apply to evaluate the basis on which the design solution currently stands. Moreover, Module 2 and the homework were completed towards the end of the content unit, indicating students had been exposed to the ideas of engineering problem framing and design specification analysis several times at this point. As such, students may have had a more wholistic understanding of these ideas and what is needed for them to be adequately applied in a design. Again, this encourages one to find repetition of these ideas and their application aid student comprehension of them especially when in-person activities are restricted.

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. These concepts were delivered to students via remote learning activities, namely, two online, interactive modules [10] and the subsequent results were correlated to their performance on an individual homework assignment highlighting the same skills.

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 with traditional assessment methods known to be successful, effective distance learning activities can be created and ultimately become widespread in first-year engineering courses.

7. Appendix



Part 1: Problem Identification			
Objective	*Section*	*Grade*	*Feedback*
4.1	Stakeholders	/6	
4.3	Need Statement	/4	
4.9	Broader Impacts	/3	
Part 2: Research			
4.5	Consult Experts	/2	
4.5	Review Publications	/2	
4.5	Ask Stakeholders	/3	
4.5	Make Assumptions	/3	
Part 3: Design Specs			
4.4	Constraints & Evaluation Metrics	/6	
Part 4: Specification Source Model			
4.4	SSM Tables	/8	
4.4	Constraints & Evaluation Metrics	/6	
Part 5: Site Plan Bubble Drawing			
1.3	Sketch	/7	

Total Score: / 50

Figure 1: Rubric and Point Breakdown for Individual Homework Assignment

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