

Investigating Engineering Students Habits of Mind: A Case Study Approach

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Abstract

Our project is an interdisciplinary study aiming to understand engineering students “habits of mind”, which are modes of thinking required for STEM students to become effective problem solvers. After presenting the goals of our project and the context of our study, we summarize our initial progress and our proposed framework. This is a work in progress.

Introduction

The need for the math and science foundation in engineering students' education to incorporate less defined but necessary skills such as persistence and willingness to take calculated risks has been acknowledged by many. In this paper, we give an executive summary of a project that supports this goal and describe our initial progress. Our work is an interdisciplinary study that combines methods from the learning sciences with machine learning techniques to characterize undergraduate engineering students' “habits of mind”, which are modes of thinking required for STEM students to become effective problem solvers capable of transferring such skills to new contexts [1]. An example of habit of mind is a willingness to make mistakes while trying to solve a problem, an attitude that allows engineers to successfully attack complex problems. Our project investigates the question: “How do engineering students exhibit scientific habits of mind in the context of signals and systems theory and application?”

The project leverages an education website [2][3] developed by one of the authors. The website, called Project Rhea, contains a rich variety of student-created learning material. This data, along with data acquired as part of a course on Signals and Systems, is being used to identify how students experience scientific habits of mind as they engage in problem solving. To this end, qualitative and quantitative research methods enhanced with machine learning techniques will be combined.

The goal of this interdisciplinary partnership is to initiate a boundary spanning research program to identify and validate novel research methods and formative and summative assessment mechanisms. The efforts center on enhancing qualitative and quantitative educational research and assessment methods with machine learning techniques such as automatic data clustering. Our specific goals are to (a) provide a context for an exploratory study to be used as a baseline for future efforts in engineering education research methods and assessment; (b) address challenges in cultivating a culture of lifelong learning among professional and future engineers via scientific habits of mind in an engineering context; and (c) develop new methods to characterize and measure different aspects of professional formation processes in engineering education.

Methods

The context of our study is a course on Signals and Systems in which students were asked to produce learning material and share it on a public website. Specifically, the instructor pre-defined nine topics covered in the course, and students were asked to prepare a “slecture” [4]

explaining the course material for a topic of their choice in their own words. The students were also instructed to review and comment on the slectures prepared by their peers. Our first task has been to gather the data and construct an analysis framework.

A total of 28 students participated: 27 students presented the slecture in written form, while one chose to present it as a video. For our analysis, we used the 27 written slectures. Every student had to create one slecture on a chosen topic and there were on average three slectures for each of the nine topics available. Further, each student was supposed to review and comment on at least one slecture per topic. However, some students did not complete the review and comment assignment. On the other hand, some made more than 9 comments while others made less than 9 comments. On average, each student made 6.89 comments.

Our second and third tasks were to build a habits-of-mind focused evaluation rubric and to use this rubric to annotate the student-created material (both slectures and comments). We performed both tasks somewhat in parallel, beginning with a pre-defined, generic rubric focused on 5 habits of mind with 4 levels of performance. As we began to annotate the material, we changed the description of the habits of minds and levels of performance in order to better capture the data.

Results

The final rubric, presented in Table 1, was thus designed and modified iteratively until it provided an accurate scale to characterize the learning habits of engineering students.

Table 1 : Rubric

Tag	Description		Level of Performance			
	Element	Definition	Below Basic 1	Basic 2	Proficient 3	Advanced 4
A	Computation and Estimation	Ability to choose an appropriate computation method and carry out the mathematical procedure accurately	Student selected an incorrect method and the solution was completely off.	Student selected a correct method but the solution was incorrect.	Student selected an appropriate method and the solution was correct. However, the student did not provide a justification for the method based on the circumstances, or the justification was inadequate.	Student selected an appropriate method, the student provided a correct justification for the selection of the method based on the circumstances and the solution was correct.
B	Mathematical Rigor	Ability to handle mathematical rigor and remember details of a definition	Student was not at all rigorous in the involved mathematics.	Student displayed some rigor but there were major errors.	Student was very rigorous but made small errors.	Student was very rigorous and made no errors.
C	Communication Skills	Ability to communicate effectively, explain background and present a good meaningful flow of ideas	Student presented an unclear and unjustified procedure.	Student presented a somewhat clear procedure but it was unjustified.	Student presented a clear procedure with a reasonable justification.	Student presented a clear procedure with a detailed justification based on the theory or principles.
D	Critical Response Skills	Ability to detect the symptoms of doubtful solutions, assertions and arguments in	Student was unable to identify incorrect procedures and provided no evidence of	Student was able to identify incorrect procedures but was unable to correct them. The	Student was able to identify incorrect procedures and corrected them properly. However, the student provided no	Student was able to identify incorrect procedures and corrected them properly or did not demonstrate any incorrect

		one's own work and in peers.	procedures for validation of their solution.	student provided no evidence of procedures for validation of their solution.	evidence of procedures for validation of their solution.	procedures. In addition, the student demonstrated evidence of applying procedures for validation of their solution.
E	Values and Attitudes	Student's attitude towards their own ability and those of their peers.	Student made negative comments about other's work or was indifferent to it.	Student made generic comments that do not provide any insight or critique.	Student made good comments providing insight and a somewhat reasonable critique.	Student made excellent comments, correcting mistakes and providing insightful critique.

The changes in each successive iteration were motivated by the recognition of different elements that were most critical to analyze performance of engineering students. For instance, the element “Values and Attitudes” was initially focused on general social values. However we found that the students’ critical views of their own work and that of their peers was a better indicator of their performance. So we shifted focus to analyzing if students were able to provide a meaningful critique of their peers’ work and how their attitude appeared in their feedback. Below are two examples of Values and Attitudes rating, one with a score of “2” and the other one with a score of “4”.

- *“I think specific outline is very helpful and make easy to follow the formula and graphs. Formulas and graphs are very clear to understand.”* – Basic Level
- *“I think an important aspect that you did not include in your final answer is that the DTFT of a DT signal must be periodic. Your answer must be "rep-ed" to denote it's periodicity. Otherwise your answer is only correct for $0 \leq \omega \leq 2\pi$. The DTFT of $x[n]$ is $\text{rep}_{2\pi}(2\pi\delta(\omega - \omega_0))$ Overall color coating was very helpful, and the slecture was concise and clear.”* – Advanced Level

Another example is the habit of mind (element) “Computation and Estimation”, which initially focused on the ability to choose an appropriate computation method and recognize when approximations can be made. However, we observed that scenarios with approximations involved were not present in the topics the students were working on. Instead, the topics they were working on required precise and accurate mathematical computations. Hence, we shifted the focus for this element to appropriateness of the computational method used and the mathematical accuracy of the computation.

A final example is the element “Mathematical Rigor”, which was earlier called “Manipulation and Observation”. This is because, while annotating the data, we recognized that in the field of signals and systems theory, mathematical rigor within arguments and explanations played a much more critical role than handling basic mathematical manipulation and observation. In fact, manipulation and observation can be bundled in with computation and estimation.

Future Work

We have developed an evaluation rubric and annotated the material using that rubric. We are now in the process of analyzing the data by computing summary statistics but have not looked at intra-rating reliability nor inter-rating reliability yet. We are currently exploring a method for recording the annotations of the material using a sequence of vectors representing the sequence of habits of mind displayed throughout the material as well as their level of performance. For

example, one part of a slecture might have been tagged with the vector, say (A4,B4,C2,D4), to denote that the student carried out the computations effectively with the necessary rigor and validation, however, the explanation was lacking in terms of communication. With this annotation, we hope to be able to tap into existing statistical analysis methods so as to provide a higher level of analysis. Note that our framework would also apply to analyzing student-created video slectures or even think-alouds.

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