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Work in Progress: Qualitative Content Analysis of Quantitative Literacy in First-Year Engineering Courses

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WIP: Qualitative Content Analysis of Quantitative Literacy in First-Year Engineering Courses

Abstract

This paper is a Work in Progress (WIP). Quantitative Literacy (QL) encompasses many of the competencies professional engineers need. QL is the ability to engage in context-specific quantitative activities for problem-solving by collecting, understanding, processing, interpreting, synthesizing, and displaying numerical information for effective communication. While engineers and engineering educators agree that QL is critical for success as an engineering student and professional, little is known about the expectations of QL for engineering students as they begin their college engineering studies. This WIP aims to share the results of using qualitative content analysis (QCA) to identify how QL appears in first-year engineering courses. These results are the initial step in developing an instrument to measure the QL of engineering students using a Student Model within the evidence-centered designed framework.

Introduction

There is broad agreement that college students need more instruction in QL, as described in [1], [2], and many other studies. Additionally, many existing instruments measure the QL for the general population of collegiate students, like the Heighten QLA [3], Collegiate Learning Assessment+ [4], and the GRE Quantitative Reasoning exam [5]. However, little has been done to examine the specific QL of engineering students. Engineering programs, however, recognize that engineering education needs to go beyond technical competencies and mathematical problem-solving abilities to embrace other professional skills, such as writing and communication [6]–[8]. QL encompasses many competencies professional engineers need, including mathematical and communicative skills.

Prince and Simpson in [9] studied undergraduate engineering students, focusing on the aspects of QL that students used. They examined the graphic processes students used to depict information and then transform it into new knowledge about the environment. They determined that students had problems with the "mathematization of space" in relation to making graphs. Fenner and O'Neill [10] had similar results from a project aimed at improving engineering students' abilities to analyze, interpret and communicate data. Their study found that engineering students in a linear circuits laboratory collected experimental data correctly but frequently failed to synthesize and summarize the findings. Hadley and Oyetunji [11] found that engineering students may possess the mathematical procedural knowledge associated with numeracy but are not necessarily able to employ these skills in specific engineering contexts. While this research explores the QL of engineering students, no current instruments are specifically designed to measure the QL of engineering students.

This work-in-progress paper reports the first phase of a more extensive study that will use the Evidence Centered Design process [12] to develop an instrument to measure the QL of engineering students. The first phase of this study aims to develop an evidence-based Student Model for future assessment instruments to measure engineering students' QL. The Student

Model refers to the specific knowledge, skills, and abilities that are desired targets in the assessment instrument [13]. To obtain the Student Model's evidence, we collected materials from first-year engineering curricula (i.e., learning objectives, homework problems, and assessment questions) from various engineering programs for analysis. In addition, we used Qualitative Content Analysis (QCA) and an *a priori* coding frame developed from a QL framework to answer the research question: *What QL skills and knowledge are expected of first-year engineering students?*

Defining Quantitative Literacy and the QCA Coding Frame

Most of the definitions of QL are not field-specific. We found seven definitions of QL, numeracy, or quantitative reasoning in the literature [2], [14], [15], [16, p. 17], [17]–[19]. In reviewing each definition, a consensus emerged that QL has four components:

1. Skill with numbers and computation.
2. Communication of quantitative information using oral, visual, and written modes.
3. Interpretation and reasoning of quantitative information and data.
4. Ability to apply concepts expressed in 1-3 in particular contexts.

Drawing on the work of Vacher [20] and Wilkins [8], dispositions and beliefs regarding quantitative activities should also be a component of a complete definition of QL. Thus, for this project, we defined QL as:

> *The ability to engage in context-specific quantitative activities for problem-solving and communication by collecting, understanding, processing, interpreting, synthesizing, and displaying numerical information. This definition includes numerical skills, dispositions, and beliefs in quantitative activities.*

Within this definition, the dimensions of QL specified by [8, p. 271] are defined in **Table 1**. These dimensions of QL are also the categories used in the coding frame for the QCA study.

Category Description: The interrelationship…		
Disposition (Dis)	**Beliefs (Bel)**	**Cognition (Cog)**
…among a person's perception of ability, intrinsic motivation, and utility of mathematics.	…among a person's views associated with the nature of mathematics.	…among a person's mathematical content knowledge and reasoning skills.

Table 1: *Category descriptions for the QCA coding frame. The coding framework was developed for the QCA study of first-year engineering course materials using the definition of QL for the project.*

Methodology and Data Collection

QCA [21] and an *a priori* coding frame were used to examine first-year course materials. We collected first-year engineering course materials, i.e., learning objectives, homework problems, and assessment questions, to obtain the evidence for the Student Model. Materials were collected from general introduction to engineering courses designed for students who have not started a specific engineering discipline or concentration offered. Instructors from five institutions, including two large public research institutions, one regional branch campus of a state university, and two small private universities, submitted materials.

The cognition dimension has three sub-dimensions defined in Table 2.

Sub-Category Descriptions for Cognition		
Content (CogC)	**Reasoning (CogR)**	**Communication (CogCom)**
The mathematical content knowledge which undergirds quantitative activities. Four components have been defined in Roohr [22]: numbers and operations, algebra, geometry and measurement, and probability and statistics.	Based on Roohr's [22] definition of problem-solving skills, we define reasoning as skills in interpretation, strategic knowledge and reasoning, modeling, and computation.	The ability to communicate procedural or conceptual quantitative concepts orally, visually, and in writing, using an active inquiry process that includes observation, questioning, and interaction [23].

Table 2: *Cognition Sub-category definitions**.** Sub-category descriptions for the cognition (Cog) category are defined in **Table 1**. The cognition sub-categories were determined using the definition of QL for the project.*

Two researchers analyzed the course materials independently; the first review determined if the task addressed QL. If it did, then it was coded for the QL dimension and subdimension. The coding results were reviewed, and any discrepancies were resolved through discussion to reach consensus and consistency. Assignments that needed more information, e.g., referred to a problem in a textbook or video that we could not access, were not analyzed.

A coding frame based on the definition of QL above was developed to perform the QCA, with category and sub-category definitions in Table 1 and Table 2. Utilizing QCA required that all QL instances be assigned a single code; multiple codes were not assigned to a single QL instance. Indicators used for assigning each category of the coding frame are in Table 3.

Indicators (including tasks)				
Disposition (Dis)	**Beliefs (Bel)**	**Cognition-Content (CogCon)**	**Cognition-Reasoning (CogR)**	**Cognition-Communication (CogCom)**
Students analyze or reflect on their ability or motivation to perform quantitative tasks	Students analyze or reflect on personal values relative to quantitative information, operations, and tasks.	Task requires comprehension of essential knowledge/skill with definitions, equations, basic quantitative operations	Task requires use of quantitative information or operations to make a decision, compare/contrast, build a model, project, plan, etc.	Task requires student write, present, or demonstrate quantitative information or concepts to an external or pseudo audience

Table 3: *Coding indicators used to determine if a student task is disposition, beliefs, cognition-content, cognition-reasoning, or cognition-communication.*

Results and Discussion

To date, the researchers have analyzed 80 distinct assignments and found 125 distinct tasks requiring QL. Of these, all represented the Cognitive dimension, and none fell into the Disposition or Beliefs categories. All sub-dimensions of Cognition were found, with 85.6% of the instances being Reasoning (CogR), 9.6% being Communication (CogCom), and 4.8% being Content (CogCon)

Cognitive Content requires students to understand basic concepts, not to apply them or communicate that information to an audience, such as in these examples:

- The height and diameter of a cylindrical can are measured using a caliper that is accurate to within 0.1 inch. The height is measured to be 5.875 inches, and the diameter is measured to be 2.54 inches. What is the surface area of the can?
- Begin measuring (using calipers) and marking the pump body block to prepare for milling it.

Cognitive Reasoning, the most common type of task, requires content knowledge but also the use of that knowledge to solve a problem, draw a conclusion, build a model, or write a program. This category included a wide range of tasks from basic problem-solving given a law or formula to multi-stepped real-world applications. Below are examples of the types of tasks in this category:

- Use Kirchoff's Voltage Law (KVL) to determine the voltage drop (in volts) across each resistor for which voltage is not already given.
- Write a flowchart (in Visio) for a program that would cause the LED on your Arduino (pin 13 has an integrated LED – try it out!) to blink faster if more light is received by the photoresistor and more slowly if less light is received. Ensure the flowchart is only one page and submit it as a PDF.
- Develop a Python program named HW11p1_Task2_UCusername.py to accomplish the logic depicted in the flow diagram on the next page. Be sure to include good input and output statements using Pythons input and print functions, respectively.

Cognitive Communication incorporates content and, in many cases, both content and reasoning. The audiences specified ranged from a family member without prior knowledge, to the general public, to more knowledgeable clients or experts. We coded a task as communication only if an audience was specified or implied outside the instructor. The communication deliverables we found included traditional written texts, oral presentations, and videos. Frequently the more complex documents came at the end of an extensive project. Below are some examples of the range of communication tasks we found:

- You are required to test your trebuchet and report quantitative results in your newspaper article (this means numbers!).
- The paper must include a minimum of four references with at least two that are not sourced from a website. It must also include at three figures, tables, and/or equations total. Graphics are frequently the best way to convey technical information.
- Usability Testing is a chance for you to present your project to your client and their audience so it can be tested for use. Your project should be complete at this point. You should have refined your presentation since the Practice Demonstration, but you may still identify areas that you need to work on and refine before the Student Showcase. This is also your client's opportunity to evaluate your project.

Some challenges in the coding included the format of assignments. For example, some instructors scaffolded assignments to distribute a significant project into multiple smaller assignments and discrete tasks. In contrast, others included more general guidelines and assignments. In addition, some assignments referenced textbooks, videos, software programs, or other resources we could not access. Hence, we were not able to code many of these assignments.

Conclusions and Future Work

In this work-in-progress paper, we present the results of the first phase of a more extensive study that uses the Evidence Centered Design process [12] to develop an instrument to measure the QL of engineering students. Using the coding frame developed from the QL definition, we analyzed QL tasks from first-year introduction to general engineering courses. The results suggest that QL tasks in first-year engineering courses require reasoning skills such as interpretation, modeling, and computation, with many fewer tasks solely focused on content knowledge. Cognitive Communication tasks, which assume content knowledge and, in most cases, reasoning, were also represented with assignments such as reporting results in a newspaper article or presenting to clients.

QL Dispositions and Beliefs were not present in the course materials we analyzed. These courses are often students' first engineering course and thus is where students start forming their identity as engineers. Focusing solely on QL Cognition may reinforce the idea that engineering is purely technical and that social aspects are 'outside' of engineering (see, for example, [24]). Incorporating QL Dispositions and Beliefs into first-year engineering courses could help students to see engineering as a sociotechnical field and incorporate sociotechnical aspects into their emerging identities as engineers.

Our work-in-progress results contribute to our understanding of the QL activities expected of first-year engineering students. We also provide a framework for considering the full range of QL needed in engineering and how they might be reflected in first-year curricula. Building on these results, we will develop surveys of engineering instructors and conduct focus group interviews with engineering students. The results from these studies will lay the foundation for our larger goal of using the Student Model to create an evidence-based instrument to measure the QL of engineering students.

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