Engineering Undergrads Effectively Communicate Their Experience

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Investigating the Role of Engineering Problem Typology in Helping Engineering Undergrads Effectively Communicate Their Experience

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Abstract: Programs across the country encourage and facilitate experiential learning through a variety of mechanisms that help students transition from theory to practice. For such experiences to be truly meaningful to professional formation, students must also be capable of internalizing and effectively communicating insights from these experiences later. We conjecture that providing an engineering problem typology and reflection framework as context for student experiences will improve students' ability to internalize and communicate the professional relevance of those experiences. In this NSF PFE:RIEF sponsored research project we are using mixed-methods to collect pre / post data on students' engineering epistemological beliefs, written reflections that consider the professional aspects of engineering projects, mock interviews, and group problem-solving discussions. Between the pre / post data collection, an intervention takes place; students participate in a professionally relevant project experience (engineering intramural) with accompanying intermediate reflection sessions where engineering problem typology is introduced. In this paper, we present findings from analysis of the pre / post problem-solving discussions for two student pairs. This analysis is toward answering one of the motivating research questions: What effect, if any, does exposure to engineering problem typology have on students' approach to problem solving?

1.0 Introduction

The origins of this research lie in engaging students in the engineering intramurals program at an R1 university in the Midwest. The essence of the program is to bring together engineering students, from sophomore through senior year, often from multiple departments, to solve engineering relevant problems as an extracurricular engagement. The problems given to students are sourced from industry and community groups, open design communities, technical competitions, and even individual students. The program is born of feedback from industry and alumni to provide more opportunities for students to engage in engineering work outside the classroom.

The program has been in place for five years and continues to grow and evolve, but the most critical challenge of the program remains. Namely, we have observed that many students, when given an open and ill-defined problem, struggle with knowing where to begin. Exacerbating this problem is the fact that the projects take place outside of the classroom, leaving the students in a place where not even the domain content and context of a class can serve as a basis for starting. The excerpt below provides an example of the types of project descriptions given to students. The company name has been redacted.

> The used oil recovery process has been in existence for over 30 years at XXX. The process was originally conceived to convert used oil returning from XXX lubricant customers, into heating fuel for internal use in our terminal boilers. As the price of fuels increased through

> the years, a demand for the recovered oil was created and sold externally to customer as heating fuel for steel manufacturing, asphalt production, small industrial heaters and feed stock for lubricant re-refineries. The XXX recovery process collects two types of used oil streams from its customers. The first stream is considered crank case oil and the other is industrial oil. The majority of the crank case oil come from the automotive industry and has fewer contaminates. Whereas, the industrial oil has a high level of solid particles and liquid contamination. Currently, all of the products collected are processed together through the recovery process by basic filtration and decantation. The final product is a refined fuel oil that will meet the environmental regulatory specifications to be burning in heaters.
>
> The objective of this project would be to evaluate the current process to determine if there is a more efficient method to process the used oil into the refined fuel oil market, and is there economic justification to install a cogen facility at the site.
>
> The project should develop an engineering analysis of future upgrades to the existing process with the economic analysis of installing a cogeneration facility to utilize the processed used oil as an energy source.

This problem was given to a team of students that included four undergraduate students from chemical, mechanical, and industrial engineering, as well as a graduate student from chemical engineering. Even after an initial kickoff meeting at the industry facility, and follow up interviews with plant operators, the team struggled to define, scope, and strategize about how they might go about the process of developing a solution to this problem. Despite their classroom successes, they did not know how to bring the knowledge developed through those successes to this problem.

Considering the problem description above as representative of the types of problems that students might encounter in internships, we believe it is important for students to practice solving these problems in the academic setting. In light of the student struggles with this problem and others like it, the anecdotal feedback of industry partners that "students are not prepared for engineering work" resonates. In this work, we consider how students struggle to orient themselves to open-ended or "ill-structured" problems and to put themselves on a trajectory that will meaningfully progress toward a defensible solution. This reality is well-aligned with the work of David Jonassen [1,2] and his assessment that engineering students are often not prepared for problems common in practice because they are not adequately exposed to the different types of problems, nor the varied technical and non-technical aspects of engineering problem solving, during their education.

Based on first hand observation, the work of Jonassen [1–3] and other researchers investigating the nature of engineering work [4] and novice versus expert problem solving [5], we believe it is critical that students be given both opportunities to practice solving ill-structured problems *and* a reflective framework and language representing the different types of problems encountered by engineers to help them in unpacking and translating those experiences to other professional contexts.

To that end, this paper presents early findings of our work on explicating and talking to students about engineering problem typology as a framework for thinking about their engineering problem solving experiences. The fundamental question of interest here:

What effect, if any, does exposure to engineering problem typology have on students' approach to problem solving?

In the next section, a brief literature review on engineering problem solving as encountered by students in academia is presented. In Section 3.0 the research methodology is detailed, while Section 4.0 reports findings of an initial analysis of problem solving by two student pairs. The paper concludes with some general discussion as it relates to potential educational implications and continuation of this research.

2.0 Literature Review

What does good problem solving look like? Researchers have argued for decades for one position or another [1,6–11]. We do not seek to argue definitively for any particular perspective. However, we do intend on challenging the notion from literature and from our own data that problem solving is a "skill" that can be directly taught to students to improve their efficiency or accuracy at problem solving, especially in open, ill-structured problem scenarios. Through this research, we seek to add to prior work that improves our knowledge about students' problem solving.

We critique the practice of teaching problem solving on the basis of two arguments: one rational, and one sociocultural. First, if we were to take the rational-deducto model of arguments and their representation and distill it to a single applied process to all problems, it would violate many accepted tenets about differences in disciplinary knowledge, knowledge construction, and facets of argumentation [12,13]. An example is the critique of the "scientific method" as a singular distillation for teaching science, which has been challenged by philosophers and science education researchers as an over simplification that leaves out some of the most important aspects of science as a dynamic process of knowledge building [14,15]. In fact, it can be argued that any problem which can be solved through a single generic process, is not really a problem at all. It is practice for computation, and formulaic application, but it is not a "problem" per se. Jonassen differentiated static, superficial, and computation-based problem solving (story-problems) from what he described as "ill-structured" problems common in engineering work [1,2]. Jonassen understood nuances and articulated a framework of problem typology [3] through which disciplinarity could be expressed and considered, including engineering. He argued further that problem typologies are defined by such characteristics as: complexity, structuredness, familiarity, range of domain knowledge, structural attributes of knowledge domains, epistemological commitments, degrees of affect, and other embedded ontological and epistemological features [3].

Socioculturally speaking, rational deductive models do not account for a number of nuances we have encountered when observing students attempting to solve "ill-structured" problems in pairs or small groups. There are all kinds of "messiness" in analyzing such contexts that must be considered when trying to fix or dislodge students' wrong or stuck thinking. Some researchers [16,17] argue that the science embedded in the arguments and solutions proposed in social settings is fraught with agendas of participants that make it difficult to determine what is being learned and thought, versus what is being heard or communicated to an observer. As opposed to learning specific strategies to be applied generically, with a prescribed order, Pintrich has even differentiated good problem solvers from poor ones by their awareness of which strategies they have used and their knowledge of where they are in their thinking relative to the final solution [18].

Such criticisms have led some to back away from the "teaching problem solving" approach emerging from the 1970's [19–21]. In fact, Schön went as far to argue that there is no such thing as problem solving in the engineering profession as "no engineer has ever been given a problem to solve." Schön's contention is the value of engineers' work is not found in their problem solving abilities. Rather, the essential facet of engineers' work is found in their "problem setting." Engineers make sense of a given messy world from which many factors need to be considered, organized, and framed before an actual "problem" appears. Problem setting is the process by which experts go about organizing the world into a problem which can be then subsequently solved. In critiquing engineering instruction, Schön observed engineering professors "defining problems" [21], and the majority of the engineering academic experience being focused problem solving, resulting in students enduring long sets of pre-defined problems that fail to prepare them professionally. Consistent with traditional engineering teaching and learning strategies [22–24], their undergraduate experiences consisted of fifty-minute non-interactive lectures, quizzes, exams, and lists of homework problems to solve. The established tradition of engineering instruction is more than 80% lecture as demonstrated in study after study.

Student participation in engineering classrooms is limited and highly structured. The student experience is largely to solve problems in a methodical fashion, and accessing knowledge through sequential presentation of textbook material. Though laboratory assignments are common in undergraduate engineering, historically, the majority of the student experience has consisted of strictly following prescribed steps to arrive at a predetermined conclusion. In their seminal work with science, engineering, and math undergraduates Seymour and Hewitt found the majority of engineering teaching to be a deductive transmission of facts, controlled by the teacher, and leaving little room for students to understand how engineering is performed [26]. The authors criticized engineering education's practice of providing ready-made problems which have been simplified by the removal of unnecessary details. This sterile, problem-solving focus results in some students never developing a deeper understanding of true engineering. As engineers have testified, the majority of their experiences as students in engineering courses involved sitting in rows of desks, facing the front of the room, and copying notes written on a chalk-board by an expert engineering faculty member who also had received no preparation in educational theory [25]. Students often engage engineering with little explanation as to the purpose, or benefit of, completing academic tasks; students, if they are to be successful, simply do what is expected [24].

Pointing to a packed and overly prescriptive curriculum, Sheppard et al argued "…opportunities for the kind of deep learning and understanding that allows students to become, over time, sophisticated, independent learners are lost in the effort to teach everything" [27]. The authors explicated "… undergraduate engineering education in the United States is holding on to an approach to problem solving and knowledge acquisition that is consistent with practice that the profession has left behind." The authors identified a remarkable consistency across engineering programs in the United States, which consists of four curricular components described as linear blocks that are more isolated than interrelated. These blocks, which include design, analysis, ethics, and laboratory, serve to fragment rather than integrate the curriculum and therefore the learning experience and preparation of engineering students. The curricula typically include many levels of pre-requisites and require students fully understand theory before being permitted to practice application. Rather than necessarily informing each other, these insular blocks, typically taught by different entities within the university structure, serve as individual appendages between which the student must somehow identify connections. The authors argued "… the workload of science and math courses can be so overwhelming that students end up losing interest in the profession for which they are being prepared" [27].

The ongoing research reported here is fundamentally motivated to provide students with experiences that overcome some of the limitations associated with the current undergraduate engineering curriculum and instructional model. Through an extracurricular intervention derived from Jonassen's problem typology [1,3], we seek to provide students experience working on open, ill-structured problems consistent with the problems encountered in practice. Important to the work is the explication of the problem typology introduced by Jonassen, wherein he describes 11 different problem categories [3]. We consider a subset of these problem types as a basis for introducing students to an "engineering problem typology," which is described in the next section.

3.0 Methodology

Before describing the specifics of the data collection and analysis protocol, it is necessary to explain the engineering intramural program from which we draw research participants. As noted in Section 1, the program brings together students from multiple departments to solve problems sourced from industry, community groups, and academic competitions. Students are selected based on review of a resume and a cover letter. As an educational program, we seek to balance teams by matching students that have some relevant background or technical skills (e.g. relevant software experience) with students who have no other project experience, rather than selecting students solely on who is likely to be most successful. Each team is assigned a graduate student as a project manager (or the program director takes this role in some instances). The projects are extracurricular, and students spend approximately five hours per week over the course of 12 weeks on the project. An important feature of the program is that the projects do not occur within the context of a class, so there is no implied domain knowledge or guidance on "what to do" and "when to do it". Given the informal setting and the nature of the projects, we consider the experience as "internship-like."

Students who participate on intramural projects have the option of pursuing a digital badge, which is managed out of the microcredential office at the university level. To earn the badge, students 1) participate in three reflection sessions; 2) submit a summative reflection that asks questions related to the professional competencies and their role in their project; 3) complete a video recorded mock interview in which they answer 4-5 behavior based interview questions; and 4) submit a reflection in which they review and assess their mock interview performance.

It is during the reflection sessions that students are introduced to engineering problem typology. Through discussion, students consider the idea that engineers solve different types of problems and that the most common problems in engineering include: design, engineering case analysis, selection, planning, troubleshooting, and diagnose-and-solve. Figure 1 provides examples of how these problem types are explicated and presented. In this work the combination of the intramural project and the reflection sessions represent the "intervention".

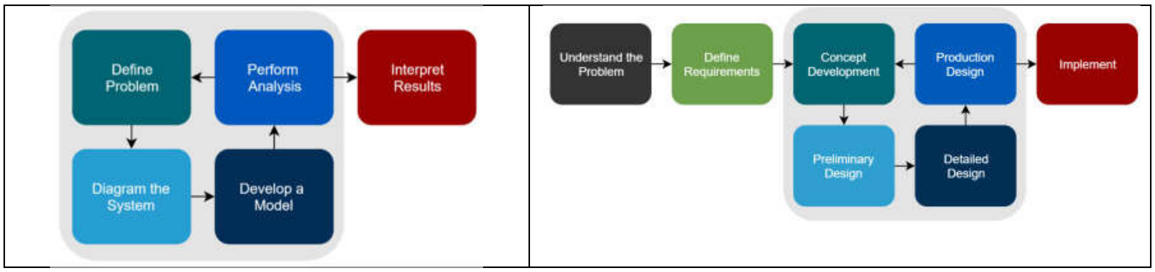

Figure 1. Problem typology diagrams for engineering case analysis (left) and design (right)

3.1 Data Collection

Our research examines how undergraduate engineers approach ill-structured problems. We began by studying how undergraduates' routines and strategies they have learned to employ in their undergraduate education shape their interpretation of ill-structured problems. We further explore to what degree this collection of approaches can be impacted by the introduction and use of a problem typology framework.

In order to gain access to student problem solving strategies we posed an ill-structured problem prior to any relevant instruction or discussion of engineering problem typologies (pre-PT). Students were brought together in groups of two or three, and asked to begin to solve the real-world scenario. Two problems were given – an engineering case analysis and a design problem – and the pair were asked to work toward solving each problem for 15 minutes. After artificially truncating their problem solving session, we conducted a 30 minute debrief interview regarding their recent process, their solution, prior instruction, and their prior training and coursework in an undergraduate engineering major. The problem statement for the engineering case analysis is provided in Appendix 1 and its development was done with consideration of the problem characteristics described by Jonassen as reported in [28]. We limit our consideration in this paper to just the engineering case analysis problem. At the end of the semester, we called each pair back for a problem solving session (post-PT) similar to the initial session. Both the pre-PT and post-PT problem solving discussions (PSD) were video recorded for subsequent analysis.

3.2 Data Analysis

All problem solving sessions and debrief interviews were transcribed verbatim for future coding. Our initial methodological approach for this study employed phenomenology in which we selected one pair of students and investigated their strategies and interpretations of the ill-structured problem. This investigation informed an open coding process [29]. This initial coding process was done collectively by two educational researchers and two engineering education researchers. As a team we noted *units of meaning* in phrases like "identifying variables" and "formula adoption" from their pre- and post- problem solving sessions (see Meaning List 1 in Appendix 2) and considered those units of meaning in the context of the problem typology diagrams. It is important to note that many of these interactions have been observed and discussed among practitioners, engineering instructors, and even some engineering education researchers. This is not the first time behaviors such as applying formulas, guessing, modeling and others have been observed and categorized as "higher-level" or "lower-level" thinking or problem solving strategies. Under such categorizations, researchers typically connect pedagogical approaches to improve undergraduates problem solving success [6,10,11,30].

In contrast, we documented speaking, thinking and acting "as they were observed," checking biases, reserving judgment, and reserving common "fixes" for their thinking patterns they might encounter from other engineers in the program. We then identified occurrences of codes only when we could code their thinking as it relates to solving the problem. This second round of axial coding intentionally compared students' collaborative solutions with that of implied steps of the problem typology frameworks. Coding schemes were further refined with observable words, phrases, and interactions, resulting in the coding scheme for engineering case analysis (see Appendix 3). This allowed us to develop an exemplary case or evidence proof for what a group of students might speak, think, and act like as they solve ill-structured problems.

After identifying open codes and subsequent axial codes, we employed more ethnographic methods for identifying how students interpreted the problem solving tasks. Adopting our notions of problem solving expertise developed from our research coding sessions, we explored how two different pairs of engineering students approached the pre-PT ill-structured problems. We took these coded behaviors as an indication of what students believe about good problem solving practices through their experience in undergraduate engineering. We are not speculating about what effective problem solving is or what is a desired way of solving problems. Rather, we are analyzing our data to illustrate students' observed strategies prior to their exposure to problem typology. After seeking meaning behind their actions, we identified how some of these interactions (e.g., guessing, assumptions, identification of variables, applying models, collecting facts) fall within or outside of the given problem. We then trained all of our research team (four researchers and three graduate students) to identify these codes until we obtained at least 75% agreement in matching video data coding. This coding scheme was utilized to locate each pair of undergraduate engineers' thinking on a representative typology framework. Findings from applying this coding scheme to two student pairs is described in the next section.

4.0 Findings

We consider findings for two student pairs who participated in the research thus far. Among the ten cases of students who have participated in the research, these two cases stand out as possible extremes on a continuum of change that might be expected among students from pre-PT to post-PT. These findings are presented as an initial comparative analysis.

Figures 2-6 show the results of our analysis for the two cases – Ron and Jeff, and Madison and Sam. The purpose of these charts it to quantify and visualize the nature of the problem solving discussion (PSD) among the students, providing a basis for comparison from pre-/post-PT within groups and a more generalized comparison between the two cases. Figure 2 presents a frequency chart representing the number of exchanges between the student pairs and the location of those engages within the engineering case analysis (ECA) process. The chart shows both pre- and post-PSD for Ron and Jeff (red) and Madison and Sam (blue). Figures 3-6 show the progression of problem solving by plotting ECA process stage versus time, similar to work of Atman [31].

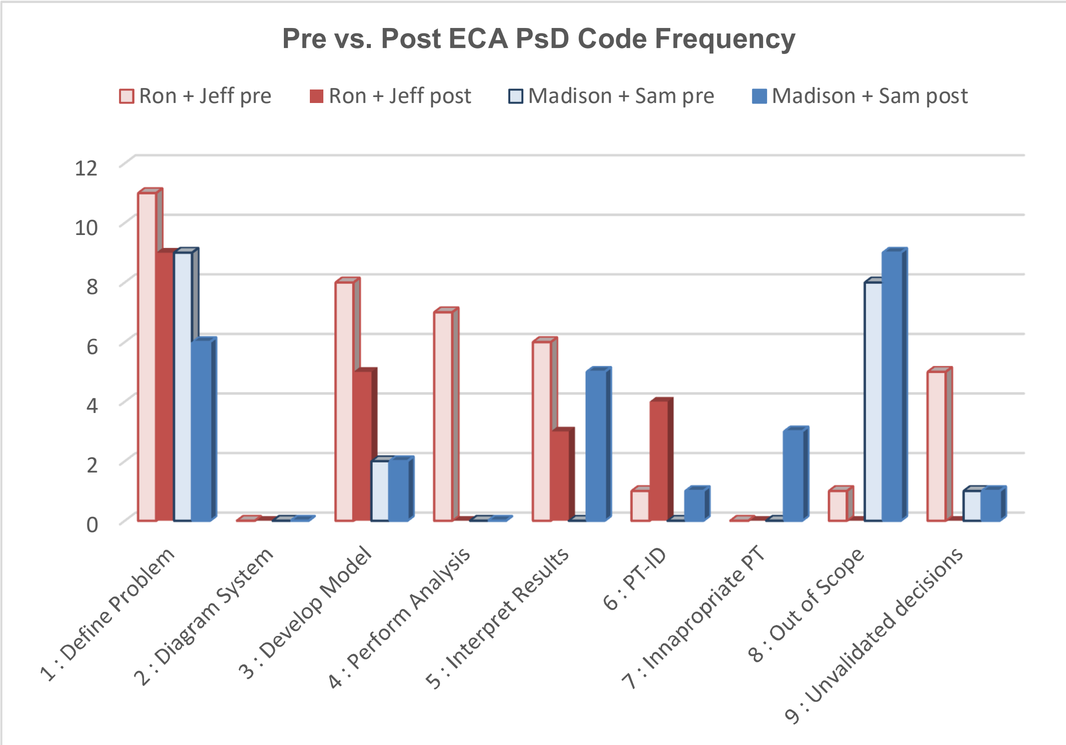

Figure 2. Frequency of engineering case analysis PsD related codes

Figure 2 also shows additional codes that emerged in the course of coding the students' discussions; codes that lie outside of the ECA typology framework and coding schema of Appendix 3. These codes include "innappropriate problem typology" (Innapropriate PT), "out of scope", and "unvalidated decisions". Each of these codes is defined and justified in the context of the student discussions summarized below.

4.1 Ron and Jeff Pre- / Post-PT ECA PSD Summary

Figure 2 shows that Ron and Jeff have a similar frequency of discussion related to defining the problem and diagramming the system (no system diagramming is also notable) in both the pre- and post-PT PSD sessions. The key differences from pre to post lie in the discussion frequency related to model development, performing analysis, and interpreting results. Figure 2 also shows that Ron and Jeff have more unvalidated decisions in their pre-PT discussion (five) as compared with the post-PT discussion (none). Ron and Jeff also have more frequent points of discussion about the type of problem (PT-ID) in the post session as compared with the pre session as shown in Figure 2.

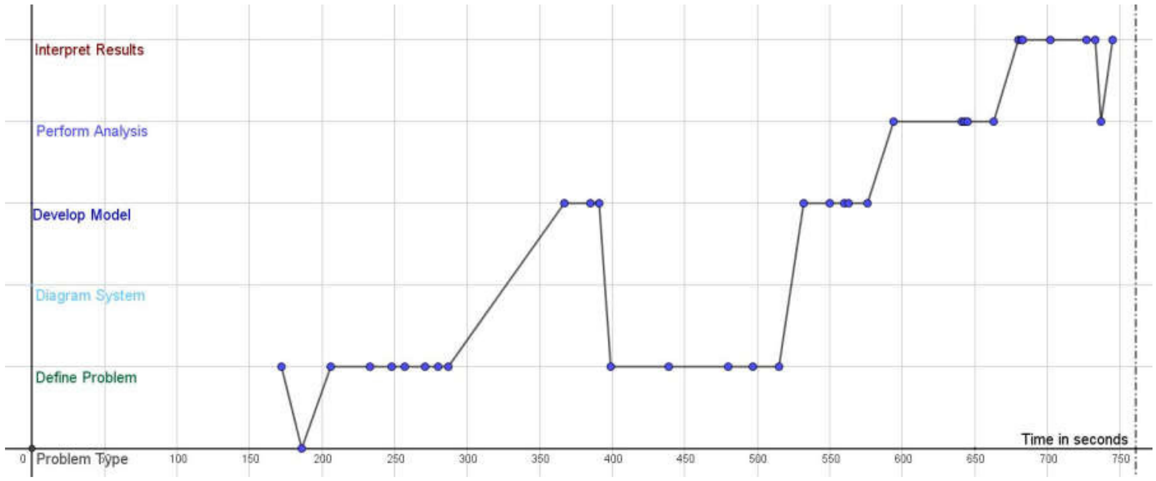

Figure 3. Ron + Jeff pre-PT Engineering Case Analysis PSD

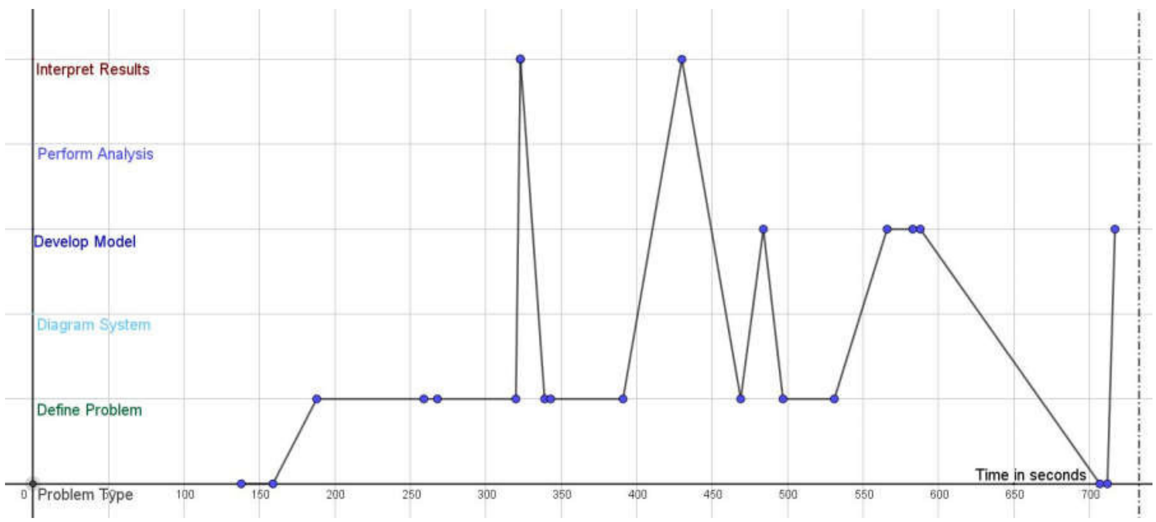

Figure 4. Ron + Jeff post-PT Engineering Case Analysis PSD

Figures 3 and 4 show how the nature of the PSD varied from pre to post for Ron and Jeff by plotting the stage of the analysis process against time in seconds. In the pre session (Figure 3), Ron and Jeff progress through the ECA stages is relatively linear fashion, with some iteration between defining the problem and developing the model, before ultimately moving through perform analysis, and concluding with interpret results.

In the post PSD (Figure 4) the nature of the discussion is less linear, with iteration between defining the problem and interpreting results occupying most of the discussion. The discussion terminates with considerations of model development and additional discussion of problem type.

4.2 Madison and Sam Pre- / Post-PT ECA PSD Comparison

Figure 2 shows that Madison and Sam have less frequent points of discussion related to defining the problem in the post relative to the pre session. There are few points of discussion related to model development in pre and post, and no discussion related to diagramming the system or performing analysis.

Figure 2 also shows that Sam and Madison have frequent points of discussion that relate to inappropriate problem type in the post session. Additionally, in both the pre and post sessions there are significant points of discussion that are not in the scope of the problem statement.

Figures 5 and 6 show the progression of the PsD discussions for pre and post sessions, respectively. In the pre session (Figure 5), Sam and Madison spend a significant amount of time in the stage of defining the problem. There is some iteration between developing a model and defining the problem but the discussion eventually devolves to consideration of issues that are "out of scope" (gray regions) in the context of the problem statement.

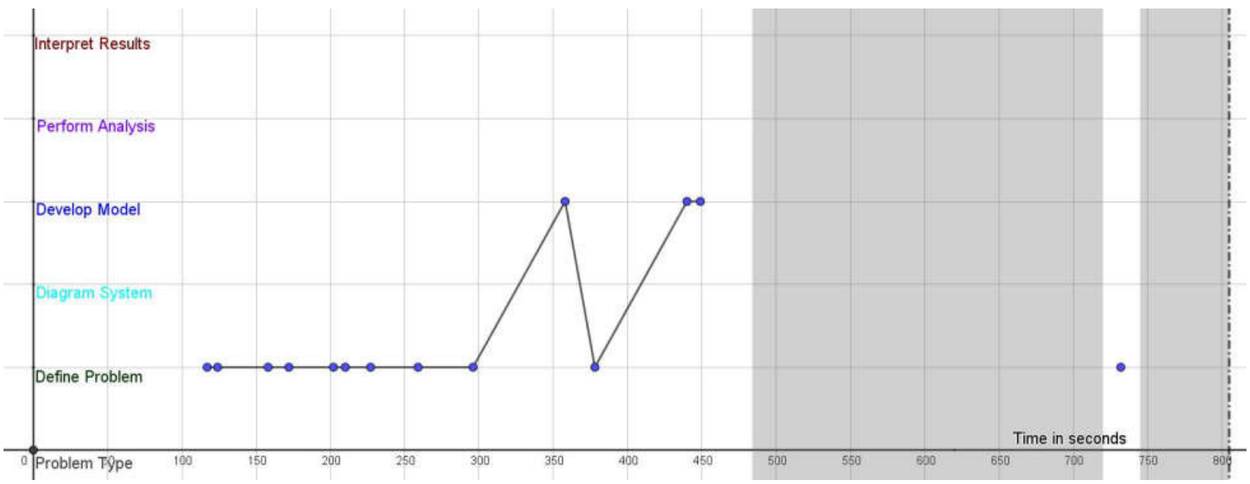

Figure 5. Madison + Sam pre-PT Engineering Case Analysis PSD

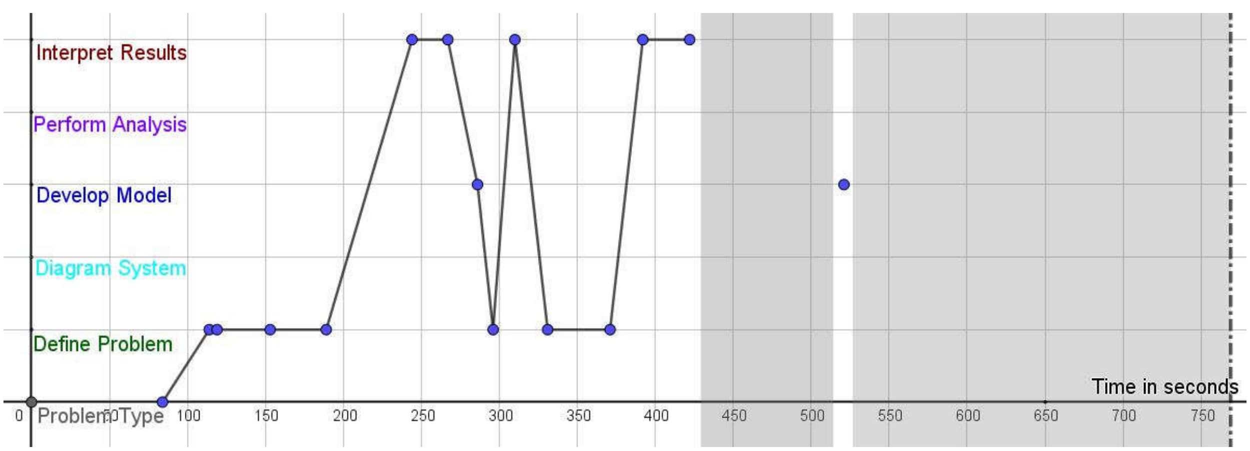

Figure 6. Madison + Sam post-PT Engineering Case Analysis PSD

In the post session (Figure 6) Madison and Sam spend some time in defining the problem, but it is about half the time spent compared to the pre session. The discussion progression also shows some iteration that moves between defining the problem and considering the eventual interpretation of results. The discussion primarily bounces between these two stages, with little time spent in any other stage. Like the pre session, the discussion ultimately devolves to considering issues that are “out of scope” in the context of the problem statement.

4.3 Qualitative Findings of ECA Problem Solving Discussions

To contextualize Figures 2-6, it is important to consider specific aspects of the discussion and artifacts generated from each student pair. Both Ron and Jeff, as well as Madison and Sam, worked on intramural projects categorized as design problems, though they had different problems in different semesters. During the course of their design intramurals, both pairs participated in three problem typology reflection sessions, which includes discussion of both design and engineering case analysis typologies, among others.

Ron and Jeff pre/post ECA PSD Qualitative Comparison

Overall, Ron and Jeff seem motivated by a need to produce a calculation in the pre session. Their discussion begins with a reference to numbers available in the problem statement; Jeff: “So we need at least it looks like four liters a day per person to be safe.” Their discussion continues in the mode of defining the problem with identification of potentially important parameters, like population, and the amount of water that can be held in the truck, but they seem “stuck” as marked by a lot of back and forth discussion necessary to progress, as shown in Figure 3.

As the pre discussion progresses, it does so along a linear trajectory, moving next to model development. Model development is primarily focused on making assumptions about unknown parameters in the interest of making a calculation. The exchange below shows how Ron and Jeff came to an “unvalidated decision” that they should assume 10 liters a day per person. Similar exchanges led to unvalidated decisions about population (100,000) and costs of bottled water ($0.25 per liter). These values were not researched, validated, or noted as uncertain parameters for future validation.

> Jeff: I guess we would really need to have more than four liters because of drinking and cooking, this is just intake for...
>
> Ron: All from food only. Okay.
>
> Jeff: Yeah, so we probably wanna bump that to like double, I'd say eight, 10 maybe.
>
> Ron: I'd say 10, probably...10 liters a day per person.

Through their discussion Ron and Jeff eventually settled on calculating the cost of providing bottled water in one of these scenarios (performing analysis). That was not a specific objective that they agreed to, rather, it naturally emerged from their discussion without contemplating if it was appropriate. Through calculation, they determine that it will cost $250,000 in water bottles per day if water bottles were used to respond to a water crisis in a city with 100,000 individuals. Their first consideration of interpreting results is in the context of this calculation; Jeff: “That's kind of like our, stay under that number.”

The post discussion is decidedly not motivated by a need to provide a calculation. The discussion begins by first agreeing as to what type of problem is being solved; Ron: "All right, so what type of problem do you think this will be? I think it would probably be an engineering analysis." They do not appear to be "stuck" in any particular stages but rather discuss important elements of defining the problem, related to objectives and parameters. They also move between defining the problem and interpreting results as a way of contextualizing and validating their thinking about the problem.

> Ron: I'm just writing down something. Some things we should consider like how many people are affected? How much water is needed?
>
> Jeff: Maybe we should take a look at the environmental effects of all the bottles being thrown out.
>
> Ron: And you can probably conduct like a decision matrix between like the actual technologies. They have like the same filtration and all those things.

Unlike the pre, where breaks in discussion reflect frustration and a sense of not knowing what to do, the post PSD breaks in discussion were spent documenting their ideas from their exchanges. The post discussion is not about getting to a single calculated value; in fact, there is no time spent calculating (performing analysis). References to uncertain numeric values are reframed in terms of a need for considering the uncertainty of actual water needs as part of a discussion about developing a model.

> Jeff: I probably want to take like the population of the city and multiply by adequate fluid needs and then maybe by like a factor in the, it's not a factor safety but like a factor of you know that...
>
> Ron: Yeah cause that only, the graph only is for...
>
> Jeff: If you have like twice as much or three times as much as required for a person.
>
> Ron: Yeah. These are like fluid intake. That's only like drinking only. We also need to consider like cooking, showering and like, cleaning and stuff...

In the post, there are no unquestioned decisions to enable a calculation. Instead, model development (assumptions) and calculation are referenced as a future task; Ron: "These are things that like go in the model that we could set up." Ron and Jeff also recognize that other problem typologies might be important to consider in terms of relevant knowledge and information generated through those problem solving processes. In this case, Jeff notes that "there's a big element of planning here too" and Ron concludes "that'd probably be like the main thing for like, our actual analysis is just like coming up with deciding like what, like how to actually carry all of this out."

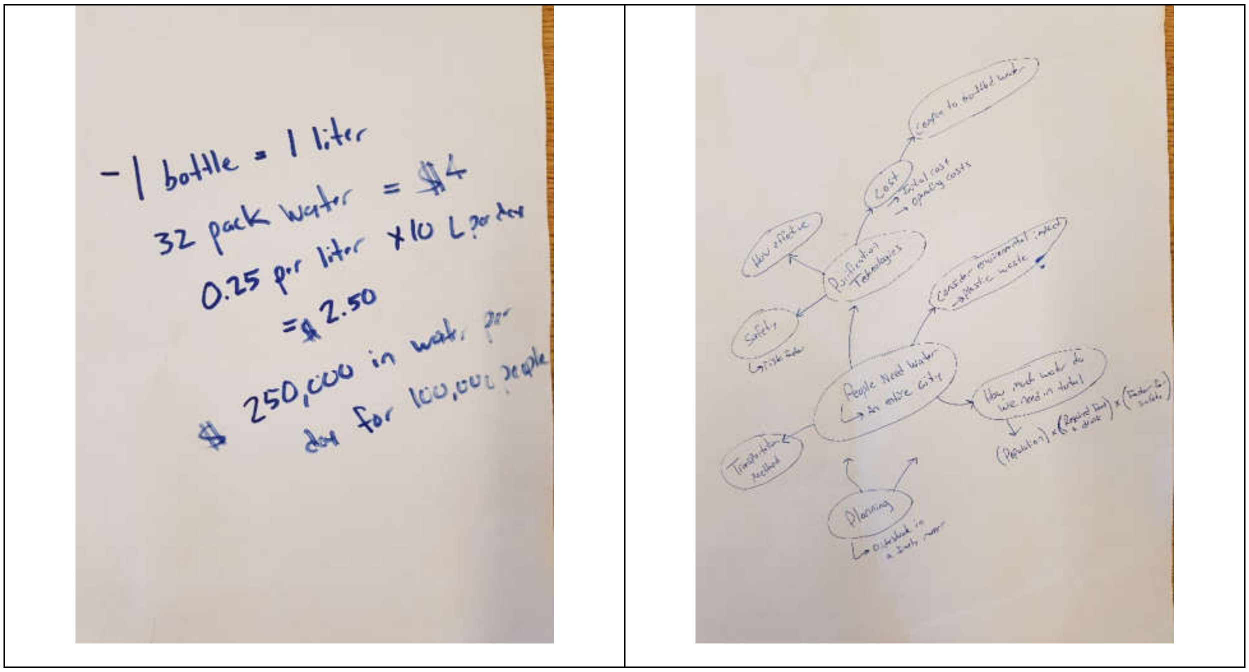

Figure 7. Jeff's pre (left) and post (right) ECA PSD artifacts

The pre and post ECA discussion between Ron and Jeff are markedly different in terms of how they spend their time. The pre and post "diagrams" from Jeff best encapsulate this difference (Figure 7). In summary, the pre-PT discussion seems consistent with much of the engineering education experience to mathematize and calculate an answer. Jeff's pre session artifact is a calculation and his attempt to document only started in the final three minutes of the discussion. The post-PT discussion is more concerned with understanding the problem before moving ahead and the diagram appears as a concept map that attempts to represent the problem in terms of a fundamental objective and parameters to be considered in meeting that objective.

Madison and Sam pre/post ECA PSD Qualitative Comparison

In the pre session, Sam and Madison spend a significant amount of time working to define the problem. Eventually, they progress their discussion to elements of model development, but they focus modeling on data acquisition aspects. Specifically, they decide (unvalidated) that they will build a platform to test and determine if the concept is feasible; Madison: "Well so from this point then I think that we should build one platform. If we have done the research thus far, build one platform in the smallest like, city that they're focusing on because that's where you'd see like the most of the goals for whatever you implement."

Once this decision is made, the discussion appears to hit a point where they do not know how to progress in ways that are relevant in the context of the problem statement. The discussion starts to consider ideas for solving the fundamental problem – acute water infrastructure failure – that do not relate to evaluating the filtration concept proposed in the problem statement. An example of such "out of scope" discussion is shown below. Discussion like this continues until the end, with several irrelevant aspects of the problem being considered, like installation in existing facilities, and a need to finding sources of funding.

> Sam: Yeah. There's also, I feel like filtration is a need but like also like, how these people would like, obtain water once it's like, filtered there.
>
> Madison: That's a good point.
>
> Sam: Because like you know, we can, we can like make all, we want to filter their water but like how is it going to be delivered to their homes?

The post discussion for Sam and Madison is remarkably similar to the pre in its overall trajectory. They start with defining the problem, though their discussion is much shorter because they simply recall their general conversation from 12 weeks earlier in the pre session. They once again progress to a point where they decide that the path forward will be to implement a small system; Sam: "Well, not necessarily prototype, I mean prototype in this case is like just the small population implementation." Their discussion again enters an extended period of "out of scope" considerations until the discussion is ended by the researcher.

There are a few differences between pre and post PSD for Sam and Madison. First, they transition between defining the problem and interpreting results several times in the post discussion; there was no evidence of considering interpreting results in their pre session.

Second, they show evidence that they explicitly categorize the problem as an engineering case analysis (PT-ID in Figure A); Sam: "…it says case analysis. And so there's already systems in place that we need to figure out which is the best." However, while this suggests that there is uptake of problem typology and seeing engineering problems as differing in important ways, it is also evident from their discussion that their understanding is superficial. Madison and Sam regularly use terminology associated with design problem solving, like requirements, customer requirements, and engineering requirements, as part of their discussion. They seem to be confounding problem types in the post discussion (Inappropriate PT in Figure 2). The statements below provide evidence of this confounding.

> Madison: So from this point then we'd have to, I mean this could, these two [grouping research and requirements on the paper], are kind of interchangeable I guess, but we would have to define like our requirements, whether we're, whether they have more other than like this or if we have to make our own way.
>
> Sam: Yeah, like a decision matrix, like, our purification technologies vs requirements.
>
> ======
>
> Sam: Well, not necessarily prototype, I mean prototype in this case is like just the small population implementation.
>
> =====
>
> Madison: So we'll just say engineer requirements because that's like where you said values are. Um, and then like customer requirements, so that kind of falls under cost.

Overall, Madison and Sam do not demonstrate any significant difference between pre- and post-PT PSD sessions in terms of how they frame and expect to solve the problem. The artifacts from their PSD sessions (Figure 8) provide visual evidence of this assessment. While the post artifact shows some evidence of adoption of problem typology as a reference for thinking about problems ("case analysis" is the title in the post artifact) there is also evidence of the confounding of problem typology specifics.

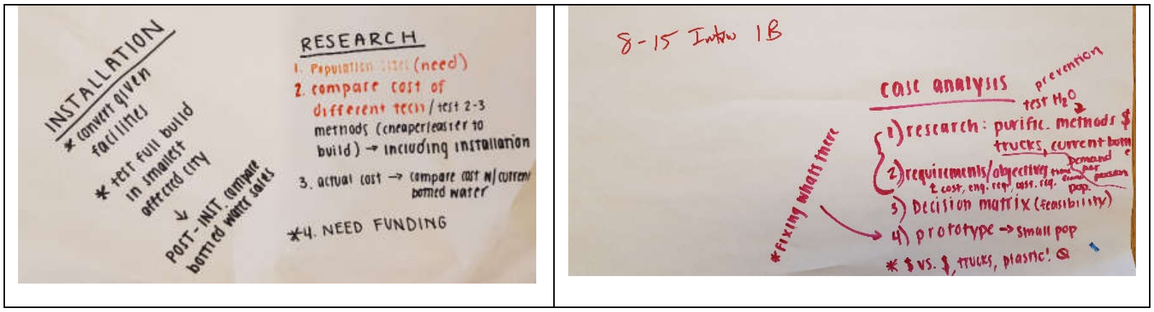

Figure 8. Madison and Sam pre (left) and post (right) ECA PsD artifacts

Between Pair PSD Qualitative Comparison

When comparing Ron and Jeff with Madison and Sam, there are two characteristics common to their respective pre/post problem discussions. First, for both pairs the nature of the discussion related to defining the problem, whether pre- or post-PT, is toward orienting themselves to the problem. This takes form in a discussion that tends toward posing questions about possible parameters or metrics, rather than statements of how they should define the problem. This type of behavior is expected given the open nature of the problem and the students' lack of familiarity with specifics of the problem domain. This inquiry-based approach to the problem may be more beneficial than one that makes simplifications through "unvalidated decisions" for the sake of moving forward.

Second, in the post PSD sessions, both pairs started discussion by explicitly, and correctly, stating the problem type with evidence of agreement among the problem solvers. Only Ron made explicit reference to a problem type in the pre discussion, but the discussion quickly moved on without any confirmation from Jeff. This evidence from the discussions suggests that problem typology provides a starting point for the students in approaching open problems.

Outside of these common behaviors, we note a significant difference between Ron and Jeff and Madison and Sam. While Ron and Jeff have a noticeable shift in approach to their problem solving discussion from pre to post, Sam and Madison are largely unchanged. Further, Madison and Sam seem to confound stages and characteristics of design problem solving with the engineering case analysis they are discussing. This might be explained in part by the fact that their intramural project was a design project, so the stages of design are likely better integrated into their thinking. However, Ron and Jeff also worked on a design intramural project and did not appear to confound design and case analysis.

As mentioned previously, these two cases Ron and Jeff and Sam and Madison - stand out as possible extremes on a continuum of change that might be expected among students from pre-PT to post-PT. Specifically, Ron and Jeff exhibited a marked change in their approach to solving an engineering case analysis problem before and after being introduced to problem typology. Madison and Sam on the other hand remained largely unchanged. Ron and Jeff represent an exemplar and the first case that we reviewed. Our analysis of the debrief discussion found that Ron and Jeff recognized a difference in their behavior and directly attributed that change to learning about engineering problem typology.

> Jeff: "*…after…learning about the...different engineering problem types*...*I could…just based on my memory of the first one...I was going about approaching the problems differently and I think in a much better way.*"
>
> Ron: "*It really helps you know where to start when you're looking at these big ill-structured problems because someone just hands you a problem and you just feel like 'I don't know what to do'. But [now] it's pretty easy…when you have a problem to look into what is required from this problem. Not really looking at how to solve it, but like…really being able to get it down to like different like sections of what needs to happen throughout this problem can really help you move forward...*"

For Madison and Sam, we have not yet analyzed their debrief discussion, so we offer no explanation for their unchanged behavior, if one even exists. That remains as a future task, along with coding and analysis of additional student PSD's. Considering these additional cases and the students' impressions of their own problem solving as revealed in the debrief interviews is important future work.

5.0 Conclusion

This paper presents early findings of our research on explicating and talking to students about engineering problem typology as a framework for thinking about their engineering problem solving experiences. The question of interest - *What effect, if any, does exposure to engineering problem typology have on students approach to problem solving?* - was explored through examination of two student pairs in pre-/post-problem typology problem solving discussions.

We recognize that students come to engineering programs with their own problem typology, which they may or may not be aware of. Further, we recognize that they may apply a singular typology to all problems. At this time, our research is not focused on developing and prescribing an intervention to help all students become "better problem solvers." Rather, we are focused on building a baseline understanding of how students think about and approach solving different types of engineering problems and contextualizing that approach through problem typology. We feel this research is an important contribution that can: 1) further our understanding of how student problem typology may (or may not) change during their undergraduate career; 2) contribute to our evolving understanding of problem solving among novices and experts; and 3) provide a foundation for negotiating understanding of "good" problem solving among students, faculty, and practitioners, serving as a feedback loop for engineering curricula.

Acknowledgement
This material is based upon work supported by the National Science Foundation under Grant No. 1830793. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Appendix 1: Engineering Case Analysis Problem Statement

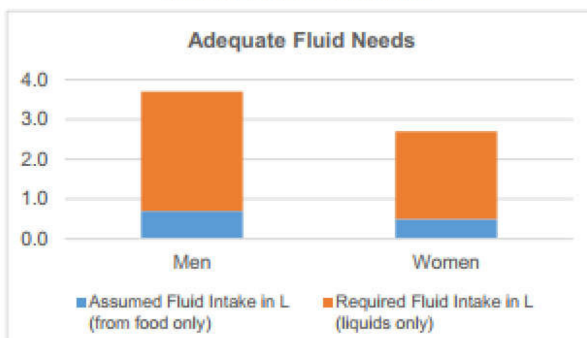
Water Purification Case Analysis

Access to clean drinking water is critical to human health and development. In the developing world, such access is a regular challenge, but even in the developed world, access to clean drinking water can be disrupted. These disruptions can be short-term due to localized infrastructure failures and natural disasters, or long-term due to more systemic infrastructure failures. Representative examples include:

- Dunkirk, NY issued an advisory for boiling water and only essential use of water in March of 2018 after a pipe leak [http://news.wbfo.org/post/water-emergency-city-dunkirk-no-non-essential-use]
- Multiple counties in NY – like Rockland County – issued boil water notices in the wake of Hurricane Sandy in 2012 [https://www.health.ny.gov/environmental/water/drinking/boilwater/sandy/]
- Flint, MI has an ongoing water crisis that began in 2014 due to lead contamination attributed to a change in water source [https://en.wikipedia.org/wiki/Flint_water_crisis]

Considering the negative impact that such water crises impose on individuals and the environment due to increased bottled water usage during the crisis, multiple municipalities in New York State and beyond are interested in the possibility of mobile water purification systems. The concept is to equip a flatbed truck with water purification technology such that it could be deployed to specific locations as-needed. These mobile water purification platforms would help to ensure that affected individuals have access to clean water for drinking and cooking, while reducing reliance on bottled water. Before issuing a request for proposals from engineering firms, the state department of health and office of emergency management are collaborating on their own feasibility analysis.

***Adequate fluid needs of males and females based on analysis from the Institute of Medicine*[1]**



Your task is to develop an initial analysis that helps to inform these agencies in determining whether to move forward or to table the project at this time. Your team is expected to deliver a report that contains the details of analysis, appropriate documentation of research to support any assumptions, and recommendations for next steps.

The report should consider the following issues and any others the team deems appropriate.

- Production needs for representative scenarios based on "adequate fluid" needs
- Purification technologies most appropriate for this concept in isolation or combination (i.e. sand filtration, ceramic filtration, distillation, UV disinfection, chemical disinfection)
- Estimated construction cost for a single platform
- Cost of system and use relative to other solution options, like bottled water

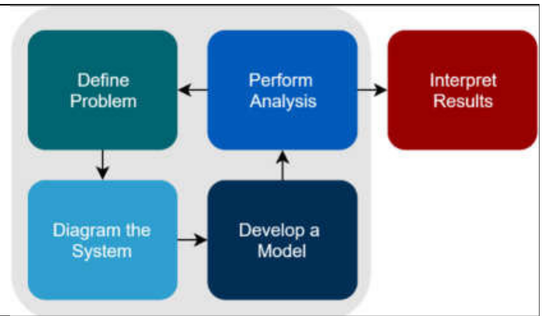
1 Institute of Medicine. 2005. Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. Washington, DC: The National Academies Press. https://doi.org/10.17226/10925.

Appendix 2 Meaning List for Developing a Problem Solving Coding Scheme

Initial Codes	**Axial Codes**	**Specified Codes**
	Problem Typology	Problem Typology: ID:Suf
Formulas	-Defining Problem	DP:OA
Math	-Diagramming System	DP:KP
Guess	-Navigating	DP:UP
Assumption	-Analysis	DP:LD
Mapping	-Interpretation	DP:PR
Drawing	-stages	DS:Dia
Lists	Socio-cultural meaning	DS:Ann
Modeling	-Gender	DM:MM
Analysis	-Navigating	DM:Assum
Decisions	-Meta cognition	DM:DAQ
Problem Discussion	-Negotiation	PA:Tool
Defining Parameters	-Limitations	PA:Execute
Agreement	-Assumptions	PA:Valid
Learning	-Hierarchy	IR:Obj
Elaboration	-Math	IR:SA
Monitor		IR:Lim
Task - appropriateness		IR:Rec
Strategic		
- Plan		
- Monitor		
- Heuristic		
Organizational		
Control		
Control		
Agreeing -		
Monitoring		
Rehearsal		
Learning – rehearsal		
Strategic-		
Heuristics		
Personal		
Motivation		

Appendix 3 Engineering Case Analysis Coding Rubric

The role of a formal engineering analysis is to support decisions (e.g. decisions necessary in the design of an artifact) or recommendations to others as in a trade study.



Process Stage	Student action/thinking as revealed through talk	Code
Problem Typology	Discussing the type of problem to be solved	PT:ID
Define Problem	Discussing the objective of the problem	DP:OA
	Discussing or identify known parameters	DP:KP
	Discussing or identify unknown parameters	DP:UP
	Discussing the level of detail or precision	DP:LD
	Writing lists or developing concept maps as a form of problem representation	DP:PR
Diagram the System	Discussion and drawing of a diagram that conceptualizes the system or subsystem in terms of behavior and function	DS:Dia
	Annotation of diagram and/or accompanying description to document behavior and parameter interactions/relations	DS:Ann
Develop Model	Discussion of modeling method – physics/equation-based model from known theory and/or empirical model	DM:MM
	Discussion of assumptions necessary for model development	DM:Assum
	Discussion of data and information acquisition	DM:DAQ
Perform Analysis	Discussion of an analysis tool/environment (e.g. simulation software, Excel)	PA:Tool
	Discussion of model execution challenges	PA:Execute
	Discussion of validity of model results	PA:Valid
Interpret Results	Discussion of presenting or interpreting results – i.e. how they might be presented or what is required for interpretation in the context of the objective	IR:Obj
	Discussion of results in terms of how they might be sensitive to certain parameters or assumptions and the uncertainty associated with those elements	IR:SA
	Discussion of analysis or model limitations that result from assumptions, current states of knowledge, technical capability, etc.	IR:Lim
	Discussion of conclusions/recommendations based on the results of the analysis process	IR:Rec