Problem Formulation during Model-Eliciting Activities: Characterization of First-Year Students' Responses

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***Abstract**: Problem formulation is a very critical stage in solving open-ended problems because solutions follow directly from the formulation. To understand student problem formulation, three distinct Model-Eliciting Activities (MEAs) were implemented in a large (N~1500) required first-year engineering course in Fall 2007. At the start of each MEA, students individually answer the questions: 1) "Who is the client?" and 2) "In one or two sentences, what does the client need?" Open coding of approximately 450 student responses per MEA was performed. Descriptive node trees were developed to show the differences in interpretation of the client's problem and level of detail in students' problem formulation. Findings here provide instructors and researchers with a deeper understanding of students' problem formulation abilities within the MEAs that informs the development of curriculum and instruction to develop these abilities.*

Introduction

Problem formulation often occurs at the early stages of the problem solving process when it has the greatest potential for affecting the direction and success of all succeeding stages (Ang, Arnott, & O'Donnell, 1994; Mintzberg, Raisinghani, & Theoret, 1976; Volkema, 1983). If the problem formulation step is not successful, the result is often an incomplete, over-simplified and unclear problem solution or even worse, an incorrect problem solution (Coman, 1986; Jackman, Ryan, Ogilvie, & Niederhauser, 2008). An important emphasis in problem formulation is the ability to resolve open-ended engineering problems in realistic context (Atman, Kilgore, & Morozov, 2007; Atman, et al., 2008; Elzey, 2006; Neeley, Elzey, et al., 2004). Engineering students must learn to solve open-ended problems that emulate the complexity of the real world, where a solution or a product must be delivered around the specifications of a client (Ansell, 1998; Howard & Schwenk, 1983). Such problems should require students to exercise communication, original thinking, judgment and decision-making skills beyond the skill set required for solving purely analytical problems. They should require students to draw on their knowledge and past experiences, outside of what is given in the problem statement (Volkema, 1983). Realistic problems are open-ended and ill-structured; therefore, there is always a level of uncertainty on the student's part associated with solving the problem (Thissen, Enserink, & Lei, 2008). The uncertainty is created by the relevant and irrelevant factors that are associated with the problem. Relevant factors include the people and artifacts involved in the problem; irrelevant factors are those that are not required to achieve a solution to the problem. This level of uncertainty is a challenge to students, especially as students come into the problem solving process with different perceptions and backgrounds. Individuals are known to have unique perspectives, such that when given the same problem situation, not all problem solvers will have the same view of the situation, even when given the same factors (Buyukdamgaci, 2003).

Many studies in problem formulation have focused on the activities of experts (Cross & Cross, 1998) and both experts and novices (Atman, Chimka, et al., 1999; Atman, Kilgore, et al., 2007; Atman, Yasuhara, et al., 2008). Atman et al. (2008) have looked into the breadth or level of details within the problem contexts of the problem formulation between novices and experts. In one study where the experts were experienced engineers and the novices were first-year students, it was discovered that novices took a broader approach to an engineering problem; in other words, their approach lacked a logistic or a technical frame (Atman, Chimka, et al, 1999). Atman et al. argue that this might be due to novices' inexperience with the engineering concepts involved. In another study comparing the level of details of problem scoping between novices who were first-year students and experts who were senior students, they discovered that experts provide a broader array of *relevant* factors in the problem scoping stages of solving an engineering problem (Atman et al., 2008). These studies suggest that successful problem formulation of open-ended engineering problems is a trait of a design expert.

Based on the literature reviews, we know that problem formulation is an important stage in solving open-ended realistic problems. We also know that it is imperative to develop students' ability to formulate open-ended engineering design problem. But how should curriculum and instruction be designed to foster the development of this ability? To answer this question, we begin here by asking, "What is the problem identified and defined by individual first-year engineering students as they start to work on a model-eliciting activity?" and "Does the focus or level of detail in the problem formulation change over a number of such activities implemented in one semester?"

Methods

The setting for this study was the Fall 2007 offering of a required first-year engineering problem solving and computer tools course with an enrollment of approximately 1500 students. Course meetings included two 50-minute lectures (N~450) and one 2-hour lab period (N~28) per week. The lab sections were led by trained Graduate Teaching Assistants (GTAs). One lab section per GTA was selected for inclusion in this study. Each GTA led multiple sections; their second or third section taught was selected to minimize the impact of first-time implementation.

Three Model-Eliciting Activities (MEAs) were implemented: MEA 1 - Theft Prevention with Laser Detection, MEA 2 - Just-in-Time Manufacturing, and MEA 3 - Nano Roughness (each is described in Zawojewski, Diefes-Dux, and Bowman, 2008). MEAs are suited for this study because they are open-ended, client-driven, realistic problems set in engineering contexts that require teams of four students to create a generalizable (share-able, re-usable, modifiable) procedure (i.e. mathematical model) for addressing the client's problem. The design of MEAs is based on six principles (Lesh et al., 2000). These problems may differ from that in previous research on students' problem formulation abilities as these problems are self-contained; students must identify and define the problem using the problem text. At the start of each MEA, students individually answer three questions: Q1 - "Who is the client – the direct user of your procedure?" Q2 - "In one or two sentences, what does the client need?", and Q3 - "Describe at least two issues that need to be considered when developing a solution for the client." These questions are designed to help students through problem formulation as they prepare to work as a team in developing a solution to the client's problem. These questions act as a scaffold to improve problem formulations, where scaffolding is thought of as a cognitive support mechanism that enables learners to perform cognitive-based task that they are not familiar with or beyond their ability (Jackman et al., 2008).

For this study, individual students' responses to Q1 and Q2 were analyzed using open coding and content analysis. Responses generated after collaboration within the four-person teams were not used in this study. As suggested by Creswell (2008) and Patton (2002), student responses were first read to get a general feel for the data and to start developing codes. Codes were informed by the MEA text and engineering design and problem formulation language. A second reading consisted of actually assigning codes. To assign codes, "like-minded" pieces were put together in "data clumps," as suggested by Glesne (1999). The codes from the second reading were refined and applied to the data in subsequent readings. Descriptive node trees were developed to visualize students' responses to Q2.

Results

Open coding of students' responses to Q1 and Q2 for MEA 1(N=483), MEA 2 (N=468), and MEA 3 (N=445) was performed. The coding scheme for Q1 – "Who is the client– the direct user of your procedure?" consisted of four categories: 1) direct clients, those who will utilize the needed deliverable, 2) indirect clients, those who will utilize the needed deliverable only indirectly, 3) non-clients, those who will not utilize the needed deliverable, and multiple clients, combinations of 1)-3).

Table 1 shows the number and percentage of student responses that were coded in each category. Results show that more than half of the students identified the direct client for MEA 2, while more than half of the students identified indirect clients for MEA 1 and MEA 3.

Table 1: Students' coded responses to Q1 – "Who is the client?" for MEA1, 2, and 3.

Codes	**MEA 1 (N = 483)**	**MEA 2 (N = 468)**	**MEA 3 (N = 445)**
Direct Client	61 (12.6%)	256 (54.7%)	52 (11.7%)
Indirect Client	265 (54.9%)	151 (32.3%)	310 (69.7%)
Non-Client	61 (12.6%)	13 (2.8%)	46 (10.4%)
Multiple Client	96 (19.9%)	48 (10.1%)	37 (8.3%)

For Q2 - "In one or two sentences, what does the client need?", a coding scheme was developed to break students' responses into four elements: 1) the deliverable that the client needs, 2) the function of the deliverable, 3) function descriptions, and 4) deliverable descriptions. To visualize differences in students' interpretation of the client's problem and the level of detail in students' problem identification, descriptive node trees (DNTs) were developed. DNTs for MEA 1 (Figure 1) and MEA 2 (Figure 2) are shown below. Each DNT is read from left to right, starting with the deliverable followed by the function of the deliverable and the function descriptions. The deliverable descriptions are listed on a branch from the deliverable. Not all students' responses contained all four elements, and some students' responses contained multiple deliverables. The values shown in the DNTs in Figures 1 and 2 are the number of coded responses, while the percentages shown are the number of code responses taken over the total number of students who provided a response to Q2.

Examples of MEA 1 students' responses that follow the dashed lines in Figure 1 are as follows:

A: "*The client needs a* ***procedure*** [deliverable] *detailing how* ***to find specific stop positions*** [function] *for a laser transmitter given its location in the room and the other locations of the laser receiver devices. This procedure must also be* ***re-useable, share-able, and adaptable*** [deliverable description] *to other situations."*

B: "*A* ***procedure*** [deliverable] ***to set up a laser theft detection system*** [function] *that is* ***subtle (to not detract from the art)*** [function description] *for the art."*

C: *"A* ***security system*** [deliverable] ***to find stop positions*** [function] *of laser transmitter."*

Examples of MEA 2 students' responses that follow the dashed lines in Figure 2 are as follows:

D: *"The client needs a* ***procedure*** [deliverable] *that will* ***rank several shipping companies*** [function] *using past data and* ***determine which company*** [function] *will be* ***optimal for minimizing shipping delays*** [function description]*."*

E: "*The client needs a* ***procedure*** *[deliverable]* ***to analyze the shipping data*** [function] *so they* ***can select*** [function] *the shipping companies that can* **meet their timing needs** [function description]*."*

F: *"The client needs a* ***shipping company*** [deliverable] *that can* ***deliver material*** [function] ***on time*** [function description]*."*

From the DNTs for different MEAs, it can be seen that students' responses to Q2 contain different elements and different levels of detail. For MEA 1, the students' identified deliverables were either coded as a "Procedure" (indicating a process for solving the problem, as in examples A and B) or a "Security system" (indicating a hardware system, as in example C). "Others" were deliverables that could not be coded in either of these two major categories. For MEA 2, the students' identified deliverables were either coded as a "Procedure" (indicating a process for solving the problem, as in examples D and E), or a "Shipping company" or "Ranking of a shipping company" or "Analysis" (all indicating a result of analysis, and not a process for doing analysis, as in example F). Again, "Others" were deliverables that could not be coded in these categories. In terms of these deliverables, a larger percentage of students identified something other than a process for solving the problem as the deliverable for MEA 1 (369 coded responses, 76.4% of students) as compared to MEA 2 (174 coded responses, 37.2% of students).

The DNTs also show patterns in students' identified function of the deliverable, where the function describes what the deliverable does. For MEA 1, when students identified a "Procedure" as a deliverable, the functions associated with this deliverable were "to install the security system" (48 coded responses, 9.9% of students), "to find stop position" (44 coded responses, 9.1% of students), "to secure art" (33 coded responses, 6.8% of students) and "to detect objects/scan the room" (10 coded responses, 2.1% of students). Also, 44 of the 177 coded "Procedure" responses had no function associated with the deliverable. When students provided "Security system" as the deliverable, many of the same functions were provided, though "to provide security" was the most common response. Further, 126 of the 349 coded "Security system" responses had no function associated with the deliverable. For MEA 2, all of the 362 coded responses that were identified to be a "Procedure" for solving the problem have a function associated with the deliverable. Examples of the functions for the deliverable "Procedure" included "to rank the shipping companies" (277 coded responses, 59.1% of students), "to choose the shipping company" (64 coded responses, 13.7% of students), "to analyze the shipping data" (11 coded responses, 2.4% of students) and "to analyse the shipping company" (10 coded responses, 2.1% of students).

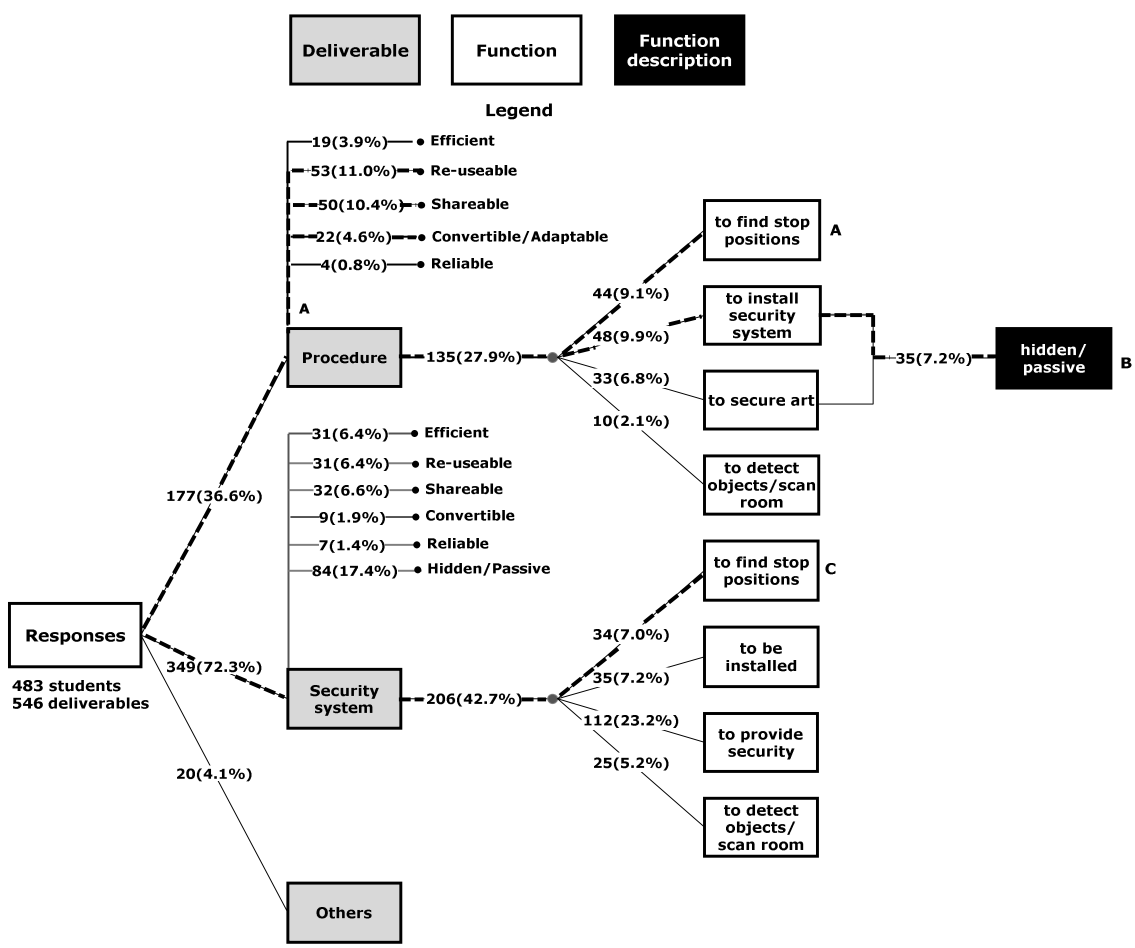

Figure 1: Descriptive node tree for MEA 1 Q2 (N=483).

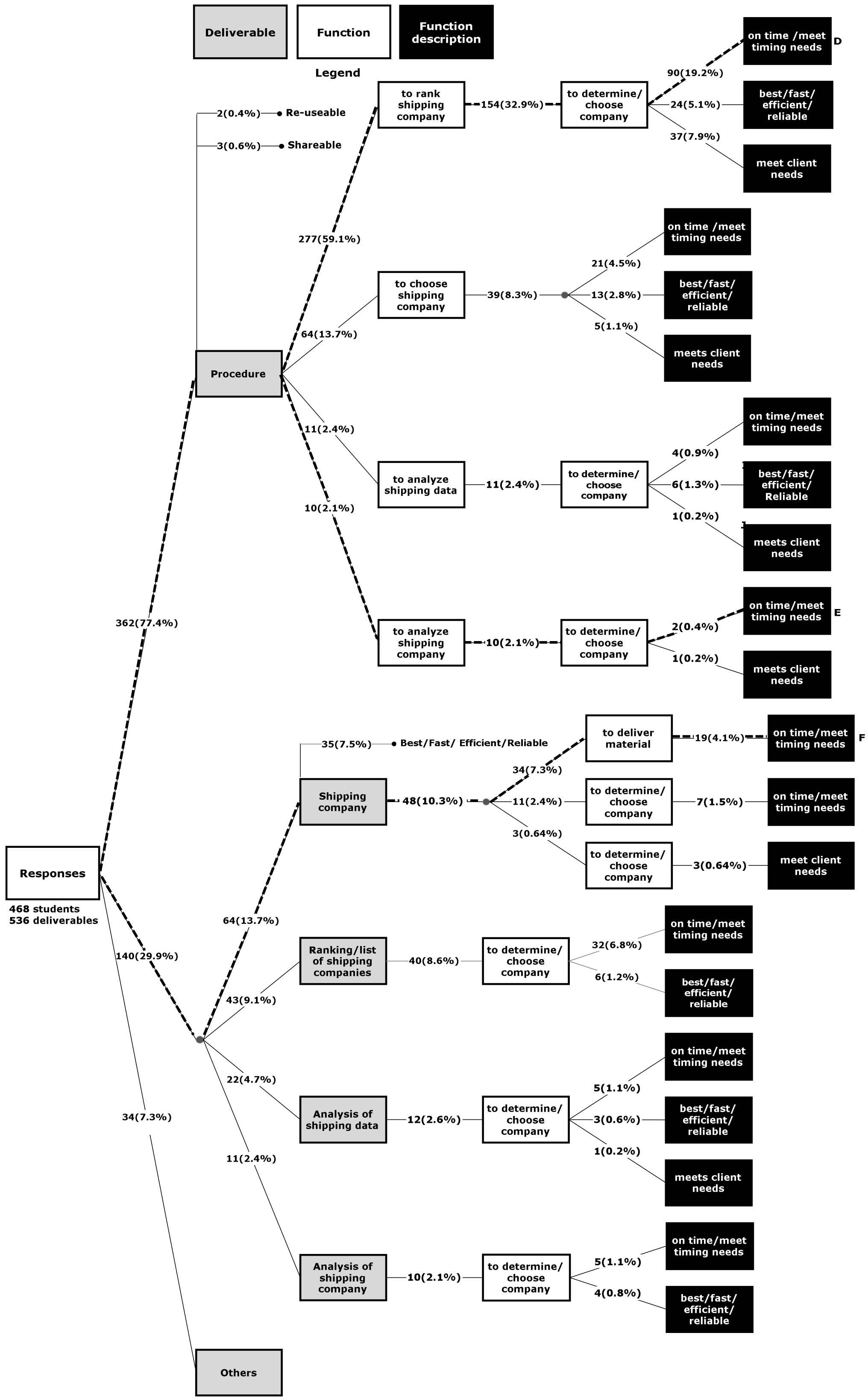

Figure 2: Descriptive node tree for MEA 2 Q2 (N=468).

Function descriptions provide detail about the function. For MEA 1, this third element only existed when the identified functions were "to install security system" or "to secure art"; then the function description was "hidden/passive" (see Example B above). For MEA 2, function descriptions were often provided, with "on-time" (delivery), "meets client needs", and "best/fast/efficient/reliable" appearing associated with a variety of functions and deliverables.

Deliverable descriptions are adjectives placed on the deliverable. For MEA 1, "Re-useable" (53 coded responses, 11.0% of students) and "Shareable" (50 coded responses, 10.4% of students) are most linked with the deliverable "Procedure", while "hidden/passive" (84 coded responses, 17.4% of students) is most linked with the deliverable "Security system", though "Re-usable" and "Shareable" are also used. For MEA 2, very few deliverable descriptions were provided. Only 5 coded responses (1.8% of students) of "Re-useable" or "Shareable" are provided as the deliverable description for a "Procedure"; 35 code responses of "Fast/ Efficient/Reliable" were provided as the deliverable description for "Shipping company".

Discussion

In Fall 2007, students were provided the three individual questions with minimal instruction. These questions were used to ensure that all students had read the MEA text and were familiar enough with the problem to engage in teamwork to develop the requested procedure. To understand why students responded in the ways that they did to Q1 and Q2, we look to the MEA problem descriptions. In the problem texts, there are a number of individuals and groups of people described as having some connection to the MEA solution. At a minimum, there is a company and a supervisor assigning the task to the student team, and a person or group that will use the procedure developed by the team. In addition, there may be other persons described to fill out the context of the problem. To identify the client (defined for the students as the direct user) for Q1, the students must determine who will actually use the generalizable procedure they are to develop. For MEA 1, students most often selected an indirect user as the client, typically the university seeking to have a security system installed by the company for which the students "work", rather than the company's installation team who will use the procedure. For MEA 2, the high percentage of students identifying a direct user is an artefact of the MEA text. Through this analysis, it was discovered that no clear direct user was described. At best, the students could identify the company or CEO requesting a team solution; these responses were taken to be the direct user. For MEA 3, students' focus was again drawn to indirect users – the company or vice president requesting the work of the team, rather than the direct user – the scientists in the company's lab that need the procedure. What is evident from this analysis is that the terms "client" and "direct user" are not clear to the students, and their confusion over these terms is not being addressed through GTA feedback. This illustrates a major stumbling block to students' problem formulation, in that they cannot properly determine the client, and thus cannot internalize the problem statement in terms of the ultimate user.

For Q2, a number of finds emerge. First, students identified that the deliverable is a procedure more often for MEA 2 (77.4% of students) than MEA 1 (36.6% of students). It is anticipated that students will initially have difficulty identifying a procedure as the deliverable as they are more likely familiar with delivering a physical product or result. By MEA 3 (not shown), 89.9% of the students identified a procedure as the deliverable.

Second, the problem text greatly impacts students' responses. Consider the words "re-usable" and "share-able". In MEA 1, these words are referred to in the problem text:

> "Your team is to use the Polk University scenario to design a surveillance system by designing a re-usable and share-able procedure to find the specific stop positions for a laser transmitter given its location and the locations of the receivers and any reflective devices in the room."

These words are reiterated by the students as both "Procedure" and "Security system" descriptors, which may or may not be appropriate. The students' use of these words could suggest that they are copying exact words when they do not clearly understand the problem. This provides insights into how these students are approaching problem formulation; they are reiterating what they acquire from the surface of the problem statement, rather than seeking meaningful information. In other words, the students are novices who lack expert ability to notice patterns of information that are non-obvious, which is relevant in solving the problem (Bransford, Brown & Cocking, 2000).

Third, some students provided responses with more elements for MEA 2. There are a number of potential explanations for this: 1) students were more familiar with the MEA 2 problem context, 2) the problem text was easier to comprehend, and 3) GTAs provided adequate feedback on MEA 1 to prompt a better response to MEA 2. These explanations require further investigation. While there are more elements included in some responses for MEA 2, a large percentage of the responses are still quite under-formulated. They lack deliverable descriptions and function descriptions that are meaningful to the students in terms of criteria for success of the deliverable. The responses also lack constraints or boundaries – an articulation of resources to solve the client's problem.

Conclusions & Recommendations

An analysis of students' responses to two individual questions at the start of an MEA was performed. The results obtained for three MEAs implemented in a single semester provided insight into first-year students' problem formulations. Students' responses to Q1 – "Who is the client?" revealed that students continually struggle to identify the direct user of the deliverable. This may be related to their not understanding the "client" and "direct user" terminology. Students' responses to Q2 – "What does the client need?" revealed that students' choice of words is often linked to the exact wording of the MEA; this may indicate a lack of experience with processes as deliverables or inadequate problem comprehension. Their responses to Q2 are also under-formulated, lacking identifiable criteria for success and constraints.

Results from this work have implications for first-year engineering curriculum and instruction focused on model development and design. These results will contribute to the guidelines for the design of MEAs; with recommendations centered on word choices and careful selection of information to be included in the problem. These results also have implications for instruction on problem formulation. Students need practice identifying direct, indirect, and non- users before they enter into a MEA or any problem-formulating task. Students also need guidance in developing appropriate problem definitions that include 1) more description of the deliverable and function (criteria for success) and 2) identification of resources and limitations (constraints). It is recommended that cycles of practice and feedback around client and problem identification be employed.

From a methodology perspective, the use of DNTs provided an excellent means of visually representing students' responses to the MEAs; the trees allowed patterns of responses within MEAs and difference across MEAs to emerge. In the future, the DNTs will be used to investigate the impact of curriculum and instruction changes to develop students' problem identification abilities. Future directions in this research will also include analysis of alignments among students' responses to the three scaffolding questions and between their responses, their GTAs feedback, and their team's problem identification statements included in their draft and final solutions to the MEAs.

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Acknowledgements

This work was made possible by a grant from the National Science Foundation (EEC 0717508). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.