Comparing and Contrasting the Process of Local vs. Global Modeling for First-Year Engineering Students

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Abstract:

Modeling is a method that enables problem solvers to develop their understanding of open-ended problems, generate relevant solutions, and analyze alternative ideas to select an optimal solution. The purpose of modeling is either problem scoping or solution detailing. Problem scoping is identifying constraints and problem identification. Solution detailing is creating possible solutions and analyzing solutions generated. The following research questions have been generated to better understand modeling completed by engineering students: 1) When do students use modeling to do problem scoping or solution detailing in an open-ended problem? 2) What similarities or differences appear in students' modeling processes in a local vs. global problems?

Two case studies using verbal protocol analysis were developed by challenging two first-year engineering students to work as a dyad to solve a local and global open-ended engineering problem. The dyad had an hour to complete each problem with only the following resources: a computer, pencils, papers, and a few books. After completion of the problems, the student work was collected and documenting videos were transcribed.

Two researchers then separately conducted a qualitative analysis on the data for the local and global problems to determine when modeling was used and its purpose. The definition of modeling by math education researchers, Lesh and Harel(2003), was the lens used to define modeling. The results were combined to create a numerical representation of when modeling occurred, its purpose, and the percentage of researchers who determined these two variables. The results were quantitatively analyzed for emerging patterns.

The key findings showed that there is a clear difference between how the dyad solved both problems. The students used a cycling process of problem scoping and solution detailing to solve the local problem. For the global problem, they began with problem scoping and ended with solution detailing.

Introduction:

Modeling is an important component to understanding the thought process of students in engineering design solutions. It is also important for engineering educators to discover the process that students understand to determine if their knowledge is sufficient for the problems they are solving. Vygotsky (1981) stated that how children acquire their intellectual skills is directly related to specific problem-solving environments and how they interact with others.

> "Understanding the cognitive strategies of technical problem solvers is critical to developing curriculum that develops technologically literate individuals. The Standards for Technological Literacy (ITEA, 2000) identified the important role of cognition in design by stating: To become literate in the design process requires acquiring the cognitive and procedural knowledge needed to create a design, in addition to familiarity with the processes by which a design will be carried out to make a product or system (ITEA, 2000, p. 90)."

The four types of modeling are graphical, physical, mathematical, and verbal. These types of modeling are used to either better understand the problem through problem scoping, which would be a problem-driven model, or to generate and/or analyze alternative solutions through solution detailing, which would be a solution-driven model. Modeling is commonly used on many complex open-ended problems especially in engineering. Two common contexts for ill-structured engineering problems are local and global. Local problems involve context that is more definable and typically more tangible to the person/s solving the problem. Global problems involve context that is broader and typically less relatable to the person/s solving the problem. These two purposes for utilizing modeling and two contexts that modeling is completed in were used to specify a lens to analyze modeling and scenarios to apply modeling, respectively.

In order to better understand first-year engineering students' modeling, the following research questions have been generated: 1) When do students use modeling to do problem scoping or solution detailing in an open-ended problem? 2) What similarities or differences appear in students' modeling processes in a local vs. global problems?

Answering these research questions could help lead to many opportunities for studies in classes to enhance students modeling abilities. It is always important to understand the current status of students’ abilities in courses so educators can develop and improve curricula to enhance their abilities. Accurate modeling is essential a component to the EDP for purpose of optimization. Types of modeling include: graphical, physical, and mathematical.

Theoretical Framework

In this analysis Vygotsky’s social constructivist theory (Vygotsky, 1978), which focuses on the interactions between students and the cognitive scaffolding that each receives is going to be combined with Richard Lesh and Guershon Harel’s definition of modeling (Lesh, Harel, 2003).

> “Models are conceptual systems that generally tend to be expressed using a variety of interacting representational media, which may involve written symbols, spoken language, computer-based graphics, paper-based diagrams or graphs, or experience-based metaphors. Model development typically involves quantifying, organizing, systematizing, dimensionalizing, coordinatizing, and (in general) mathematizing objects, relations, operations, patterns, or rules that are attributed to the modeled system” (Lesh & Harel, 2003).

A quantitative analysis will be used to help understand the common types of modeling, when they are used, and compare the iterations between problem solution or problem definition. A coding scheme would allow for a way to measure time spent on specific steps as well as what methods the students are using in frequency. One problem with the broad picture definition of modeling is that “Mathematical models are distinct from other categories of models mainly because they focus on structural characteristics (rather than, for example, physical, biological, or artistic characteristics) of systems they describe (Lesh, Harel, 2003).” In mathematics education, models and modeling perspectives emphasize the fact that “thinking mathematically” is about interpreting situations mathematically at least as much as it is about computing (Lesh, Lehrer, 2003) Two categories that are incorporated into the definition of modeling is “1) A conceptual system for describing or explaining the relevant mathematical objects, relations, actions, and patterns that are attributed to the problem-solving situation and 2) Procedures for generating useful constructions, manipulation, or predictions for achieving a clearly recognized goal (Lesh, Harel, 2003).

Additionally, a qualitative analysis would be important to help understand and develop a more in-depth detail of individuals' thought process and actions in their design project. A study within a PBL based course for engineering students that have already had modeling classes or will receive modeling lessons in the curriculum would be appropriate. Implementing some interviewing questions to develop an understanding of how students go from modeling to final design (or an engineering report) would help to gain a deeper insight on how students model.

> "Humans use cultural signs and tools (e.g., speech, literacy, mathematics) to mediate their interactions with each other and with their surroundings. A fundamental property of these artifacts, Vygotsky observed, is that they are social in origin; they are used first to communicate with others, to mediate contact with our social worlds; later, with practice, much of it occurring in schools, these artifacts come to mediate our interactions with self; to help us think, we internalize their use. It is by mastering these technologies of representation and communication that individuals acquire the capacity, the means, for "higher-order" intellectual activity (Moll 1990)."

Methods:

Setting & Participants

This verbal protocol analysis study created a test environment of two recruited first-year engineering students working as a dyad, in order to best analyze the students thinking process to solve two problems with different contexts. One problem was in a local context and the other was global; the dyad had the same allotted time period of an hour to solve each problem.

The first problem was the global problem that challenged the dyad to determine how to provide clean water to people in Ghana, West Africa. The second problem was the local problem that challenged the dyad to create a method to provide clean water to people in the state of Indiana.

This study was conducted in Engineering Learning Observatory, a research laboratory for engineering education at Purdue University. In this lab, the dyad was provided a computer and books for data collection and a poster board with writing utensils for sketching. Within this setting the dyad could discuss freely and concentrate on each problem without being disturbed.

Data Collection

In the whole process, students' web search and navigation patterns were recorded by using computer screen activity recording software. Their discussions and activities were also recorded by video cameras and then transcribed. The transcribed text from the videos was then segmented into ten second increments. After the task, all the design drawings and artifacts were collected. In addition, students were asked to accomplish a survey about their demographic backgrounds and engagement during the problem-solving process.

Data Analysis

The segments of the transcribed text were coded based on developed scheme by the researchers. The coding scheme was derived from Kruger and Cross definitions of problem and solution driven modeling as well as a general definition for modeling (Table 1). The problem-driven model consisted of coding that referred to problem scoping aspects, so this is the term that the team focused on. The solution-driven model consisted of coding that referred to solution detailing, so this is the term used in the coding. The focus of the coding was determine if the modeling was to understand the problem or to create a solution and not to make a generalization of creativity within the modeling that this definition targets.

Table 1: Kruger & Cross Lens of Problem-Driven vs. Solution Driven Modeling

Modeling	Problem-Driven	Solution-Driven
Model development typically involves quantifying, organizing, systematizing, dimensionalizing, coordinatizing, and (in general) mathematizing objects, relations, operations, patterns, or rules that are attributed to the modeled system. Consequently, the development of sufficiently useful models typically requires a series of iterative "modeling cycles" where trial descriptions (constructions, explanations) are tested and revised repeatedly. *Lesh, Richard, Harel, Guershon, (2003).*	• Emphasis of problem defining. • Low Creativity • High Overall Score *Kruger & Cross (2006)*	• Emphasis on solution generation. • High Creativity • Low Overall Score *Kruger & Cross (2006)*

First, the researchers decided whether a segment is considered modeling based on the definition from *Lesh, Richard, Harel, Guershon, (2003).* If a segment was coded modeling, the researchers would categorize the segment as either problem scoping or solution detailing as defined by Kruger & Cross (2006). Table 2 shows an example of two segments that were considered modeling; then coded as problem scoping and solution detailing.

Table 2: Example of Problem Scoping vs. Solution Detailing Modeling

Modeling Segment	Problem Scoping	Solution Detailing
"Actually it's just like… so it would be easier if it's This one is close 'cause. So you get a pipe from here to come to hand pump."		*Focused on solution generation.*
"Should be feasible, cost effective, and have the capacity to provide clean water for at least 30 days."	*Focused on identify criteria and constraints.*	

The coding process was applied to both the global and local data. A pair of researchers each independently coded the segments. These were then combined and analyzed to determine reliability and analyze for an emerging patterns. A fixed-Kappa value of .87 for the global design challenge data and a fixed-Kappa value of .89 for the local design challenge data indicate a strong inter-rater reliability. "Values of kappa can range from -1.0 to 1.0, with -1.0 indicating perfect disagreement below chance, 0.0 indicating agreement equal to chance, and 1.0 indicating perfect agreement above chance. A rule of thumb is that a kappa of .70 or above indicates adequate interrater agreement" (Randolph, 2008).

<u>Findings:</u>

Once both of the qualitative analyses were combined and the Kappa value proved the data reliable, the team compared the overall results of the coding. The global problem took an extra 14 minutes to solve. Both problems were solved with about 23% of the time spent modeling (Table 3, 4). The dyad spent about the same amount of time doing solution detailing in the local and global problem, but they spent about twice as much time doing problem scoping. In the dyad's solving of the global problem, there were 65 instances coded out of the 288 segments analyzed that both researchers considered modeling (Table 3). Out of these 65 coded segments, there were 31 instances of problem scoping and 34 instances of solution detailing (Table 3). In the dyad's solving of the local problem, there were 47 instances coded out of the 204 segments analyzed that both researchers considered modeling (Table 4). Out of these 47 coded segments, there were 18 instances of problem scoping and 29 instances of solution detailing (Table 4).

Table 3: Summary of Coding Results of Global Problem

	Global Problem		
	Number of Segments Coded out of 288 Analyzed (48 minutes)		
	Modeling	Purpose of Modeling	
	Yes	Problem Scoping	Solution Detailing
one researcher coded	14	1	13
both researchers coded	65	31	34

Table 4: Summary of Coding Results of Local Problem

	Local Problem		
	Number of Segments Coded out of 204 Analyzed (34 minutes)		
	Modeling	Purpose of Modeling	
	Yes	Problem Scoping	Solution Detailing
one researcher coded	9	4	5
both researchers coded	47	18	29

When the coding results were mapped out to display the timings that the problem scoping and solution detailing modeling occurred, there was an apparent difference between the local and global problems. The global problem appeared to begin with modeling focused on problem scoping then about half way through the problem solving process switch to modeling focused on solution detailing (Figure 1). There were some points in the global problem that varied from this pattern, but the overall coding suggests a clear transition point.

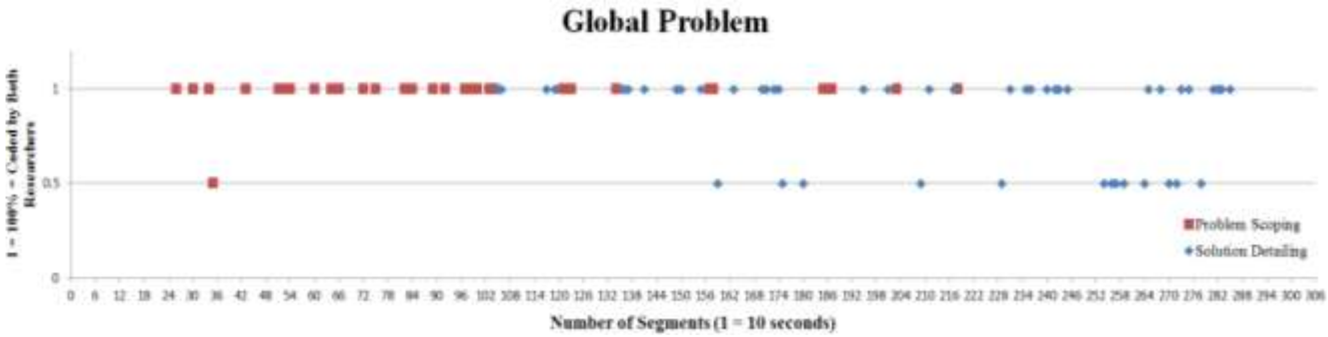

Figure 1: Graph of Solution Detailing and Problem Scoping throughout the Global Problem

The local problem appeared to be completed through a continuous cycle between problem scoping and solution detailing modeling (Figure 2).

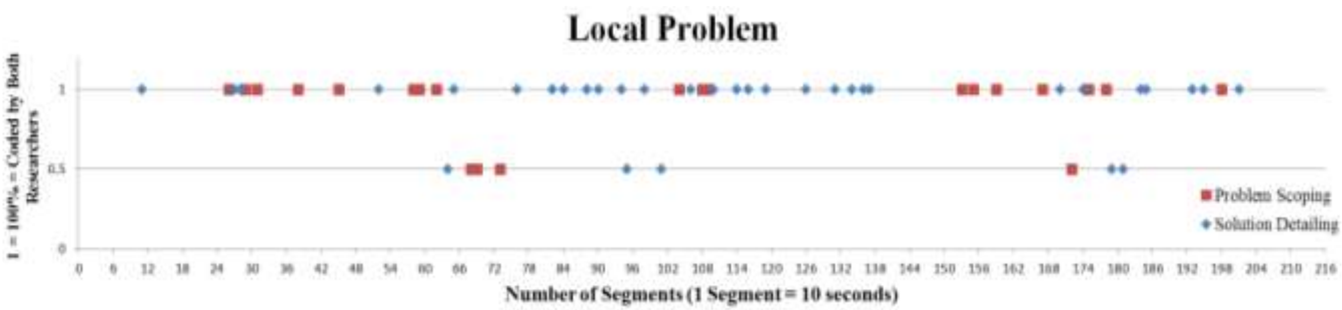

Figure 2: Graph of Solution Detailing and Problem Scoping throughout the Local Problem

Conclusions and Implications:

The findings suggest that students use modeling to do both problem scoping and solution detailing. The dyad appears to use modeling for problem scoping more in the global problem and solution detailing in the local problem. According to the Kruger & Cross (2006), this would suggest a higher creativity level in the local problem solving. This difference could have also been due to an increase in teaming abilities or understanding of water purification problems, because the local problem was the second problem the team completed. Or this change could have been because the students were able to be more creative on the local problem because they had a greater grasp on the context. This variation between the emphasis on problem scoping versus solution detailing on local and global problems presents a point that should be further researched to determine the source of increase in problem-solving creativity.

The findings also suggest that students have a different process for modeling in engineering problems with a global context compared to a local context. The dyad appears to have a clear two-step process of modeling for global problems that begins with problem scoping and ends with solution detailing. The dyad appears to have a cycling process of modeling for the local problem. This variation may suggest a difference in modeling processes for local and global problems. The change could have also been due to the students going through a learning curve and switching to a cycling process, which appeared to be more efficient due to the 14 minute time decrease on the local problem. For either scenario this change in modeling process should be further studied to understand if this is a common transition of growth or a common theme for different local and global modeling processes.

Future Research Plans:

Since there are limitations due to the small case study number, the research team would suggest these research questions be addressed again with a larger sample size. The team would propose a quasi-experimental design research. There should be a sample size of at least two or four dyads. In the case of four dyads, two dyads should be challenged to complete a local problem first and the global problem second and the other two dyads should be challenged to do the vice versa. This variation would be to better control the extraneous variable of problem order. All of the dyads should receive the same local and global problems. Also the local problem should be a different context of the global problem with a similar level of difficultly to best control extraneous variables of increase of knowledge on a problem and requirement of necessary skills, respectively. It is recognized though that a change in problem content would create an extraneous variable of varying familiarity levels. The purpose of this research would be to determine if any of these patterns emerge and how they varying amongst different scenarios. Also the team would be looking for any new emerging themes that may further answer the originally proposed research questions.

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