10-1-2015

Students' Perceptions of and Responses to Teaching Assistant and Peer Feedback

Kelsey Joy Rodgers
Purdue University

Aladar K. Horvath
Ivy Tech Community College - Muncie

Hyunyi Jung
Marquette University, hyunyi.jung@marquette.edu

Amanda S. Fry
Purdue University

Heidi A. Diefes-Dux
Purdue University

See next page for additional authors

Published version. *Interdisciplinary Journal of Problem-Based Learning*, Vol. 9, No. 2 (October 2015).
DOI.
Hyunyi Jung was affiliated with Purdue University at the time of publication.

Authors
Kelsey Joy Rodgers, Aladar K. Horvath, Hyunyi Jung, Amanda S. Fry, Heidi A. Diefes-Dux, and Monica E. Cardella

THE INTERDISCIPLINARY JOURNAL OF
PROBLEM-BASED LEARNING

ARTICLE

Students' Perceptions of and Responses to Teaching Assistant and Peer Feedback

Kelsey J. Rodgers (Purdue University), Aladar K. Horvath (Ivy Tech Community College),

Hyunyi Jung (Purdue University), Amanda S. Fry (Purdue University),

Heidi A. Diefes-Dux (Purdue University), and Monica E. Cardella (Purdue University)

Authentic open-ended problems are increasingly appearing in university classrooms at all levels. Formative feedback that leads to learning and improved student work products is a challenge, particularly in large enrollment courses. This is a case study of one first-year engineering student team's experience with teaching assistant and peer feedback during a series of open-ended mathematical modeling problems called Model-Eliciting Activities. The goal of this study was to gain deep insight into the interactions between students, feedback providers, and written feedback by examining one team's perceptions of the feedback they received and the changes they made to their solutions based on their feedback. The practical purpose of this work is to begin to make recommendations to improve students' interactions with written feedback. The data sources consisted of individual student interviews, videos of the team's meetings to revise their solutions, the team's iteratively-developed solutions, the team's documented changes to the their solutions, and the written feedback they received from their teaching assistant and peers. The students explained that helpful peer feedback requires a time commitment, focuses on the mathematical model, and goes beyond praise to prompt change. The students also stated that generic TA feedback was not helpful. The greatest difference between the students' perceptions of TA and peer feedback was that the TA had influence over the team's grade and therefore the TA feedback was deemed more important. Feedback strategies to increase peer participation and improve teaching assistant training are described. Suggestions for continued research on feedback are provided.

Keywords: peer feedback, teaching assistant feedback, first-year engineering, open-ended problem solving

Introduction

In discovery learning environments (e.g., problem-based learning and model-eliciting activities), feedback plays a critical role in solution development and learning. Feedback presents an opportunity for instructors, teaching assistants (TAs), and student peers with alternative perspectives on solution development to give input on work products to address misconceptions, mitigate shortcomings, and point out aspects that need improvement. In addition to developing an improved solution, iterative experiences with feedback help students develop fundamental abilities (e.g., communication, critical thinking, problem solving, and professionalism skills). One fundamental ability that is crucial for engineering students to develop is an ability to construct mathematical models (ABET, 2012; Cardella, 2010; Gainsburg, 2006). In this context, mathematical modeling refers to the construction of a system, using a variety of representations (e.g. graphic, symbolic, language), to describe, think about, make sense of, explain, or make predictions about another system (Lesh, Hoover, Hole, Kelly, & Post, 2000). In this study, first-year engineering students' perspectives of the feedback they receive as they iteratively developed solutions to three different open-ended, mathematical modeling problems, specifically Model-Eliciting Activities (MEAs) (Diefes-Dux, Hjalmarson, Miller, & Lesh, 2008), were investigated. During the development of each MEA solution, the team received feedback from peers and a TA. This study focused on one team's perceptions of and responses to the feedback they received, as well as the actual feedback they received and their revised work. The specific research questions that this study addresses are:

http://dx.doi.org/10.7771/1541-5015.1479

1. How do students perceive feedback from their peers and teaching assistant?
2. What changes do students make to their open-ended problem solutions based on feedback?

Literature Review

Model-Eliciting Activities (MEAs)

MEAs are realistic, user-driven, team-oriented problems that require the development of a mathematical model (Diefes-Dux et al., 2008; Lesh et al., 2000). One of the goals of implementing authentic mathematical modeling episodes is to cultivate higher-order thinking skills (Lesh, Lester, & Hjalmarson, 2002). Through team collaboration that provides multiple perspectives on the problem and its potential solutions (Moore & Diefes-Dux, 2004) and participation in peer feedback to develop and enhance mathematical models, students develop communication, critical thinking, and problem solving skills, which are called for by the Engineering Accreditation Commission (ABET, 2012). During solution development, feedback from peers and TAs helps students improve their mathematical models and communicate them more clearly (Diefes-Dux, Zawojewski, Hjalmarson, & Cardella, 2012; Rodgers, Diefes-Dux, & Cardella, 2012). Based on feedback, students iteratively develop solutions which are shareable with others, reusable in similar situations, and modifiable for different contexts (Lesh et al., 2000).

As in problem-based learning (PBL), students develop their MEA solutions by expressing a potential direction, receiving feedback, and revising their trial solutions. Both PBL and MEAs promote a learning environment in which problem design encourages multiple viable solutions, team collaboration is essential, and students are enabled to be more proficient at self-assessment (Diefes-Dux, Hjalmarson, Zawojewski, & Bowman, 2006). According to Scott (2014), there are five main components that are necessary for effective PBL design: 1) starting with the problem, 2) requiring student-directed learning, 3) reflection, 4) small group collaboration, and 5) facilitation to guide learning. MEAs fulfill all five of these essential aspects. Cross Francis, Hudson, Vesperman, and Perez (2014) explain that MEAs, project-based learning, and problem solving activities have many pedagogical commonalities, but have differing process details and products.

Feedback

Formative Feedback

Feedback plays an important role in helping students learn and succeed by providing them with guidance on how to make improvements (Smith & Gorard, 2005; West, Williams, & Williams, 2013). Formative feedback is given while work is being completed, as opposed to summative feedback which is given upon completion of an assignment (Shute, 2008). Formative feedback can occur at any point during the solution development phase of an assignment or project (e.g. in class, during office hours) and can take a variety of forms (e.g. verbal, written, e-mail). Formative feedback is intended to improve student learning (Shute, 2008) and positively impacts student learning when appropriate interpretation of feedback guides a student's learning trajectory (Black & Wiliam, 1998). According to Gipps and Stobart (1993), formative feedback is a crucial component of the teaching and learning process because it plays a central role in guiding students through open-ended problem solving.

Helpful Types of Feedback

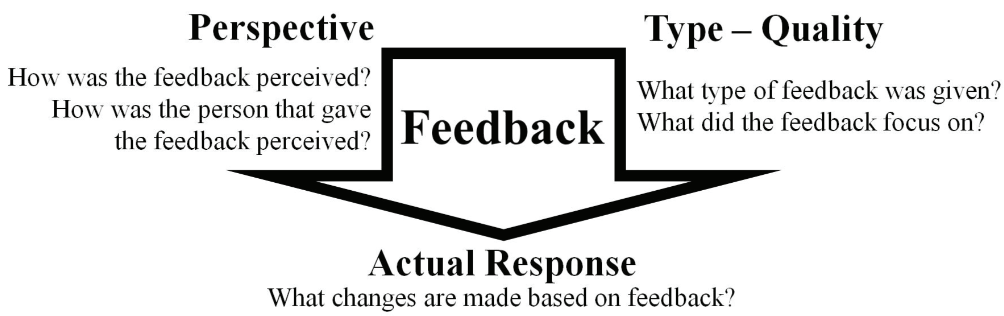
When students participate in open-ended problem solving, feedback can be helpful or unhelpful depending on the nature of feedback (Gipps & Stobart, 1993) and students' perspectives of feedback (Nilson, 2003). Hmelo-Silver and Barrows (2006) developed feedback frameworks for a complex environment, specifically a PBL session with medical students. Some of the facilitation strategies suggested by the feedback frameworks include open-ended questioning (encouraging explanations, recognizing knowledge limitation), re-voicing (clarifying ideas, legitimizing ideas, influencing direction), summarization, evaluation of hypotheses, and encouraging construction of visual representations (building connections to ensure learner's gain deeper understanding).

These frameworks for giving effective feedback are also recommended by other researchers (e.g., Hattie & Timperley, 2007; Nelson & Schuun, 2009; Shute, 2008). Shute (2008) advises using summarization to establish a rapport between the reviewer and reviewee. Kelly and LeDocq (2001) also recommend first identifying what is done correctly and incorrectly; though these techniques are often used in summative feedback. Once a common understanding of the given problem and current work are established, Shute (2008) suggests using questioning techniques and cues to help guide the student to an improved solution. Nelson and Schuun (2009) discuss the importance of prompting change in feedback and avoiding praise.

Perception Affects Feedback

The frameworks above discuss effective techniques for giving feedback, but students' perceptions of the person giving them the feedback also affects how it is received. Feedback can be given by an instructor (e.g., TA or professor; See Diefes-Dux et al., 2012; Ice, Swan, Diaz, Kupczynski, & Swan-Dagen, 2010) or a peer (e.g., Nelson & Schuun, 2009; Nilson, 2003; Rodgers, Diefes-Dux, & Cardella, 2012). Peer feedback is an alternative way of assessing students' work and currently receives much

Figure 1. Components of Research Design



attention due to its successful impact on student learning (Topping, 1998; Rada & Hu, 2002). Some students consider peer feedback to be misleading and unhelpful because peers do not assign grades (Nilson, 2003). These students, however, fail to recognize the benefits, such as developing metacognitive and reflective thinking skills (Smith, Cooper, & Lancaster, 2002), that come from assessing others' works (Tseng & Tsai, 2007), giving feedback, and interpreting others' feedback.

Feedback on MEAs

The type of feedback that is given is affected by the content focus and context of the problem. Diefes-Dux and colleagues (2012) developed a framework for analyzing TA feedback given to student teams regarding their solutions to MEAs. They found that the nature of TAs' feedback was different on students' mathematical models than on problem formulation content. Feedback given in the context of MEA solution development is unique in that there are targeted content areas that capture important aspects of a successful solution. The three primary characteristics that are focused on are the situation of the solution in a realistic context (that is, problem formulation), mathematics employed in the solution, and the communication (e.g., grammar, format, mathematical writing) of the solution.

Further, Diefes-Dux and colleagues (2012) found that feedback is not only influenced by the context of the problem, but also by the quality of the work being analyzed. When the quality of student work was low, TAs made more open suggestions on students' mathematical model and accompanying rationales, compared to student work at a higher level.

Research Design

Even though several studies have addressed feedback on student writing (Ice et al., 2010; Nelson & Schuun, 2009; Parr & Timperley, 2010), investigations of feedback on mathematical writing is limited (Kelly & LeDocq, 2001). Further research is needed on feedback that targets students' mathematical writing, as well as their mathematical thinking. MEAs present an opportunity to investigate students' mathematical thinking by targeting their development of a mathematical model, while focusing on their logic, communication, and understanding of the situated context.

As seen in the literature review, these previous studies are about what makes TA and peer feedback effective. There are also some studies on students' perspectives of peer feedback. In this study, we are interested in the intertwining of the feedback given, the team's perspective of the feedback, and the changes made based on feedback from both a TA and peers. The relationship among the three components of this research are shown in Figure 1.

Another aspect that is not explicitly addressed in the literature review is the method of giving feedback. Face-to-face feedback is more desirable, especially in PBL, because it allows the reviewer and reviewee (such as a TA and student team) to have an open discussion that allows the TA to ask questions about the team's solution and the team to ask questions about the TA's feedback. However, written feedback presents a more feasible means of giving feedback in large classroom settings where time for individual feedback is limited. In this study, we investigated written feedback, which has the potential to become the norm as we serve larger populations and utilize more cyber learning environments.

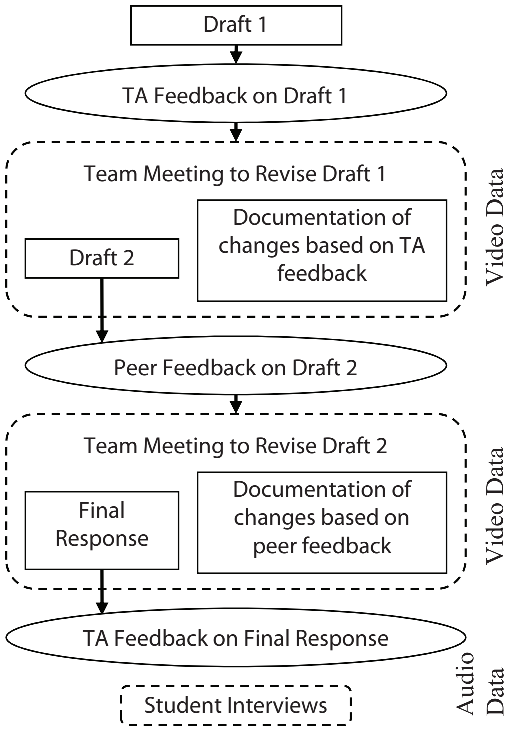
In this case study, we followed one student team as they solved three MEAs presented in a required first-year engineering course. Each MEA was implemented according to the sequence outline in Figure 2. The team portion of each MEA was initiated in the classroom with Draft 1; student teams revised their work outside of class following TA feedback to produce Draft 2 and again following peer feedback to produce their Final Response. The case study team was videotaped responding to feedback and revising their work on each MEA. The team members were individually interviewed concerning their perceptions of TA and peer feedback at the conclusion of each MEA. Students' interviews were analyzed for themes that were substantiated through an analysis of the actual feedback they received and their iterative solutions to the MEAs. The methods are further detailed below.

Methods

Participants and Setting

The data for this study was collected in Fall 2008 at a large Midwestern university. Approximately 1200 students were

Figure 2. Fall 2008 MEA Sequence



enrolled in a required first-year engineering problem solving and computer tools course. Students attended a paired instructor-led 110-minute lecture and TA-led 110-minute laboratory (in section sizes of up to 120 students). TAs taught the lab sections in teams of four, with each TA facilitating two sections. The curriculum included three MEAs that were solved in teams. Teams of three or four students were formed prior to the first MEA and remained the same for the entire semester. The teams were assigned based on student responses to the CATME team formation survey; CATME used students' genders, nationalities, time availabilities, scholastic history, and some other self-reported variables to form teams (Layton, Loughry, Ohland, & Ricco, 2010).

In MEA 1 (*Purdue Paper Plane Challenge*), student teams used flight measurement data to develop a method for selecting the winners of paper airplane contests (Verleger, Diefes-Dux, Ohland, Besterfield-Sacre, & Brophy, 2010). More specifically, the team created a procedure (mathematical model) to rank paper airplane contestants' flights for best boomerang, most accurate, best floater, and best overall based on time in the air, length of flight, and distance from target data. In MEA 2 (*Just-in-Time Manufacturing*), teams used data concerning the minutes late of deliveries to develop a model for ranking shipping companies (Diefes-Dux et al., 2012). In MEA 3 (*Travel Mode Choice*), student teams developed a model to predict students' transportation choices to inform a university's master plan development process (Diefes-Dux, Hjalmarson, & Zawojewski, 2013). Specifically, the model was to predict each student's method of travel based on travel data (i.e., frequency of bus arrival, bus stop location, cost of parking and bussing, and time to walk, bus, or drive to campus). A version of the *Just-in-Time Manufacturing* MEA and the *Travel Mode Choice* MEA can be downloaded from the Modeling: Elicitation, Development, Integration, and Assessment (MEDIA) online community at: http://modelsandmodeling.net/MEA_Library.html. Solutions to these MEAs were student team written memos back to the client describing the problem, detailing the mathematical model, and presenting results of applying the model to various test cases.

As an example of one of these MEAs consider the *Just-In Time Manufacturing* MEA. This MEA challenges teams to develop a generalizable mathematical model (procedure) to rank prospective shipping companies in order of best to least able to meet the client's timing needs based on historical late delivery time data. The direct user of the solution to the problem is a logistics manager at a manufacturing company that uses a just-in-time production strategy and must move partially manufactured components between two manufacturing facilities. The full historical data set includes 270 arrival times in minutes late, ranging from 0 to 100 minutes for eight shipping companies. All eight shipping companies have varying data with different distributions that have similar means (9.45 min. +/– 0.7 min.). Student teams' exploratory analysis of the data should help them understand the need to account for distribution of the data rather than just mean and/or standard deviation when developing their mathematical models (Carnes, Cardella, & Diefes-Dux, 2010; Carnes, Diefes-Dux, & Cardella, 2011). Hanoglu, Horvath, and Diefes-Dux (2014) provide a detailed account of one team's iterative solution to this MEA.

Figure 2 shows the MEA implementation sequence for Fall 2008. Each MEA was delivered to the teams in the form of a memo from a client describing the problem and providing some additional information (e.g., background reading, company profile, data sets). Solutions to each MEA were created through the same six step process. First, each individual completed a problem scoping homework assignment to understand the posed problem. Second, the teams created their first draft solution to the MEA (Draft 1). The teams began to compose their Draft 1 solution in the laboratory setting under the direction of the TA; they completed this draft and all other MEA work outside of class as part of homework. Third, the team received written feedback from their TA. Fourth, the team used this TA feedback to create a further developed solution (Draft 2); teams tracked their responses to the TA feedback separately in the Documentation of Changes. Fifth, each individual student gave peer feedback to another team through a double-blind peer review process. Sixth, each team used peer feedback to improve their solution for the final

Table 1. MEA Rubric Dimensions (Fall 2008 Implementation)

Dimension	Description
Mathematical Model (MM)	A mathematical model may be in the form of a procedure or explanation that accomplishes a task, makes a decision, or fills a need for a direct user. A high quality model fully addresses the complexity of the problem and contains no embedded errors. The procedure takes into account all types of data provided to generate results OR *reasonably* justifies not using some of the data types provided. The procedure is supported with *acceptable* rationales for critical steps in the procedure.
Reusability and Modifiability (R&M)	*Reusability* means that the procedure can be used by the client for new but similar situations. *Modifiability* means that the procedure can be modified easily by the client for slightly different situations. The procedure not only works for the data provided but is clearly re-usable and modifiable. Re-usability and modifiability are made clear by well-articulated steps and clearly discussed assumptions about the situation and the types of data to which the procedure can be applied.
Audience (Shareability) (SA)	The procedure is easy for the client to understand and replicate. All steps in the procedure are clearly and completely articulated. Results from applying the procedure to the data provided are presented in the form requested. There is no extraneous information in the response.

time (Final Response). Again, teams tracked their responses to the peer feedback separately in the Documentation of Changes. The Final Response was submitted for a grade. Written TA feedback on this final submission was intended to aid the team in performing better on successive MEAs. The video and audio data, noted in Figure 2, were only conducted with the eleven teams that consented to participate in the research study.

Training for Students on Giving Feedback

Students received training on solving MEAs and interpreting and providing feedback on MEAs. Prior to solving MEA 1, students participated in an instructor-led practice MEA called the *Sports Equipment* MEA. The purpose was to set expectations for high quality work and establish the role of the TAs during Draft 1 development (Verleger, 2009). The day TA feedback on MEA 1 was released, students attended a lecture on feedback. The students were told what kind of feedback to expect: "(1) explicit directions on how to fix something (very rare), (2) statements to guide your team to rethink your solution, and (3) questions to get your team to rethink your solution." The faculty then discussed with the students specific common feedback comments on MEA 1 that cut across the aspects on which the team work was evaluated, pointing out what the feedback is referring to and how to address each comment. The students were then given time in class to examine the feedback from their TA on MEA 1.

Before engaging in the double-blind peer review for each MEA, students went through a peer calibration exercise in which they were given one sample MEA solution to evaluate. After evaluating the sample work, their evaluation was shown next to an expert's review of the same solution. Students were asked to compare their review to that of the expert and identify ways that they could improve their feedback. After completing the calibration exercise, students were able to complete a peer review of one other team's MEA solution.

Each student was assigned to peer review another team based on random assignment or an informed peer review matching algorithm that accounted for the accuracy of the student's scores in the calibration exercise and teams' scores from their TA on their Draft 1 submission (Verleger, 2009). Students within a particular team were not intentionally assigned to review the same team or different teams—it is statistically unlikely that students from one team were all assigned to review the same team's work. Further, it was unlikely that students peer reviewed the same team across the three MEAs.

Training for TAs on Giving Feedback

TAs also received training with each MEA to facilitate their ability to provide effective feedback to students (Verleger, 2009). Prior to the start of the semester, the TAs took part in eight hours of face-to-face training split across two days. The training was led by a MEA expert that spearheaded the implementation of and research on MEAs in the first-year engineering course; the expert was also an instructor for a section of the first-year engineering course.

Prior to attending the initial two days of training, the TAs read and individually solved the *Sports Equipment* MEA. Day 1 of the training began with defining open-ended problems, mathematical models, and a model development process. The expert then lead the TAs through the student version of the *Sports Equipment* MEA lecture content and activities so that the TAs were familiar with the students' first MEA experience. The TAs then worked MEA 1. Day 1 concluded with a discussion of MEA design principles (Lesh et al., 2000), the challenges of teaching with open-ended problems, like MEAs, in a first-year engineering course, and the TAs role in laboratory when teaching with MEAs. As homework for Day 2, TAs were asked to review two sample student solutions to MEA 1; specifically, the TAs were asked to summarize the mathematics used in the solutions and apply the students' mathematical models to get results and describe any problem(s) experienced when trying to apply their procedures.

The focus of Day 2 was on using the general *MEA Rubric* and the MEA-specific *Instructors' MEA Assessment/Evaluating Package* (*I-MAP*). The *I-MAP* is a guide that helps TAs consistently apply the *MEA Rubric* for a given MEA. Dimensions of the *MEA Rubric* are shown in Table 1 and a lengthier description is provided by Diefes-Dux, Zawojewski, and Hjalmarson (2010). Each dimension is used to help students construct complete and coherent MEA solutions and enables TAs to effectively assess and evaluate students' MEA solutions. As a side note, the *MEA Rubric* was refined to better clarify the dimensions for the students and TAs in Spring 2009 (e.g., Carnes et al., 2010; Diefes-Dux et al., 2012) and that rubric is still used today.

At the beginning of the discussion of how to assess student teams' solutions, the expert stated, "The goal is to make feedback and assessment as *authentic* (client-like) and *consistent* as possible while facilitating students' development as problem solvers and their achievement of course learning objectives." The expert went on to describe the three *MEA Rubric* dimensions (described below) and the features of high quality student work with regards to each dimension in the context of MEA 1. Particular attention was paid to the assessment strategy for each dimension.

For the Mathematical Model dimension, the TAs were to briefly summarize the students' mathematics, apply their mathematical model, describe problems with the application, and provide constructive recommendations on how to better address the complexity of the problem or eliminate errors. For the Reusability and Modifiability dimension, TAs were to summarize students' stated assumptions and provide constructive comments on anything missing that would help the client better understand the circumstances under which this procedure can be used. And for the Shareability dimension, TAs were to provide constructive recommendations on how to make the procedure easier for the client to use and replicate results.

As each dimension was discussed, the expert guided the TAs through an examination of one of the pieces of student work the TAs reviewed for homework. An expert's feedback of the sample student work was presented along the way. Once all three dimensions had been discussed and the first student sample completely evaluated, the expert and TAs examined and provided feedback on the second student sample.

The TAs performed evaluations on five additional representative student solutions, were shown an expert's review of each, and were asked to identify ways to improve their feedback. At the conclusion to the practice evaluations, the TAs received personalized feedback on their reviews from the expert.

Before the implementation of MEA 2 and 3, TAs attended additional training to develop solutions to the upcoming MEA and discuss typical student solutions, appropriate feedback, and assessment. In each of these training sessions, the expert led the TAs through an examination of two pieces of sample student work and presented expert feedback. While, the expectations for student work with regards to the Reusability and Modifiability and Shareability dimensions were fairly similar across all of the MEAs, the requirements for the Mathematical Model dimension were unique to each MEA. So, particular emphasis was placed on the core features of a high quality mathematical model for each MEA.

For the *Just-In-Time Manufacturing* MEA, the core features are an error-free procedure that ends in a ranking of prospective shipping companies, an accounting of the distribution of the data, and a means of breaking ties. For the *Travel Mode Choice* MEA, the core features are a quantitative method for predicting the travel mode with a clear articulation of the variables included in the model and a means of assessing accuracy of the model. For this MEA, the TAs were also apprised of a number of common mathematical problems, for instance issues with units (e.g. adding time and cost together).

Following each of these training sessions, the TAs again performed evaluations on five additional representative student solutions, were shown an expert's review of each, and were asked to identify ways to improve their feedback. At the conclusion to the practice evaluations, the TAs received personalized feedback on their reviews from the expert.

After each training session, each TA was responsible for launching each MEA in the laboratory and subsequently giving feedback on teams' Draft 1 and the Final Responses. Each TA gave feedback to their assigned teams in two sections (seven to eight teams per section). Due to the size of the overall course and number of laboratory sections, the instructors interacted with the students minimally beyond the faculty-led lectures; the TAs were primarily responsible for helping students develop their MEA solutions.

Data Collection

The purpose of the first research question—How do students' perceive feedback from their peers and teaching assistants?—was to understand the students' perspectives of received feedback. With the goal of inquiry being to understand, the constructivist paradigm should be used (Lincoln, Lynham, & Guba, 2011). In the constructivist paradigm, it is crucial to capture the voice of the participants, in this case both as individuals and as a team. This exploration required iterative, frequent contact with participants throughout the study. All of the approximately 1200 enrolled students were given the opportunity to participate in this study; 11 teams agreed to be video-recorded and interviewed and only one team completed every phase of the data collection.

The purpose of the second research question—What changes do students make to their open-ended problem solutions based on feedback?—was to explain the types of feedback the team received and the changes the team made to their MEA solutions. An inquiry that focuses on explanation comes from a more post-positivist paradigm (Lincoln et al., 2011). To answer this question, authentic student work and feedback was needed for the analysis.

This study compares the realities presented based on a constructivist and post-positivist data collection and analysis. A case study is an effective research approach to investigate the fundamental details of a phenomenon (Yin, 2009). This case study focuses on one team's in-depth experience to investigate their individual and team perspective of the feedback process through their development of solutions to three different MEAs.

The data analyzed included the student interviews, video-recordings of team revision meetings, peer and TA feedback, and team written work, as shown in Figure 2. As mentioned, the particular team was chosen because it had the most complete data set; each team member consented to the study, each student completed the individual interviews for all three MEAs, and the team participated in all six video recorded revision meetings. Among the other eleven cases that participated in the study, some team members did not complete the interviews, and some teams were video recorded for only a subset of the six revision meetings. The selected team consisted of four male team members: Dave, Jerry, Ryan, and Stan (pseudonyms).

Student interviews were conducted after the team submitted their Final Response for each MEA, as shown in Figure 2. The semi-structured interviews were conducted with the students individually, were audio recorded, and lasted 20 to 30 minutes. The protocol is provided in Appendix 1.

Video-recordings of the entire team revising their MEA solutions occurred twice during each MEA—once after the team received TA feedback on Draft 1 and again after receiving peer feedback on Draft 2, as shown in Figure 2.

The written work (i.e. team MEA solutions and feedback) was collected through a web-based interface connected to a database system (Verleger et al., 2010). Peers were not randomly assigned to provide feedback to this team. Rather, they received feedback from peers who, based on the calibration exercise, provided feedback that was similar to an expert for at least one of the *MEA Rubric* dimensions. In theory, the team received high quality feedback from at least one peer for each dimension (Verleger, 2009). The TA feedback was given by a graduate student new to teaching in this course.

Data Analysis

The analysis of the data began with an inductive analysis of the student interviews (Hatch, 2002). Forty-one students (from the eleven teams that volunteered for this study) participated in the interview portion of the study. The transcribed interviews from all forty-one students were coded by a single researcher using an emergent coding scheme in which categories were generated based on an initial examination of the data (Patton, 2002; Stemler, 2001). Themes that appeared a significant number of times in the interviews (i.e. appeared in at least one third of the interviews) were identified and categorized. To ensure greater reliability, the first coder brought the coding scheme and interview excerpts to the larger research team for feedback and refinement (Patton, 2002). Two other coders re-applied the modified, emergent themes to the transcribed interviews for the four students from the team in this case study. The coders also conducted a more interpretative analysis of the four students' interview responses to ensure the researchers fully captured the view points of the selected team's members (Hatch, 2002). The perspectives of the individuals found in the interviews were also compared to the team's perspective as a whole based on their discussion of their feedback in the video data and their Documentation of Changes.

The iterative MEA solutions (i.e., Draft 1, Draft 2, and Final Response) were analyzed through a typological analysis to determine how well the solutions met the criteria for each rubric dimension and an inductive analysis to identify changes made during the development of each iterative solution (Hatch, 2002; Diefes-Dux et al., 2010). The typological analysis, which consisted of using the grading rubric to score each MEA solution on either a 3-point or 4-point Likert-like scale (depending on the dimension analyzed), showed that many of the team's MEA dimension scores did not change across their drafts for each MEA. The inductive analysis began with the comparisons of the three iterations for each MEA solution to find every change made. The comparisons presented specific details of the changes the team made rather than just major changes that could be seen by the grade changes. The found changes were then categorized based on the dimensions of the *MEA Rubric* (Table 1) to determine what aspect of the problem the changes addressed. The Documentation of Changes completed for each revision (i.e. based on TA and peer feedback) and the video data that was collected during the revision meetings was used to determine what influenced the changes, either feedback or something else.

The TA and peer feedback were analyzed differently because the students' interviews elicited different perceptions of the two sources of feedback. The TA feedback was analyzed to substantiate students' perceptions that the feedback was vague and generic. Each piece of TA feedback the team received was compared with all of the feedback the TA gave to other teams in the same course. This enabled unique feedback to this team to be identified.

The peer feedback was analyzed to verify students' perceptions that it lacked constructive comments. To verify this perception, the number and types of feedback comments and the number and content focus of the feedback comments that each peer gave were determined. This typological analysis was based on previous studies of feedback (Hatch, 2002; Rodgers, Diefes-Dux, & Cardella, 2012; Rodgers et al., 2013). Constructive feedback consists of any feedback that prompts change (Rodgers, Diefes-Dux, & Cardella, 2012; Rodgers et al., 2013). Feedback that is not constructive either consists of a comment that literally states "none," only gives praise, or summarizes the current work. The content focus of the constructive feedback is based on the MEA dimensions, as previously described in Table 1.

Findings

The team members' perceptions of the MEA feedback process were identified from their comments in the three interviews. They perceived various aspects of TA and peer feedback to be helpful and other aspects to be unhelpful; the process of giving feedback was viewed as beneficial. For each of the three MEAs, the students believed that they made changes that were in response to the feedback that they received. This section details these perceptions and substantiates these perceptions with the students' written work and team meeting discussions.

TA Feedback

Perception of TA feedback

All team members perceived TA feedback to be helpful. They mentioned that receiving feedback gave them a general sense of the revisions they needed to make to improve their work. Jerry stated that the team did not understand the task at hand until receiving the TA feedback. Dave and Ryan discussed some specifics about how they used the TA feedback, such as pursuing the TA's hints and ensuring completion of every component the TA discussed.

> Jerry: I guess you basically learn as you go. That's the helpful part about the TA feedback because [. . .] you're going with no idea of what to do and through their feedback is really how you learn about the memos. (Interview 3)

> Dave: Giving us hints on what we need to have in the mathematical model, telling us that it needs to be kind of simple and just telling us some stuff that we should think about. (Interview 1)

> Ryan: We got [. . .] more detailed feedback from the TAs that went over [. . .] every aspect of [. . .] our model [. . .]. And it gave us [. . .] a rubric for modeling our next draft. (Interview 1)

Although TA feedback was considered fundamental to their success, the type of TA feedback was identified as unhelpful. Each team member perceived the TA feedback to be vague and generic. Dave stated that the lack of details made the feedback difficult to understand, and Stan discussed why the feedback seemed generic.

> Dave: The bullet points that they choose could be a little bit more specific. It's just kind of hard to tell exactly what the points are getting at. (Interview 3)

> Stan: It seemed very general so [it] seemed like he just copy and pasted it into everyone's. 'Cause some of the stuff, like, he'd point out that we actually did it (Interview 1)

The perception of feedback being vague and generic was seen in other data sources as well. In the team meeting videos, there were instances where the students expressed their uncertainty about what the TA was trying to communicate in the feedback. During the team meeting to discuss TA feedback on MEA 1, the team accused the TA of not even reading their memo because the feedback was very generic. During the team meeting to discuss TA feedback on MEA 3, the team continued to struggle to understand the TA's feedback. This struggle is demonstrated in the video data excerpt in Table 2.

Actual TA Feedback

Analysis of the TA's feedback revealed that the majority of the TA's written feedback was either copied directly from the MEA-specific I-MAPs or was given verbatim to multiple teams, irrespective of the variation in teams' solutions. For MEA 1, none of the TA feedback was unique for this team.

Table 2. Sample of Video Data about TA Feedback on MEA 3

Time	Student	Conversation about Feedback from the TA
40:34	Dave	*Did* [*the TA*] *rip our rationales? Like, are our rationales bad on each of the statements?*
41:50	Stan	*Well, it's hard to tell because* [*the TA feedback is*] *all generic. It just says,* "[*rationales*] *must be provided.*"
54:44	Jerry	[Reading the TA's feedback] "*Mathematical errors must be eliminated.*" *What errors? I don't get that one.*

Every sentence appeared verbatim in feedback this TA gave to other teams. The TA feedback for MEAs 2 and 3 contained only two unique sentences each. In the generic feedback, the TA requested the team add information to their solutions that was already provided (e.g., the TA feedback for MEA 1 requested the team address what to do in the case of ties even though the team had tiebreakers incorporated in some of their procedure, the TA feedback for MEA 2 stated the team needed results even though the team had included results in their solution, and the TA feedback for MEA 3 requested the team include the direct user but the team already stated the direct user in their solution).

Peer Feedback

Perception of Peer Feedback

Team members expressed opinions about what makes helpful and unhelpful feedback. The team perceived that helpful peer feedback results from a significant amount of time spent providing feedback and focuses on the mathematical model. The students also noted that praise and the lack of constructive feedback was unhelpful.

All team members agreed that the amount of time a peer spent on their feedback clearly determined how helpful the feedback would be. Stan stated simply that peers who spent more time had more helpful feedback. Ryan stated that the best peer feedback his team received explained the shortcomings of their current mathematical model well.

> Stan: The one who actually spent more time, we actually used a sizable chunk of what they said. (Interview 1)

> Ryan: One of the six peers' reviews was very useful and I think that was the first review that we had and that had [. . .] a really good with addressing the mathematical model and where we had problems. So probably the mathematical model in that case. (Interview 3)

All of the team members complained about excessive praise in conjunction with a lack of constructive feedback. Jerry explained why the team did not find feedback that only praised their current solution helpful. Stan explained that a peer needs to at least point out something that needs to be fixed or strengthened to help improve their solution.

> Jerry: Well, you can't really respond [. . .] if they just say, "Everything is good," You have nothing to really change. (Interview 2)

> Stan: (laughter) We didn't really fix anything 'cause there was nothing that was pointed out and nothing—[The peers] didn't tell us anything to strengthen either. (Interview 2)

The majority of the team explicitly stated that the quality of the peer feedback degraded across the MEAs. Ryan stated that the quality of the peer feedback declined from MEA 1 to MEA 2 and then just remained poor for MEA 3; he also explained why he thought this decrease in quality occurred.

> Ryan: The feedback kinda declined very quickly. [. . .] It was from pretty good in the first one to not so good and not so good, but Two and Three didn't really vary 'cause at that point the students knew that it was only worth one point, one percentage point of their hundred points of the MEA. (Interview 3)

The students also agreed that the quality of feedback not only changed over time but also varied from peer to peer on a given MEA. Ryan also discussed the differences in the quality of peer feedback from the perspective of his team members; he explained that two members of his team enjoyed giving good feedback while the other two did not seem to care about it.

> Ryan: I think there's, like, a small percentage that takes the peer feedback seriously actually tried to do—give, like, good feedback to other teams. And I know two of the members of my group really didn't like it, and myself and another member actually didn't mind it and liked giving good feedback. (Interview 3)

Differences did exist in the students' perceptions of peer feedback. For example, two students expressed differing viewpoints about the general concept of peer feedback. Stan seemed to be more skeptical about peer feedback and questioned peers' credibility. Jerry, on the other hand, felt that feedback is feedback and anything can help no matter who it is coming from, though he did wish his peers would have tried to be more helpful when providing feedback.

> Stan: We checked [peer feedback that seemed to be helpful] with what the TA's comments were and we kinda saw they were in line so we [used it]. (Interview 1)

> Jerry: It was just kinda less helpful than we woulda liked it to be. 'Cause [. . .] you like to get constructive criticism anywhere you could get it no matter who it's from. 'Cause that's only gonnna help raise your grade, if anything, so [. . .] it wasn't really a challenge. It was just kinda a letdown more so than anything. (Interview 2)

Actual Peer Feedback

Analysis of the peer feedback that the team received supported the team's perceptions about constructive peer feedback being helpful. Table 3 shows the number of feedback comments that the team received of each type for each MEA. For

Table 3. The amount of constructive and non-constructive peer feedback for each MEA

	Not Constructive			Constructive		
	"None"	Praise	Summary	MM	R&M	SA
MEA 1 (2 peers)	-	2	3	5	1	7
MEA 2 (2 peers)	-	4	1	-	1	3
MEA 3 (3 peers)	3	2	1	7	2	3

Table 4. The amount of constructive and non-constructive peer feedback for MEA 3 (by peer reviewer)

	Not Constructive			Constructive		
	"None"	Praise	Summary	MM	R&M	SA
Peer 1	1	1	-	-	-	2
Peer 2	2	-	1	1	1	-
Peer 3	-	1	-	6	1	1

Table 5. Sample of Video Data about Peer Feedback on MEA 2

Time	Student	Conversation about Feedback from Peer 3
05:04	Stan	*We got no one that really knew what they were doing. Yeah. That's great. We got the shaft this time.*
05:21	Dave	*They've got good points on this one.*
05:24	Ryan	*By the peer? (laughing)*
05:26	Jerry	*Yeah, that doesn't really mean anything.*
05:28	Dave	*No, but it's better than the last one at least.* [Reading peer feedback aloud.] *Yeah, these aren't going to be very helpful in doing a third draft.*

example, two peer reviewers gave the team feedback on MEA 1 that had instances of both non-constructive and constructive feedback (e.g., two instances of praise and five instances of Mathematical Model feedback). Based on this analysis, the team received constructive peer feedback concerning the Mathematical Model dimension for MEA 1 and MEA 3, but none for MEA 2.

The analysis also demonstrated that the number of constructive feedback comments varied from peer reviewer to peer reviewer for each MEA. For example, Table 4 shows the feedback each peer reviewer gave on MEA 3. Peer 3 gave comparatively more constructive feedback than Peers 1 and 2, who gave an equal amount of or more non-constructive than constructive feedback comments.

Differences between TA and Peer Feedback

There were differences in how the students perceived TA and peer feedback. First, all team members pointed out that TAs control the grades whereas peers do not. Stan thought that his classmates' feedback was handicapped because they knew nothing more or less than he did. Three of the four team members made comments similar to Dave's regarding the TA's role in determining grades.

> Stan: It's hard to have peer critiques to be [. . .] helpful, [. . .] 'cause they're in the same boat as you. So, I don't think they can be very helpful. (Interview 3)

> Dave: [TAs] know what they're grading on, so if they're telling us what they're grading on then we can change it so we get a good grade hopefully. (Interview 1)

The perception that their peers did not have much authority on creating a good MEA solution also occurred in the video when the team met after receiving peer feedback on MEA 2 (Table 5).

Changes to MEA Solutions

The previous sections have discussed the students' perceptions of the TA and peer feedback they received and compared that to analyses of the actual feedback. This section includes the students' perception of how they changed their solutions from Draft 1 to Draft 2 and Draft 2 to the Final Response through their Documentation of Changes and the actual changes they made after receiving feedback and giving feedback. It also includes evidence from the teams' written work that supports or contradicts the expressed perceptions.

Table 6. Change to MEA 3 solution based on TA feedback on R&M dimension

Data Source	Sample data from the corresponding data source
TA Feedback	"Your team should state that the procedure is designed to be used by the E3 Trans Consultants Planners Group to predict student travel mode choice (bus, drive, walk), given cost (for bus ticket and parking), travel time (in minutes for each option), proximity to bus stop (in miles), and bus frequency (in minutes)." *(This TA comment was copied from the I-MAP.)*
Change to Solution	The team added the underlined portion of feedback into their written solution to replace previous statement: "The Planners Group will use this procedure to predict the method of transportation students are most likely to use to get to classes."

Table 7. Change to MEA 2 solution based on TA feedback on MM dimension

Data Source	Sample data from the corresponding data source
TA Feedback	"Hard-coded quantitative values imbedded in a procedure require explicit assumptions or explanations. . . . Limitations might be centered around hard-coded quantitative values imbedded in a procedure." *(This TA comment was copied from the I-MAP.)*
Team's Documentation of Changes	"We weighted the data based on bins. The lowest bin received the smallest weight and the highest bin received the largest weight."
Change to MEA Solution *(researchers' analysis)*	The team had two ranking systems with an overall ranking system to determine the best shipping company. Draft 1: rank 1 – sum of the squares of the deviations, rank 2 – mean Draft 2: rank 1 – same, rank 2 – hard-coded values for a bin scoring method
Change to MEA Solution *(excerpt of team's Draft 2)*	Rank 2: "Create bins with increasing intervals of 5 minutes. The bin containing 0 minute to 5 minutes is considered bin number 1. The bin containing 6 to 10 minutes is bin 2 and so on. Determine how many data points from each company go in each bin. Multiply bin number by the number of data points in the bin to get a score."

Perception of Responding to TA Feedback

All of the team members discussed making changes by addressing every component of TA feedback to ensure they received a good grade. Stan stated that they tried to make sure to address every point in the feedback, and Jerry discussed addressing all the feedback in a step-by-step manner. Ryan mentioned that they tried to address all of the feedback because they wanted to ensure they would receive a good grade.

> Stan: Well, we read what [the TA] wrote and we tried to hit all the points that he had. (Interview 1)

> Jerry: When we—we looked at [TA feedback] pretty much step by step so we'd look at what he wanted to fix and we'd fix it. (Interview 1)

> Ryan: [The TA] provided lots of feedback and we wanted to make sure we could cover every aspect so we got a good grade. (Interview 1)

Actual Responses to TA Feedback

The team's actual response to TA feedback showed that the team did in fact try to address every aspect of TA feedback. An instance of a clear connection between TA feedback and the team's response to feedback is shown in a change made to the Re-Usability and Modifiability dimension of MEA 3 (see Table 6). The TA pointed out a need for an overarching statement of the purpose of the model in the team's memo and the team wrote exactly what the TA said in the feedback in their solution.

Not all attempts by the team to address the TA's feedback were as successful. An instance of a disconnect between the TA's feedback and the team's Documentation of Changes is shown for a change made to the team's mathematical model for MEA 2 based on TA feedback about the Re-Usability and Modifiability dimension (see Table 7). The TA gave generic feedback about types of limitations and assumptions that should be made in the procedure. One part of the TA's feedback described the importance of communicating limitations regarding the inclusion of hard-coded values in a mathematical model. The team did not presently have any hard-coded values in their mathematical model. The team addressed this generic feedback by then adding hard-coded values to their model (e.g. bin edges for a weighted calculation). Hard-coded values are not an ideal in mathematical

Table 8. Changes to MEA 1 solution based on Peer Feedback on MM dimension

Data Source	Sample data from the corresponding data source
Peer Feedback	"Explain how to calculate with missing data."
Team's Documentation of Changes	"Missing times travelled will be found by taking the mean of all times from all team's throws (boomerang and straight) that provide both time in air and length of throw. This mean will be divided by the mean of the distances of every throw's (boomerang and straight) length in the competition that provide both time in air and length of throw. The resulting number (the divided means) are multiplied by the distance travelled of throw in question. If distance from target, distance thrown, or all fields are missing, the data for the throw is then omitted in all calculation. The procedure for missing data was developed in order to account for all possible missing data. We used the means of all throws in the competition in order to create a measure of the typical plane."
Change to MEA Solution	Draft 2: no explanation of what to do when data is missing Final Response: statement from Documentation of Changes (quoted above) added to solution

models because it limits the use of the model to data sets that are appropriate for the set numbers and values, hence the TA was notifying the team of the importance of addressing how hard-coded values limit a mathematical model in the feedback.

Perception of Responding to Peer Feedback

Dave discussed only using peer feedback as another perspective to understand the level of clarity in the communication of their procedure. Although Dave saw the benefit of this point, he still felt peer feedback was unnecessary. Jerry also thought that the peer feedback was not helpful. He did acknowledge that it was at least a reason for the team to meet to improve their solution. The overall attitude presented by each of the students was that peer feedback was not a major impetus for the changes they made to their solutions.

> Dave: It's good to find out if other people have problems with your model and understanding it, but other than that, I still don't really see much of a point in [peer feedback]. (Interview 3)

> Jerry: So [peer feedback is] not something that absolutely needed to happen in our group for us to get a better grade. It was just some—just another reason for us to meet. (Interview 3)

Actual Response to Peer Feedback

Although the team members stated in their interviews that the peer feedback was unhelpful, some peer feedback was discussed by the team in their Documentation of Changes as something that led to changes other than just points of miscommunication. An instance of peer feedback that was directly connected to changes made in the team's solution to MEA 1 is shown in Table 8. A peer reviewer told the team to address the problem of missing data. The team addressed this in their solution, and then the team stated this change was related to the peer's feedback in their Documentation of Changes.

There were also instances of peer feedback being used to improve the team's solutions but not being acknowledged in the Documentation of Changes. An example of this is seen in MEA 3 where the team stated that there were no changes to better address the Mathematical Model and Shareability dimensions based on the peer feedback. They also stated there were some minor changes to better address the Reusability and Modifiability dimension based on feedback from Peer 2. Recall that for MEA 3, Peer 3 made a number of constructive feedback comments (see Table 4). This team did not refer to Peer 3 as being helpful in their interviews or Documentation of Changes, but they did discuss feedback from Peer 3 multiple times during their revision meeting. Table 9 shows some places in the video data that the team discusses the feedback from Peer 3 and changes made based on the feedback.

The analysis of the student work showed that some of the changes could be related to feedback from Peer 3 (Tables 10 and 11). The team's revisions resulted in communicating their solution in a more professional manner, ensuring that the procedure had the appropriate components, and incorporating rationales about unused data.

Perception of Changes Based on Giving Peer Feedback

Each of the team members perceived giving feedback to be useful because it allowed them to compare their own model with other teams' models, see other teams' perspectives on the problem, and experience assessment from a TA's perspective. Stan expressed that he felt this enabled the team to make adjustments to their own model.

> Stan: Well, I noticed things that [the people I gave feedback to] did well. [. . .] I made sure that our model did stuff just as well as their model did—and explanations—and hopefully better. And when I gave feedback,

Table 9. Sample of Video Data about Feedback from Peer 3 on MEA 3

Time	Student	Conversation about Feedback from Peer 3
12:04	Stan	(Discussing feedback from Peer 3 about using all of the data or justifying not using it) *We used all the data, right*?
12:14	Dave	*No.*
12:16	Stan	*What did we not use?*
12:17	Dave	*Frequency of bus.*
12:19	Stan	*Oh yeah. We need to justify that.*
12:24	Dave	*And cost of car.*
17:19	Stan	(reading feedback from Peer 3) *Alright. He is kinda right on that actually.*
17:22	Dave	*Yeah.*
17:24	Stan	*The first guy is pretty good; I like him. Or I should say he or she.*
36:37	Dave	(discussing cost of the car feedback brought up by Peer 3) *I think we can just put in our assumptions like, no car costs more than $100.*
45:26	Stan	Reading aloud the justifications written in their procedure for the data they didn't use to address the feedback from Peer 3

Table 10. Changes to MEA 3 solution based on Peer 3 feedback on SA dimension

Data Source	Sample data from the corresponding data source
Peer Feedback	"the > needs to be switched with a < sign otherwise the final step doesn't work"
	"It may be easier for the client to understand if your statements and variables are written out in plain English"
Corresponding Changes to MEA Solution	The team had multiple steps in their procedure that involved logical expressions. From Draft 2 to Final Response, all ">" and "<" signs were written out. For example: Draft 2: step 8 – If time to drive > time to take the bus minus 15, then the student will drive. Final Response: step 8 – ">" changed to "is less than or equal to"

Table 11. Changes to MEA 3 solution based on Peer 3 feedback on R&M dimension

Data Source	Sample data from the corresponding data source
Peer Feedback	"There are a few places where explanations are needed. Why did you leave out the frequency of the bus in your conditions? The bus stop may be close but it may not come at a convenient time. Would the student still take the bus? Also, while the cost of auto is given as a variable in the start, it is not used anywhere in your conditional statements. Why did you decide to leave this information out? If the car and bus are equally convenient and the bus costs $1 and parking costs $100, would they drive or take the bus? Your procedure in some situations says the student will drive even though it is much more expensive."
	"Most of the rationales are clear and concise. A few more may be needed for why you didn't use some types of data such as cost of auto and frequency of bus."
Changes to MEA Solution	Draft 2: There were no reference to the cost of parking and frequency of the bus beyond mentioning that these are given data Final Response: Team added the following statements: "The cost of parking will never be over one hundred dollars." "We determined that the following data does not affect the decision of which mode of transportation students choose: The frequency of the bus and the cost of the car. The frequency of the bus holds no weight in the student's decision since the bus arrival can be planned on accordingly. The cost of the car will [always] be less than riding the bus."

Table 12. Changes to MEA 2 solution based on experience of giving peer feedback

Data Source	Sample data from the corresponding data source
Video Data	After giving and receiving peer feedback, Ryan shared the model that he reviewed with other team members. Later in the team meeting Ryan said, "*Do we have a reason for why we used precision and accuracy? In the model that I critiqued, they did that really well.*"
Changes to MEA Solution	Draft 2: precision was mentioned in the solution four times; accuracy was not mentioned Final Response: precision was mentioned in the solution five times and accuracy was added to the model (mentioned three times) e.g. "We used accuracy since parts need to arrive on time so that [the client] can continue assembly of their products."

it seems like I was in the TA's shoes so I could see kind of how the TA would view it." (Interview 2)

Actual Changes Based on Giving Peer Feedback

While each team member perceived the process of conducting a peer review to be helpful, there was only one example found during all three MEAs in which the team actually reflected on their experience of giving peer feedback and making modifications based on that experience. This example occurred during the MEA 3 Draft 2 revision meeting (in the video data) and resulted in minor wording changes and a rationale change (shown in Table 12).

Summary of Findings

The following perceptions concerning TA and peer feedback were garnered from the analysis of one first-year engineering team's interview, video-taped team meetings, documented works, and TA and peer feedback.

- The team appreciated feedback from the TA as means to better understand the assignment and used the feedback as a checklist for revising their work to get a better grade.
- The team was sensitive to generic TA feedback, feedback that did not apply directly to their solution. Yet, the team attempted to address all TA feedback, whether or not it applied to their work.
- Some team members questioned the value of peer feedback, though they felt that time spent on the feedback raised the quality of the feedback.
- The team would have preferred more constructive feedback and fewer praise-only comments from peers.
- The team found that the quality of peer feedback degraded across MEAs and varied across peers on a given MEA.
- This team felt that peer feedback did not lead to change, though their work indicates otherwise.
- Some team members felt that the experience of giving peer feedback has multiple benefits, although these benefits did not seem to manifest themselves in their solution development.

Discussion and Implications

This case study focused on students' perceptions of TA and peer feedback and described how the team incorporated the feedback into their revised MEA solutions. While the data in this manuscript is limited to a single team of four students, the use of multiple data sources provided rich insights that help us to understand this case. Through our use of triangulation, we were able to examine the same phenomenon from the students' perspectives that are voiced in the interviews, an observers' perspective through the videos of the team meetings, and an objective perspective in seeing the actual student work and actual feedback. Through these three different lenses we have a more accurate understanding of the students' experiences with feedback than we would have had with a larger sample size but a single data source.

Effective Feedback: Students' Perspectives Vs. Research

Researchers state that in order for feedback to be effective it must be response-specific (Nelson & Schuun, 2009; Shute, 2008). The students in this study expressed an awareness that not all of the feedback from the TA was relevant to their work. In other PBL studies, students have expressed dissatisfaction with vague feedback from their instructors (Henry, Tawfik, Jonassen, Winholtz, & Khanna, 2012). Nelson and Schuun (2009) also suggest that feedback should avoid praise because it can be misguiding. The students agreed with this as well; they stated that the peer feedback was not helpful because it was mostly praise. The students perceived reviewers that clearly committed time to giving feedback, gave constructive feedback, and focused on giving feedback on the Mathematical Model dimension as being helpful. Researchers also agree that constructive feedback and spending time to ensure feedback is of high-quality are important aspects of giving effective feedback (Shute, 2008; Hattie & Timperley, 2007). While these students agree with researchers on the characteristics of effective feedback, authority over grades seemed to matter more than the quality of feedback.

Who Gives the Feedback Matters

The TA feedback in fact did consist almost entirely of generic feedback offered to all student teams. Yet, the students noted that receiving the TA feedback was the most helpful part of the process. On the other hand, the students felt that the peer review process was overall not helpful despite two peers giving mostly constructive feedback.

Overall the team clearly had different perceptions of feedback from TAs and peers; these sources of feedback also resulted in different types of changes. Based on the findings, it appeared the team believed the TA alone knows what an acceptable answer should be, controls the grades, and must be listened to. As a result, the team attempted to respond to all components of TA feedback, even if they felt the comments were not pertinent to their solution. A prime example of this is the students' effort to address the generic feedback discussing the limitations of hard-coded values in a mathematical model by adding hard-coded values to their model (see Table 7).

In contrast, the team seemed to more critically judge the peer feedback to the point where the team was resistant to making any changes based on their peers' feedback. An example of this is where a peer gave constructive feedback that had the potential to help them rethink some aspects of their procedure, but the team only made a minor change (see Table 11). This devaluing of peers' feedback undermines the use of peer feedback in the classroom and needs to be addressed through instruction.

Purpose of the Feedback: More Than a Grade

The purposes of feedback include improving the final product (i.e., the MEA solution) and scaffolding student learning (Shute, 2009; Hattie & Timperley, 2007). Students showed their desire for specific feedback, but they focused more on their grades than their learning. This student struggle of focusing on their grades in a seemingly less structured environment is not unique to this study (i.e. Henry et al., 2012). Helping students focus on the direct user as their audience instead of the grader is essential for students to develop high-quality solutions instead of merely achieving high grades. Also, helping students consider peer feedback as advice from a colleague working on the same problem with a different perspective would be helpful for students to gain insights from and act on peer feedback. More broadly, instruction needs to target the development of skills for giving and receiving feedback in professional practice.

Peer Feedback: Improving Quality

Students commented on the low participation in and quality of peer feedback. The number of students in the course makes monitoring the quality of peer feedback difficult. So, strategies employed have to be manageable with available resources. To increase participation, the peer feedback portion of the overall MEA grade was, in subsequent semesters, increased to about 10% of the MEA grade, with participation points going towards calibration and actual peer review. To increase quality, teams were required to review the peer feedback they received (Diefes-Dux & Verleger, 2009). The results pointed to the need for student training on how to critique the feedback they receive. Another approach to improving participation and the quality of peer feedback was to instruct students that the class would receive extra credit when the entire class received an A or B on the Final Response. Anecdotal evidence suggests that students exhibited higher commitment to providing peer feedback including late submission of extensive peer feedback for no credit.

To increase the opportunity for peer feedback, peer feedback has been moved to occur before TA feedback. At Draft 1, the solutions are less polished and the peers are better able to identify something on which they can provide meaningful feedback; though early indicators (prior to additional student training on with the *MEA Rubric* dimensions) suggest the impact was still low (Carnes et al., 2010). In addition, the number of calibration items has been increased from one to two. Peer reviewers now also receive training on the characteristics of constructive feedback, the importance of focusing on the mathematical model when giving feedback, and how to respond to feedback of mixed quality.

TA Feedback: Improving Quality

Changes have also been made to the TA training. The modified TA training now:

- addresses how generic (copy and paste) feedback is unhelpful and frustrating to students,
- requires the TAs summarize what they find in the students' solutions that addresses each *MEA Rubric* dimension and then make recommendations, and
- requires the TAs show evidence that they attempted to use the students' procedures to generate results.

While summarizing and applying were required as part of training in Fall 2008, they were not formally prompted to continue to do this when actually providing feedback on students' work (Verleger et al., 2010). In training, we now emphasize the importance of summarizing and applying. We discuss how these assessment steps build trust with students that their work has been read and the application results provide evidence to students that their models are or are not working. Further, this level of TA engagement in the student work enables the TAs to detect issues in the student work that they would miss by simply reading their work.

In addition, the *MEA Rubric* dimensions were revised and better defined. In other research it was noted that TAs had considerable trouble differentiating Reusability, Modifiability, and Shareability (Diefes-Dux et al., 2012). This caused TA feedback to be non-specific and repetitive across or misplaced in the *MEA Rubric*. The revised definitions are now emphasized in the training of peers and TAs.

Ultimately, with clearer *MEA Rubric* dimensions and strategies for critically evaluating at student work, the TAs should be enabled to provide more response-specific feedback. Our future work will focus on how these changes influence the ways that students perceive and incorporate feedback into their solutions.

Significance and Future Work

High quality formative feedback, whether from instructors, TAs, or peers, is necessary in classrooms employing an increasing amount of authentic learning activities such as mathematical modeling and design. However, there are complex relationships between students' work, those giving and receiving feedback, and the feedback itself that need to be better understood to improve the effectiveness of formative feedback. This study utilized an in-depth analysis of one team's experience to begin to highlight what feedback is effective and why written feedback works and does not work. A case study is an effective method for gaining depth of understanding, but it lacks the ability to have breadth and generalizability. The purpose of this case study was to gain insight on the feedback process through multiple lenses to enable development of more informed and meaningful directions for future research. Future research should address the limitations of and seek to answer a number of intriguing questions raised by this study. Some of these questions follow.

What are effective strategies for redirecting students' focus from their grades to their learning? That is, how can instructors increase students' intrinsic motivations for learning within the richness of authentic problem solving situations? Means of assessing students' motivation for revising their work following various types of feedback would need to be developed and tested.

How do we better train TAs to give high quality feedback in open-ended problem solving situations? TA training in the context of the first-year engineering program has been provided and steadily reworked to resolve a variety issues since 2003 (Diefes-Dux et al., 2008; Diefes-Dux et al., 2010; Rodgers, Diefes-Dux, Jung, & Cardella, 2013). For instance, the identified problem of vague and generic TA feedback has been mitigated by making TAs aware of what it is, why it is not effective, and how to give response-specific feedback (Rodgers, Diefes-Dux, & Cardella, 2012). As of academic year 2013–14, TA training is offered at two levels. The beginner level training focuses on helping TAs understand a given open-ended problem, potential solutions, how to interact with students, and how to use the provided assessment tools to give feedback. The intermediate level training focuses on helping TAs improve the quality of their feedback through self-regulation. TAs analyze the feedback they have given students, classify its type and quality, investigate students' responses, and identify ways to improve their feedback. The effectiveness of these TA training efforts still needs to be investigated through another look at the type and quality of feedback that TAs provide to students following their various levels of training.

What is the effect of peer feedback training? How can peers' engagement in providing effective feedback be improved? How does authority influence students' responses to peer feedback? How does the quality of one's own given peer feedback influence one's perspective of received peer feedback? (More specifically, do students project their own poor quality of work onto their peers or do students assume no peer can give as high-quality feedback as they do?) Exploring these questions would lead to improvements in the utilization of peer feedback and the realization of student learning benefits of peer feedback (Verleger, 2009).

As shown in the questions above, the research around feedback in complex learning situations still merits further exploration to better understand the interplay between students, instructors, learning, work products, and grades. The results of such investigations should lead to better instructional strategies for scaffolding student learning as students' solve authentic problems. Ultimately, better feedback strategies should play a significant role in preparing students to solve the real and challenging problems they will face after graduation.

Acknowledgments

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

References

Accreditation Board of Engineering and Technology Accreditation Department (ABET). (2012). *Criteria for accrediting engineering programs, 2013–2014*. Baltimore, MD: ABET Inc. Retrieved from http://www.abet.org/DisplayTemplates/DocsHandbook.aspx?id=3149

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education, 5*(1), 7–74. http://dx.doi.org/10.1080/0969595980050102

Cardella, M. E. (2010). Mathematical modeling in engineering design projects: Insights from an undergraduate capstone design project and a year-long graduate course.

In R. Lesh, P. L. Galbraith, C. R. Haines, & A. Hurford (Eds.) *Modeling students' mathematical modeling competencies* (pp. 87–98). New York: Springer. http://dx.doi.org/10.1007/978-1-4419-0561-1_7

Carnes, M. T., Cardella, M. E., & Diefes-Dux, H. A. (2010). Progression of student solutions over the course of a Model-Eliciting Activity (MEA). In *Proceedings of the 40th ASEE/IEEE Frontiers in Education Conference, Washington, DC.* http://dx.doi.org/10.1109/FIE.2010.5673279

Carnes, M. T., Diefes-Dux, H. A. & Cardella, M. E. (2011, June). *Evaluating student responses to open-ended problems involving iterative solution development in Model Eliciting Activities*. Paper presented at the 118th ASEE Annual Conference & Exposition, Vancouver, B.C., Canada.

Cross Francis, D., Hudson, R., Vesperman, C., & Perez, A. (2014). Comparing technology-supported teacher education curricular models for enhancing statistical content knowledge. *Interdisciplinary Journal of Problem-Based Learning*, *8*(1), 50–64. http://dx.doi.org/10.7771/1541-5015.1416

Diefes-Dux, H. A., Hjalmarson, M. A., & Zawojewski, J. S. (2013). Student team solutions to an open-ended mathematical modeling problem: Gaining insights for educational improvement. *Journal of Engineering Education, 102*(1), 179–216. http://dx.doi.org/10.1002/jee.20002

Diefes-Dux, H. A.; Hjalmarson, M. Miller, T. & Lesh, R. (2008). Model-eliciting activities for engineering education. In J. S. Zawojewki, H. A. Diefes-Dux, & K. J. Bowman, (Eds.). *Models and modeling in engineering education* (pp. 17–35). Rotterdam, The Netherlands: Sense Publishers.

Diefes-Dux, H. A., Hjalmarson, M., Zawojewski, J. S., & Bowman, K. (2006). Quantifying aluminum crystal size part 1: The Model-Eliciting Activity. *Journal of STEM Education: Innovations and Research*, *7*(1&2), 51–63.

Diefes-Dux, H. A. & Verleger, M. A. (2009, October). *Student reflections on peer reviewing solutions to Model-Eliciting Activities*. Paper presented at the 39th ASEE/IEEE Frontiers in Education Conference, San Antonio, TX.

Diefes-Dux, H. A., Zawojewski, J. S., & Hjalmarson, M. A. (2010). Using educational research in the design of evaluation tools for open-ended problems. *International Journal of Engineering Education*. *26*(4), 807–819.

Diefes-Dux, H. A., Zawojewski, J. S., Hjalmarson, M. A., & Cardella, M. E. (2012). A framework for analyzing feedback in a formative assessment system for mathematical modeling problems, *Journal of Engineering Education, 101*(2), 375–406. http://dx.doi.org/10.1002/j.2168-9830.2012.tb00054.x

Gainsburg, J. (2006). The mathematical modeling of structural engineers. *Journal of Mathematical Thinking and Learning*, *8*(1), 3–36. http://dx.doi.org/10.1207/s15327833mtl0801_2

Gipps, C., & Stobart, G. (1993). *Assessment: A teacher's guide to the issues*. London: Hodder and Stoughton.

Hanoglu, O., Horvath, A., & Diefes-Dux, H. A. (2014). First-year engineering team responses to feedback on their mathematical models—a video study. *Paper presented at the 121st ASEE Annual Conference and Exposition, Indianapolis, IN.*

Hatch, J. A. (2002). *Doing qualitative research in education settings*. Albany: State University of New York Press.

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, *77*(1), 81–113. http://dx.doi.org/10.3102/003465430298487

Henry, H. R., Tawfik, A. A., Jonassen, D. H., Winholtz, R. A., & Khanna, S. (2012). "I know this is supposed to be more like the real world, but . . .": Student perceptions of a PBL implementation in an undergraduate materials science course. *Interdisciplinary Journal of Problem-Based Learning*, *6*(1), 43–81. http://dx.doi.org/10.7771/1541-5015.1312

Hmelo-Silver, C. E. & Barrows, H. S. (2006). Goals and strategies of a problem-based learning facilitator. *Interdisciplinary Journal of Problem-Based Learning*, *1*(1): 21–39. http://dx.doi.org/10.7771/1541-5015.1004

Ice, P., Swan, K., Diaz, S., Kupczynski, L., & Swan-Dagen, A. (2010). An analysis of students' perceptions of the value and efficacy of instructors' auditory and text based feedback modalities across multiple conceptual levels. *Journal of Educational Computing Research*, *43*(1), 113–134. http://dx.doi.org/10.2190/EC.43.1.g

Kelly, S. E., & LeDocq, R. L. (2001). Incorporating writing in an integrated calculus, linear algebra, and differential equations sequence. *Problems, Resources, and Issues in Mathematics Undergraduate Studies*, *11*(1), 67–78.

Layton, R. A., Loughry, M. L., Ohland, M. W., & Ricco, G. D. (2010). Design and validation of a web-based system for assigning members to teams using instructor-specified criteria. *Advances in Engineering Education*, *2*(1), 1–28.

Lesh, R., Hoover, M., Hole, B., Kelly, A., & Post, T. (2000). Principles for developing thought revealing activities for students and teachers. In A. Kelly & R. Lesh (Eds.), *The handbook of research design in mathematics and science education*. (pp. 591–645). Mahwah, NJ: Lawrence Erlbaum.

Lesh, R., Lester, F. K., & Hjalmarson, M. (2002). A models and modeling perspective on metacognitive functioning in everyday situations where problem solvers develop mathematical constructs. In R. Lesh & H. M. Doerr (Eds.), *Beyond constructivism: Models and modeling perspective on mathematics problem solving, learning, and teaching*. (pp. 383–403). Mahwah, NJ: Lawrence Erlbaum.

Lincoln, Y. S, Lynham, S. A., & Guba, E. G. (2011). Paradigmatic controversies, contradictions, and emerging confluences, revisited. In N. K. Denzin & Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research*. (pp. 97–128). Thousand Oaks, CA: SAGE Publications, Inc.

Moore, T., & Diefes-Dux, H. A. (2004, October). *Developing Model-Eliciting Activities for undergraduate students based on advanced engineering content.* Paper presented at the 34th ASEE/IEEE Frontiers in Education Conference, Savannah, GA.

Nelson, M. M., & Schunn, C. D. (2009). The nature of feedback: How different types of peer feedback affect writing performance. *Instructional Science*, *27*(4), 375–401. http://dx.doi.org/10.1007/s11251-008-9053-x

Nilson, L. B. (2003). Improving student peer feedback. *College Teaching, 51*(1), 34–38. http://dx.doi.org/10.1080/87567550309596408

Parr, J. M., & Timperley, H. S. (2010). Feedback to writing, assessment for teaching and learning and student progress. *Assessing Writing*, *15*(2), 68–85. http://dx.doi.org/10.1016/j.asw.2010.05.004

Patton, M. Q. (2002). *Qualitative research and evaluation methods*. Thousand Oaks, CA: Sage Publications.

Rada, R., & Hu, K. (2002). Patterns in student–student commenting. *IEEE Transactions on Education, 45*(3), 262–267. http://dx.doi.org/10.1109/TE.2002.1024619

Rodgers, K. J., Diefes-Dux, H. A., & Cardella, M. E. (2012, June). *The nature of peer feedback form first-year engineering students on open-ended mathematical modeling problems*. Paper presented at the 119th ASEE Annual Conference and Exposition, San Antonio, TX.

Rodgers, K. J., Diefes-Dux, H.A., Jung, H., & Cardella, M.E. (2013). A comparative analysis of feedback from undergraduate and graduate teaching assistants on open-ended problems. *Paper presented at the annual meeting of the 2013 American Educational Research Association. San Francisco, CA.*

Scott, K. S. (2014). A multilevel analysis of problem-based learning design characteristics. *Interdisciplinary Journal of Problem-based Learning*, 8(2). http://dx.doi.org/10.7771/1541-5015.1420

Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research, 78*(1), 153–189. http://dx.doi.org/10.3102/0034654307313795

Smith, E., & Gorard, S. (2005). 'They don't give us our marks': The role of formative feedback in student progress. *Assessment in Education: Principles, Policy & Practice*, *12*(1), 21–38. http://dx.doi.org/10.1080/0969594042000333896

Smith, H., Cooper, A., & Lancaster, L. (2002). Improving the quality of undergraduate peer assessment: a case study from psychology. *Innovations in Education and Teaching International, 39*(1), 71–81. http://dx.doi.org/10.1080/13558000110102904

Stemler, S. (2001). An overview of content analysis. *Practical Assessment, Research & Evaluation*, *7*(17), 137–146.

Topping, K. J. (1998). Peer assessment between students in colleges and universities. *Review of Educational Research, 68*(3), 249–276. http://dx.doi.org/10.3102/00346543068003249

Tseng, S. C., & Tsai, C. C. (2007). On-line peer assessment and the role of the peer feedback: A study of high school computer course. *Computers & Education*, *49*(4), 1161–1174. http://dx.doi.org/10.1016/j.compedu.2006.01.007

Verleger, M. (2009). *Analysis of an informed peer review matching algorithm and its impact on student work on model-eliciting activities*. (Doctoral dissertation). Retrieved from Purdue Library Collections.

Verleger, M., Diefes-Dux, H., Ohland, M. W., Besterfield-Sacre, M., & Brophy, S. (2010). Challenges to informed peer review matching algorithms. *Journal of Engineering Education*, *99*(4), 397–408. http://dx.doi.org/10.1002/j.2168-9830.2010.tb01070.x

West, R. E., Williams, G. S., & Williams, D. D. (2013). Improving problem-based learning in creative communities through effective group evaluation. *Interdisciplinary Journal of Problem-Based Learning*, *7*(2), 102–127. http://dx.doi.org/10.7771/1541-5015.1394

Yin, R. K. (2009). *Case study research: Design and methods*. Thousand Oaks, CA: Sage.

Kelsey J. Rodgers, *kelseyjoy@purdue.edu,* is a doctoral student in engineering education at Purdue University. Her research interests include the impact of feedback on student works, effective feedback training techniques, and students' understandings of mathematical models and simulations.

Aladar K. Horvath, *ahorvath5@ivytech.edu,* is an assistant professor of mathematics at Ivy Tech Community College.

Hyunyi Jung, *jung91@purdue.edu,* is a doctoral student in mathematics education at Purdue University. Her experiences include teaching math at K–12 levels in the U.S. and in Korea, supervising student teachers, and reviewing a CCSSM Curriculum Alignment Tool. Her research interests center around teachers' knowledge for mathematical modeling.

Amanda S. Fry, *afry@purdue.edu,* is a doctoral student in art education at Purdue University. Her research interests center around using art and mentoring as tools to help academically struggling students.

Heidi A. Diefes-Dux, *hdiefes@purdue.edu,* is a professor of engineering education at Purdue University. Her research focuses on the development, implementation, and assessment of authentic learning experiences.

Monica E. Cardella, *mcardell@purdue.edu,* is an associate professor of engineering education at Purdue University.

Appendix 1. Student Interview Protocol

Part I: Experiences responding to feedback

First I will be talking with you about your experiences in responding to feedback you received from your peers and your TAs.

1. *Can you please describe for me the type of feedback that you received from your TA?*
2. *How did your team respond to this feedback? Would you have done anything differently if you were responding by yourself?*
3. *Did you encounter any challenges in responding to the feedback from your TA? If yes, How did you work around these challenges?*
4. *Can you please describe for me the type of feedback that you received from your classmates?*
5. *How did your team respond to this feedback? Would you have done anything differently if you were responding by yourself?*
6. *Did you encounter any challenges in responding to the feedback from your classmates? If yes, How did you work around these challenges?*

Part II: Experiences providing feedback

Now I will be talking with you about your experiences in providing feedback to another team on their MEA response.

7. *What kinds of feedback did you provide to another team? Probe: emphasis on mathematical model vs. reusability/sharability vs. meeting client's need.*
8. *Did you encounter in any challenges in trying to provide feedback to your peers on their model-eliciting activities? If so, please describe them.*
9. *How did you work around these challenges?*
10. *Can you think of anything that would have helped you to give better feedback to your peers?*

Part III. Experiences in Responding to / Receiving Feedback on the Feedback Given

The final activity you did for the Model-Eliciting Activity was to give feedback to your peer reviewers on the feedback they provided you. I will now talk with you about giving and receiving this feedback.

11. *Is there anything that you decided not to mention in the feedback you gave to your peer reviewer?*
12. *Did the feedback you received about your feedback help you?*