120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #7119

A Teaching Assistant Training Protocol for Improving Feedback on Open-Ended Engineering Problems in Large Classes

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A Teaching Assistant Training Protocol for Improving Feedback on Open-Ended Engineering Problems in Large Classes

Teaching Assistants (TAs) are vital to teaching large classes. TAs often function as students' primary contact within a large course, and, in many cases, they evaluate the majority of student work on assignments. For TAs, evaluating students' work on open-ended problems is challenging because students produce a variety of solutions that the TA must interpret to accurately apply a given rubric. Reliable evaluation of student work is desirable. This paper describes and begins to explore a TA training protocol for identifying TAs who are in need of additional guidance on how to evaluate students' work on open-ended engineering problems in a large class.

This work is set in a large first-year engineering program context in which open-ended problem solving has been incorporated and TA training has been implemented to facilitate the use of such problems. This paper will do the following: (1) explore the history and need for TA training in this context, (2) describe the context in which training occurs, (3) describe the training process and protocol in detail, (4) examine current data to explore the effectiveness of the TA training protocol, and (5) identify future direction for informing the design of the TA training protocol.

History and Need for TA Training

Bringing authentic[1], open-ended learning experience into early undergraduate engineering courses is encouraged as a means of showcasing and engaging students in the nature of engineering practice as well as laying the foundation for addressing multiple ABET and institutional program objectives that go beyond purely the development of content knowledge and analytical skills. The challenge is that many first- and second- year engineering courses are large and assessment and evaluation of student work is in the hands of TAs who are often provided little to no training to perform more traditional short answer problem grading much less complex student work assessment. So, bringing authentic open-ended problem solving into a large engineering course necessitates a level of TA training for which there is little precedence in the teaching of engineering.

Much of the development and research on training and professional development of TAs has focused on large introductory courses, particularly in science where graduate TAs (GTAs) duties entail leading laboratory and discussion sessions.[2,3] Formal training for TAs, provided at the university level, department level, and course level[4], often focuses on the basics and mechanics of being a TA. The most basic training for new TAs includes topics such as TA responsibilities and grading (e.g. homework and exam). More advanced, yet still introductory, TA training topics include knowing students, lecture techniques, leading discussions, classroom management, creating optimal learning environments, academic integrity, class planning and instructor evaluations.[5,6] Opportunities for in-depth development of TAs pedagogical skills are limited, and the prevalence of optional versus mandatory training leaves many TAs floundering to develop their teaching skills in an ad hoc fashion.[6] The lack of systemic pedagogical training for TAs can be seen as a challenge to making significant changes to the learning environment in large introductory courses. However, others argue that TA training provides the best opportunity for instructional change as the reward structure for faculty is often prohibitive of their engaging in significant change.[7] Whether a challenge or an opportunity, TA training is central to successful educational reform.

When significant educational reform is sought in large introductory courses, such as incorporating significant authentic open-ended problem solving, the success of the reform rests in the hands of the TAs because their contact with students is greater than that of the university faculty or staff instituting the reform. They are burdened with not only having to enact the reform but also explaining the innovation to the students enrolled in the course. Enacting the reform may entail the TAs taking part in teaching practices that are unfamiliar and uncomfortable. As such TAs need adequate and ongoing training in not just the mechanics of the innovation but also in the basis for the innovation; they also need to provide input and feel that the input is valued. Seymore (2005) describes this as making the TAs partners in the innovation.[8] Instances where TA training in support of educational reform has been reported as being central to the reform include inquiry-based instruction[8] and intrinsic motivation (IM) supported instruction[9].

Our reform has focused on the introduction of open-ended problem in the form of Model-Eliciting Activities (MEAs) in a large first-year engineering course.[10] MEAs are authentic, open-ended, client-driven, engineering-based mathematical modeling problems.[11] Teams of students develop a written document describing their generalizable procedure (mathematical model) for solving a given problem and similar problems. MEAs have been conducted at a Midwestern university since 2002 in the required First-Year Engineering (FYE) Program courses.[12] TA professional development with MEAs at our university began in earnest the year after MEAs were introduced[13] and has evolved over the last 10 years.

In the first year of MEA implementation, we quickly learned that GTAs need to understand what MEAs are and what the purpose of them is with regards to the course learning objectives. Such training is necessary so that the GTAs can communicate in a positive manner with first-year engineering students who are unfamiliar with and frustrated by the open-ended nature of MEAs and are having difficulty understanding the learning value of the open-ended problem solving experiences.[14]

GTA training then turned to assessment of student work which involved the development of a *MEA Rubric* that both assess the student team solutions against criteria of value to engineering practice and could be reliably used by the TAs.[15] GTA training and the *MEA Rubric* evolved in concert as analysis of GTAs' use of the *MEA Rubric* revealed weaknesses in their ability to reliably apply the rubric dimensions.[13,15] Early on it was evident that the GTAs struggle to assess the quality of the mathematical models the students produce. Other GTA assessment issues that needed to be addressed were TAs' ability to identify and assess when and to what degree student teams had produced results from applying their models, written a well-developed problem formulation statement, and justified the decisions they made in their mode development. A companion to the *MEA Rubric* became necessary to guide the TAs in assessment of student work on specific MEAs, this MEA-specific document is called the *Instructors MEA Assessment/Evaluation Package* (*I-MAP*). Over time, GTA training ramped up from 2 to 3 hours to 8 hours in which the GTAs spent a considerable amount of time assessing prototypical student work in face-to-face training.[15]

In Fall 2009, the role of undergraduate TAs (UTAs) in the first-year engineering course changed dramatically. They had played the role of peer mentors in the course – attending laboratory sections and office hours to answer student questions. They too had received TA training with MEAs since Fall 2003 but their training only included working the MEA and thinking through how they would interact with students during the in-class implementation of the MEA. They were not involved in the assessment of student work on MEAs. Due to a change in instructional facilities, that grew the laboratory size from 32 to 120 students, the number of instructors needed in the laboratory space to facilitate active learning and open-ended problem solving changed. This was not a unique change, as other universities are also employing UTAs for various reasons (e.g. large enrollment, financial, retention) to perform an array of teaching duties.[14,16] By Spring 2010, UTAs responsibilities shifted to include assessment of student work on MEAs. This had the benefit of reducing GTA workload but also raised concern over the preparation UTAs would need to engage in high-level and reliable assessment of student work on open-ended problems. Time for TA training also became a concern because UTAs have limited time available for face-to-face training. So our protocol that had developed for training GTAs would no longer work for all TAs.

In Spring 2012 and Fall 2012, the student enrollment in the FYE program was approximately 1700 students, necessitating that the 2-semester required course sequence be staffed by 9 GTAs, 70 UTAs, 11 faculty, and 3 staff. All TAs (both graduate and undergraduate) were the primary point-of-contact for students; the TAs evaluated almost all class assignments, including MEA solutions. The UTA pool included sophomores, juniors, and first and second year seniors from all 13 engineering disciplines offered at Purdue. GTAs also represented a cross-section of the engineering graduate programs offered at Purdue. The primary faculty responsibility was to teach the content portion of the class and act as the formal section guide. The staff members provide the support necessary to manage a course of this size; this includes managing the hiring, basic training, and weekly update meetings with the TAs. Typically, each GTA oversaw 10 UTAs (5 UTAs per section of 120 students divided into teams of 4 students each: 4 UTAs that attend all classes and one dedicated UTA grader). Ensuring that each of the approximately 80 TAs is adequately prepared to reliably evaluate student work on MEAs presents a significant challenge.

Context of TA Training

TA training has two purposes. The first purpose is to move TAs away from their belief that there is a "right answer". One goal for using MEAs is to expose first-year engineering students to open-ended problems, where there may be many possible good and distinct solutions. While the majority of the TAs, both GTAs and UTAs, experienced MEAs from a student perspective when they took their FYE courses at our institution, there is still a prevailing belief that there is a perfect answer. It is critical for TAs to understand that there are many different approaches to solving any given open-ended problem and these may be wholly dissimilar in design to the TAs' own ideas for a good solution. Without that understanding, TAs naturally tend to push, either directly or indirectly, their own conception of the right answer and not support the solutions being produced by the students.

The second purpose is to prepare TAs to reliably evaluate and provide feedback on students' work on the MEA(s) slated for implementation in a given semester. TAs need guided practice with prototypical student work that highlights different solution paths that they might encounter. This enables the TAs to develop a level of expertise with the problem posed in the MEA. Because the feedback the TAs provide is critical for students to be able to improve their solutions, the primary activity of the TA training model is focused on allowing TAs to explore and practice their feedback skills.

TA Training with MEAs in Detail

At the start of each semester, all TAs receive approximately 2 hours of basic training that focuses on their daily responsibilities. Throughout the semester the GTAs meet weekly for 1 hour to review upcoming course events and the grading criteria for the more traditional homework assignments that students complete. The UTAs meet with the GTA either in or out of class each week. The faculty instructors arrange meetings with their GTAs and in some instances with their UTAs. Faculty instructors' meetings with their TAs are at their discretion.

The MEA training provides an additional 7 hours training that are spread over a number of weeks and encompass face-to-face training and pre and post training activities the TAs perform on their own time. The MEA training model involves: (1) practice with an activity like a student, (2) exposure to the research-base and/or theoretical underpinnings, (3) practice with interpreting student work, and (4) reflective comparison to an expert.[16] These four training model components map to four professional development (PD) phases.

Phase 1: Complete the Activity as a Student. Two to four weeks prior to the start of the semester, TAs are provided with the set of documents that the students will see as the MEA unfolds in class. TAs are asked to solve the MEA individually. Once the TAs create their own solution to the MEA and post it to the online MEA management system[18], they are provided with copies of the *I-MAP*. The TAs are then asked to apply the *MEA Rubric* to their work using the *I-MAP* as a reference. This is also done via the online MEA management system. The purpose of this phase is for TAs to become familiar with the MEA, the *MEA Rubric*, and the *I-MAP* before attending face-to-face training (Phase 2). Depending on the group of TAs (particularly their previous experience with MEA assessment), they may begin practice grading prototypical students' responses to the individual problem scoping questions that launch a MEA[19,20]; else this practice is all moved to Phase 3.

Phase 2: Face-to-face Training. In a 2.5 hour face-to-face PD session, the course coordinator leads the TAs in a discussion of the role of open-ended problems and MEAs in a first-year engineering course and the TAs' role during MEA implementation and assessment. A portion of this time is devoted to helping TAs understand the steps in the MEA implementation sequence which spans 4 to 6 weeks. The TAs are also exposed to the, often research-driven, though sometimes logistical, reason for everything being done in the MEA implementation sequence. The bulk of the PD time is spent reviewing and applying the *MEA Rubric* with the aid of the *I-*

MAP. With the course coordinator leading the discussion, the TAs walk through assessment of a selection of prototypical responses to the problem scoping questions and two prototypical student team solutions in detail.

<u>Phase 3: Practice on Prototypical Student Work & Comparison to Expert</u>. After the face-to-face training, TAs individually practice evaluating 3 to 5 sets of prototypical student responses to the problem scoping questions and three prototypical student team solutions via the online MEA system. For each student solution, the TAs submit their evaluation of the sample solution, compare their evaluation to that of an expert (one who has extensive background in MEA development and assessment), and then critically reflect on how they can improve their subsequent evaluations. The MEA management system forces the TAs through the practice in a linear fashion, preventing them from looking ahead at the expert evaluation before submitting their own evaluation.

For each prototypical student team solution, the TA must go through all steps of the evaluation that they will perform when actually grading. These steps are:

(1) Apply the student team's model to the data sources with which the students had to work, show results, and describe problems experienced when applying the procedure,
(2) Summarize the mathematics used in the model,
(3) Rate the *MEA Rubric* "Mathematical Model" dimension items
(4) Make recommendations to improve the mathematical model
(5) Repeat steps (2)-(4) for each of the remaining three *MEA Rubric* dimensions: Re-usability (problem formulation statement), Modifiability (justifications for the mathematical model), and Shareability (communication of the model including results of applying the model).

Step (2) always involves the TAs summarizing what the student team has done in regards to the particular rubric dimension. This step is designed to help the TAs focus on what is and is not present in the student work and to encourage the TAs describe the student work in their own words as a means of getting them thinking deeply about the student teams' solutions.

For the critical evaluation, the TAs are asked to identify the difference between their assessment of the student work and the expert along each of the dimensions of the MEA Rubric. Then, they are asked what they need to change to better guide the student teams.

<u>Phase 4: Feedback to TAs</u>. Upon completion of Phase 3, the course coordinator assesses the training work of each TA (as described in the next section) and documents common problems with the TAs assessments. More specific feedback to individual UTAs is provided by the GTA. The GTA assigned to a given section reviews his or her UTAs' training assessments completed in Phase 3 and gives his or her UTAs additional feedback on how to grade more effectively. If the GTA is found to be having trouble performing the assessments, a staff member works with the GTA.

A typical schedule of TA training (PD: professional development) and grading for a MEA implementation sequence is shown in Table 1. UTAs are typically responsible for the grading of 5 teams of 4 (sometimes 3) students; the GTA may be responsible for as many as 10 teams because they support the instruction occurring in two sections. While training is intensive, it is purposefully positioned during "low-tide" times when other TA time commitments are not as significant, such as between exams.

Table 1. Sample MEA 1 TA training and grading schedule for Spring 2012.

Task	Who Completes	Start Date	End Date
PD: Submit Own Solution	TAs	Dec 2	Jan 9 (5 PM)
PD: Grade Own Solution Problem Scoping practice	TAs	Jan 9 (5 PM)	Jan 11,12
PD: Face-to-face MEA Training	Course Coordinator With Staff Support	Wed, Jan 11th or Thurs, Jan 12th 6-8:30 pm	
PD: Practice Grading – Samples 1,2,3	TAs	Jan 11/12	Jan 19 (5 PM)
PD: Feedback to TAs on Problem Scoping	Course Coordinator	Before grading starts on Jan 19	
Grading: Individual Problem Scoping	TAs	Jan 19	Jan 26
Grading: Team Problem Scoping	TAs	Jan 26	Feb 2
PD: Report to GTAs with data on each UTA	Course Coordinator With Staff Support	Jan 19	Jan 26
PD: Feedback to UTAs	GTA	Jan 26	Feb 2
PD: Meet with UTAs	GTA	Feb 2	Feb 9
Grading: Draft 2	TAs	Feb 9	Feb 16
Grading: Final Draft	TAs	Feb 23	Mar 1

Effectiveness of the TA Training Protocol

For the TAs, evaluating MEAs is time consuming, taking between 20 and 40 minutes per student team solution to provide adequate feedback. With each student solution, there is a tremendous amount of quantitative and qualitative data that could be used to assess the TAs effectiveness. The problem facing the course coordinator is that identifying TAs in need of further training must be done quickly to ensure they are prepared for the first round of grading. The quick turn-around needed and the fact the students' MEA grades are assigned based on the TAs' quantitative assessment of their work, currently forces the quantitative data to be the primary source of evidence used to identify TAs most in need of help. The assumption is that TAs who cannot provide quantitative assessments consistently similar to those of the expert are likely confused about MEA or the meaning of the *MEA Rubric* dimensions or the *I-MAP* or are struggling to interpret student work. So the TAs' quantitative alignment with an expert is seen as a viable approach for making a first pass at quality assurance.

For the student team solution evaluations, the *MEA Rubric* contains seven (7) quantitative items, each rated on a scale from 1 to 4. During Phase 3 of training, TAs evaluate three (3) pieces of student work. Each piece of work is also independently evaluated using the same *MEA Rubric* by the course coordinator, acting in the role of an expert. For each item and each piece of sample work, the course coordinator determines a difference between the TA rating and the expert rating. From these TA-expert differences, a quality label is assigned for each of the seven quantitative items. If the TA aligned exactly with the expert on two or more of the samples (a difference of 0), then the TA's assessment is considered "On Target" for that item. If two or more samples were rated as being better than the expert's rating, the TA's assessment gets a quality label of "Too Easy" for that item. Likewise, two or more samples being rated lower than the expert results in a quality label of "Too Hard" for that item. If the TA rated one of their samples too easy, another too hard, and the third accurately, then they are tagged with a "Random" label for that item.

The seven (7) quality labels (one for each rubric item) are collected and counted for each TA. For each "On Target", the TA receives 10 points. If a TA is "On Target" across all items, the TA would score a 70. The TA loses 5 points for each "Random" and 2 points for each "Too Easy" or "Too Hard" they obtained. TAs are then sorted by their final score and given a concern level based on Table 2.

Table 2. Concern level for TA practice assessments.

Score	Concern Level	Description
≥58	None	7 "On Target" 6 "On Target" and 1 "Too Easy/Hard"
55-57	Low	6 "On Target" and 1 "Random"
54-30	Medium	4-5 "On Target" and no more than 2 "Random"
< 30	High	3 or fewer "On Target"

The course coordinator checks the individual MEA solution assessments to see if there are consistent patterns in the TA deviations from the expert. Digging through the TA written feedback to the sample student solutions reveals their misinterpretation of a particular aspect of the sample student work. To be fair, on occasion, it reveals a problem with the expert evaluation of the student work. The course coordinator also evaluates any of the 7 rubric items that is consistently problematic. This typically reveals a misunderstanding of a particular *MEA Rubric* dimension. All common problems are summarized in a report that is distributed to the GTAs, who then check their UTAs' practice assessments (Phase 4). A sample of a report to the GTAs is shown in Figure 1.

Math Complexity
Those with a High and Medium Level of concern tended to grade Too Hard. In these instances, it seems there is difficulty recognizing when distribution ideas are present in student team solutions. Whenever frequency of any range of values is computed, this is idea about distribution.

Modifiability
Those with a High and Medium Level of concern tended to grade Too Easy. It would help to identify and count all of the places where justification is needed and then count how many places where an evidence-based rational is provided. Then the ratio of the number of places an evidence-based rationales are provided to the total can be used as a guide for assigning the grade level. To get the highest level, 90% of the places where rationales should be provided should have evidence-based rationales.
Evidence-based rationales are needed for:

- Each step in the procedure for which there are alternative approaches (e.g. mean vs median, std vs range)
- Hard coded values

Share-ability Results
Those with a High and Medium Level of concern tended to grade Too Easy.

- A presentation of rank with ONLY the rank values (e.g. 1-8) is NOT sufficient quantification of results. Such results should be marked at the lowest level.
- Problems with significant figures and units drops the results grade level by one level.

Figure 1. Sample report on TA practice assessment of prototypical student team work on the Just-in-Time Manufacturing MEA (Spring 2012).

This training protocol was used in Spring 2012 and Fall 2012 to identify TAs needing more training intervention on three different MEAs. Of the 236 TAs who received training (including duplicates, TAs who participated in the training of more than one MEA), 59.7% raised no concern, 15.7% were considered Low concern, 19.5% were Medium concern, and 5.1% were considered High concern. Of the 22 TAs who were trained on all three MEAs, only 4 raised any level of concern by the third MEA.

In Spring 2012, 79 TAs participated in both MEA training sessions; the first focused on MEA 1: Just-in-Time Manufacturing (JITM) MEA and the second focused on MEA 2: Shredded Document MEA. For the JITM MEA students must develop a procedure to rank shipping companies based on historical data of minutes late for scheduled delivery[15]. For the Shredded Document MEA, students must develop a procedure for reassembling images of black and white documents shredded into strips from pixel information. The JITM MEA ad been used each semester since Fall 2011; the Shredded Document MEA had been used in Fall 2012 for the first time in five years. As shown in Table 3, of the seven *MEA Rubric* (described in detail in [15]), TAs generally showed acceptable improvement on five of the seven items. Two items, Mathematical Model Complexity and Share-Ability: Apply-Replicate, showed a concerning decrease in accuracy. The Mathematical Model items evaluate the quality of the model being produced, while the Share-Ability item focuses on how easy it is to follow the procedure to reproduce the stated results.

The concern level results for the Mathematical Model Complexity item demonstrates one of the most significant problems when trying to compare TA training performance across MEAs directly –each MEA is quite different with regards to the mathematics required to produce a high quality solution. This makes determining whether TAs are improving in their ability to assess students mathematical models a challenge. It is speculated that the reason so many TAs moved off target for MEA 2 is the increased complexity of the Shredded Document MEA as compared to the Just-In-Time Manufacturing MEA, making it more difficult for the TAs to accurately evaluate a model's quality. Further, a number of the TAs had multiple experiences with the Just-In-Time Manufacturing MEA as a student and TA, whereas the Shredded Document MEA has new to nearly all TAs.

For the Share-Ability: Apply-Replicate item, of the 25.3% who moved off target, 85% of those moved from being On Target to being Too Easy. The increase in error on this item could be due to a number of causes. First, this could be a problem-specific issue, similar in nature to the Mathematical Model items. Because each MEA is different, it is possible that the ability to follow the students' procedures and reproduce the results is more contextual than previously thought. It is also likely that due to the complexity of student solutions, the TAs are not actually engaging in the full process of trying to replicate results using the procedure. A closer look at TAs application of the students models would need to be done to determine this. Another second cause could be a general decrease in TA expectation, resulting in TAs evaluating a poor solution as being better than it actually is, and thus the quality of their assessment being labeled Too Easy. Because TAs have completed their evaluation of student work on MEA 1, they have now been exposed to a much broader array of actual student solution quality. Their expectation for what constitutes a well-written, repeatable solution may have decreased. Finally, it could be due to TA fatigue. While the first training session occurs very early in semester, the training for the MEA 2 occurs in the middle of the semester when TAs are more actively involved in other tasks, including their own coursework. It is possible that the TAs, in an effort to save time, are not reading the solutions in the detail necessary to accurately assess how well the results can be reproduced. They are likely skimming the solutions and filling in the missing steps with their own assumptions. Further research will need to be conducted to more accurately identify the cause of this issue.

Table 3. Change in *MEA Rubric* item concern level for TA practice assessment from MEA 1 and to MEA 2 in Spring 2012 (N = 79).

	Mathematical Model		**Re-Usability**	**Modifiability**	**Share-Ability**		
	Mathematical Model Complexity	Data Usage			Results	Apply-Replicate	Extraneous Information
Stayed On Target	75.9%	98.7%	92.4%	86.1%	75.9%	63.3%	97.5%
Moved to On Target	12.7%	0.0%	2.5%	10.1%	22.8%	7.6%	2.5%
Never On Target	1.3%	0.0%	0.0%	1.3%	0.0%	3.8%	0.0%
Moved Off Target	10.1%	1.3%	5.1%	2.5%	1.3%	25.3%	0.0%

Future Changes to Improve TA Training

The TA training protocol described above is challenging for the course coordinator, the staff, and the TAs. For every MEA that is implemented, training materials need to be assembled. This includes the *I-MAP* and the prototypical student responses and expert assessment. For new MEAs, these can be created from the TAs attempts to solve the problem, though the turn-around time to select and expertly evaluate samples is short. For more mature MEAs, actual student work can be used, though expert evaluations must still be generated. Ultimately, the selection of prototypical student work is informed by an understanding of the range of student work that can be expected on a given MEA. The *I-MAP* is treated like a living document as assessment of more student work informs its content. Changes in the MEA, as a result of identifying what does and does not work, also have to be reflected in the *I-MAP* and selection of prototypical student work used in training. So, the maintenance of the training materials is an ongoing process.

The real value of assessment of student work on MEAs is not in the quantitative scores assigned by the TAs but in their written feedback. The idea is that the student teams will use this feedback to improve the quality of their mathematical model. However, making an assessment of the quality of TAs written feedback is difficult during the training period. Certainly word count gives one impression – little to none gives students nothing to act on, too much overwhelms or confuses students. But the nature of the feedback is the crux of good feedback. Literature review and our own research on feedback has guided the PD topic on constructive feedback. Literature tells us that written feedback needs to be responsive to the students' work as opposed to generic, at a level the students can understand, and strike a balance between directing and guiding the student teams to rethinking their work.[21] Research conducted offline of the TA training on TA written feedback is currently our best mechanism for unpacking what works and does not work in terms of encouraging students to react to and learn from TA feedback. These research results are fed back in to the TA professional development with open-ended problems.

Acknowledgements

The authors wish to express their appreciation of the staff and TAs who have participated in MEA training and grading. Their dedication has made a significant contribution to our understanding of how to successfully implement open-ended problems in first-year engineering courses.

This work was made possible by a grant from the National Science Foundation (EEC 0835873). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

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