Rethinking Tools for Training Teaching Assistants

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Abstract. The ability to categorize problems is a measure of expertise in a domain. In order to help students learn effectively, instructors and teaching assistants (TAs) should have pedagogical content knowledge. They must be aware of the prior knowledge of students they are teaching, consider the difficulty of the problems from students' perspective and design instruction that builds on what students already know. Here, we discuss the response of graduate students enrolled in a TA training course to categorization tasks in which they were asked to group problems based upon similarity of solution first from their own perspective, and later from the perspective of introductory physics students. Many graduate students performed an expert-like categorization of introductory physics problems. However, when asked to categorize the same problems from the perspective of introductory students, many graduate students expressed dismay, claiming that the task was impossible, pointless and had no relevance to their TA duties. We will discuss how categorization can be a useful tool for scaffolding and improving pedagogical content knowledge of teaching assistants and instructors.

INTRODUCTION

The content knowledge of instructors is not sufficient to help students learn effectively. Indeed, instructors should possess pedagogical content knowledge and familiarize themselves with students' prior knowledge in order to scaffold their learning with appropriate pedagogies and instructional tools. Vygotsky's notion of "zone of proximal development" [1] (ZPD) refers to what a student can do on his/her own vs. with the help of an instructor who is familiar with his/her prior knowledge and skills. Scaffolding is at the heart of ZPD and can be used to stretch a student's learning far beyond his/her initial knowledge by carefully crafted instruction which is designed to ensure that the student makes desired progress and gradually develops independence. With awareness of students' initial knowledge state, the instructor can continuously target instruction a little bit above students' current knowledge state to ensure that the students have the opportunity and ability to connect new knowledge with what they already know and build a robust knowledge structure.

Piaget [2] emphasized "optimal mismatch" between what the student knows and where the instruction should be targeted in order for desired assimilation and accommodation of knowledge to occur. Bransford and Schwartz [3] also proposed a framework for scaffolding student learning. They theorized that the preparation for future learning (PFL) and transfer of knowledge from the situation in which it was acquired to new situations is optimal if instruction includes both the elements of innovation and efficiency. In their model, efficiency and innovation are two orthogonal coordinates. If instruction only focuses on efficiency, the cognitive engagement and processing by the students will be diminished and they will not develop the ability to transfer the acquired knowledge to new situations. Similarly, if the instruction is solely focused on innovation, students may struggle to connect what they are learning with their prior knowledge so that learning and transfer will be inhibited. They propose that the preparation for future learning and transfer will be enhanced if the instruction focuses on moving along a diagonal trajectory in the two dimensional space of innovation and efficiency. One common element of all of these seemingly different frameworks is their focus on students' prior knowledge in order to scaffold learning. Indeed, the instructor must be familiar with students' prior knowledge in order for instruction to be in the zone of proximal development and to provide optimal mismatch to ensure adequate preparation for future learning.

A crucial difference between the problem solving strategies used by experts in physics and beginning students lies in the interplay between how their knowledge is organized and how it is retrieved to solve problems [4, 5, 6]. In a classic study by Chi et al.[7], introductory physics students were asked to group mechanics problems into categories based on the similarity of their solutions. Unlike graduate students (experts) who categorize them based on the physical principles involved to solve them, introductory students categorized problems involving inclined planes in one category and pulleys in a separate category [7].

Here, we will discuss the process and outcome of the categorization of 25 introductory mechanics problems by

21 physics graduate students enrolled in a TA training course at the end of the course [8]. Graduate students first performed the categorizations from their own perspective and later from the perspective of a typical introductory student. We wanted to investigate if the graduate students have an understanding of the differences between their physics knowledge structure and those of the introductory physics students. One surprising finding is the resistance of graduate students to categorizing problems from a typical introductory physics student's perspective with the claim that such a task is "useless", "impossible", and has "no bearing" on their teaching assistant (TA) duties. Based on our finding, we suggest that inclusion of such tasks can improve the effectiveness of TA training courses and faculty development workshops and help TAs and instructors focus on issues related to teaching and learning.

RATING OF CATEGORIES

We were unable to obtain the questions in Ref. [7] other than the few that have been published. We therefore chose our own questions on sub-topics similar to those chosen in Ref. [7]. The context of the 25 mechanics problems varied and the topics included one- and two-dimensional kinematics, dynamics, work-energy, and impulse-momentum [8]. Many questions were adapted from an earlier study [9, 10, 11] because their development had gone through rigorous testing.

Although we had an idea about which categories created by individuals should be considered good or poor, we validated our assumptions with other experts. We randomly selected the categorizations performed by twenty introductory physics students and gave it to three physics faculty who had taught introductory physics recently and asked them to decide whether each of the categories created by individual students should be considered good, moderate, or poor. We asked them to mark each row which had a category name created by a student and a description of why it was the appropriate category for the questions that were placed in that category. If a faculty member rated a category created by an introductory student as good, we asked that he/she cross out the questions that did not belong to that category. The agreement between the ratings of different faculty members was better than 95%. We used their ratings as a guide to rate the categories created by everybody as good, moderate, or poor. A category was considered "good" only if it was based on the underlying physics principles. We typically rated both conservation of energy or conservation of mechanical energy as good categories. Kinetic energy as a category name was considered a moderate category if students did not explain that the questions placed in that category can be solved using mechanical energy conservation or the work energy theorem. We rated a category such as energy as good if students explained the rationale for placing a problem in that category. If a secondary category such as friction or tension was the only category in which a problem was placed and the description of the category did not explain the primary physics principles involved, it was considered a moderate category.

More than one principle or concept may be useful for solving a problem. The instruction for the categorizations told students that they could place a problem in more than one category. Because a given problem can be solved using more than one approach, categorizations based on different methods of solution that are appropriate was considered good. For some questions, conservation of mechanical energy may be more efficient, but the questions can also be solved using one- or two-dimensional kinematics for constant acceleration. In this paper, we will only discuss categories that were rated good. If a graph shows that 60% of the questions were placed in a good category by a particular group (introductory students, graduate students, or faculty), it means that the other 40% of the questions were placed in moderate or poor categories.

GRADUATE STUDENTS FROM THEIR OWN PERSPECTIVE

A histogram of the percentage of questions placed in good categories (not moderate or poor) is given in Fig. 1. This figure compares the average performance of 21 graduate students at the end of a TA training course when they were asked to categorize questions from their own perspective with 7 physics faculty and 180 introductory students who were given the same task. Although this categorization by the graduate students is not on par with the categorization by physics faculty, the graduate students displayed a higher level of expertise in introductory mechanics than the introductory students and were more likely to group the questions based on physical principles. Physics professors and sometimes graduate students pointed out multiple methods for solving a problem and specified multiple categories for a particular problem more often than the introductory students. Introductory students mostly placed one question in only one category. Professors (and sometimes graduate students) created secondary categories in which they placed a problem that were more like the introductory students' primary categories. For example, in the questions involving tension in a rope or frictional force [8], many faculty and some graduate students created these secondary categories called tension or friction, but also placed those questions in a primary category, based on a fundamental principle of physics. Introductory physics students were much more likely to place questions in inappropriate categories than the faculty or graduate students, for example, placing a problem that was based on the impulse-

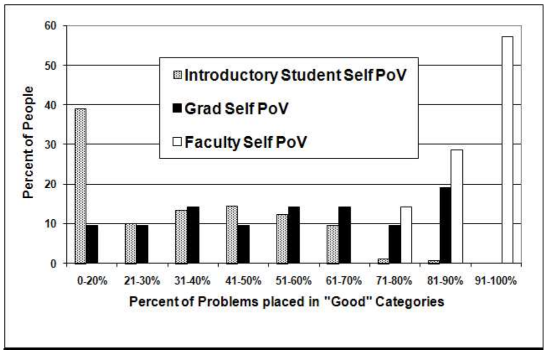

FIGURE 1. Histogram of percentages of introductory physics students, graduate students, and physics faculty who categorized various percentages of the 25 problems in "good" categories when asked to categorize them based upon similarity of solution from their own point of view (Self PoV).

momentum theorem or conservation of momentum in the conservation of energy category. Many of the categories generated by the three groups were the same, but there was a major difference in the fraction of questions that were placed in good categories by each group. There were some categories such as ramps, and pulleys, that were made by introductory physics students but not by physics faculty or graduate students.

GRADUATE STUDENTS FROM INTRO. STUDENTS' PERSPECTIVE

After the graduate students had submitted their own categorizations, they were asked to categorize the same questions from the perspective of a typical introductory physics student. A majority of the graduate students had not only served as TAs for recitations, grading, or laboratories, but had also worked during their office hours with students one-on-one and in the Physics Resource Room at the University of Pittsburgh. The goal of this task was to assess whether the graduate students were familiar with the level of expertise of the introductory students whom they were teaching and whether they realized that most introductory students do not necessarily see the same underlying principles in the questions that they do. The graduate students were told that they were not expected to remember how they used to think 4–5 years ago when they were introductory students. We wanted them to think about their experience as TAs in introductory physics courses while grouping the questions from an introductory students' perspective. They were also asked to specify whether they were recitation TAs, graders, or laboratory TAs that semester.

The categorization of questions from the perspective of an introductory physics student met with widespread resistance. Many graduate students noted that the task was useless or meaningless and had no relevance to their TA duties. Although we did not tape record the discussion with the graduate students, we took notes immediately following the discussion. The graduate students often asserted that it is not their job to "get into their students' heads." Other graduate students stated that the task was "impossible" and "cannot be accomplished." They often noted that they did not see the utility of understanding the perspective of the students. Some graduate students explicitly noted that the task was "silly" because it required them to be able to read their students' minds and had no bearing on their TA duties. Not a single graduate student stated that they saw merit in the task or said anything in favor of why the task may be relevant for a TA training course. The discussions with graduate students also suggest that many of them believed that effective teaching merely involves knowing the content well and delivering it lucidly. Many of them had never thought about the importance of knowing what their students think for teaching to be effective.

It is surprising that most graduate students enrolled in the TA training course were so reluctant or opposed to attempting the categorization task from a typical introductory student's perspective. This resistance is intriguing especially because the graduate students were given the task at the end of a TA training course and most of them were TAs for introductory physics all term. It is true that it is very difficult for the TAs (and instructors in general) to imagine themselves as novices. However, it is possible for TAs (and instructors) to familiarize themselves with students' level of expertise by giving them pre-tests at the beginning of a course, listening to them carefully, and by reading literature about student difficulties, for example, as part of the TA training course.

After 15–20 minutes of discussion we made the task more concrete and told graduate students that they could consider categorizing from the perspective of a relative whom they knew well after he/she took only one introductory mechanics course if that was the only exposure to the material they had. We also told them that they had to make a good faith effort even if they felt the task was meaningless or impossible. Figure 2 shows the histogram of how the graduate students categorized questions from their own perspective and from the perspective of a typical introductory student/relative who has taken only one physics course and also categorization by introductory students. Figure 2 shows that the graduate students recategorized the questions in worse categories when performing the categorization from the perspective of a typical introductory physics student. However, if we look at questions placed in each category, for example, conservation of momentum, there are sometimes significant differences between the categorization by graduate students from an introductory students' perspective and by introductory students from their own perspective. This implies that while graduate students may have realized that a typical introductory student/relative who has taken only one physics course may not perform as well as a physics graduate student on the categorization task, overall they were not able to anticipate the frequency with which introductory students categorized each problem in the common less-expert-like categories.

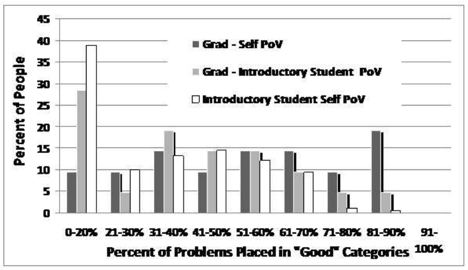

FIGURE 2. Histogram of percentages of introductory students and graduate students who categorized various percentages of the 25 problems in "good" categories when asked to categorize them based on similarity of solution. Graduate students categorized from their own point of view and from the perspective of a typical introductory physics student.

DISCUSSION AND SUMMARY

The reluctance of TAs to re-categorize the questions from introductory students' perspective raises the question of what should the graduate students learn in a TA training class. In a typical TA training class, a significant amount of time is devoted to emphasizing the importance of writing clearly on the blackboard, speaking clearly and looking into students' eyes, and grading students' work fairly. There is a lack of discussion about the fact that teaching requires not only knowing the content but understanding how students think and implementing strategies that are commensurate with students' prior knowledge.

After the graduate students had completed both sets of categorization tasks, we discussed the pedagogical aspects of perceiving and evaluating the difficulty of the questions from the introductory students' perspective. We discussed that pedagogical content knowledge, which is critical for effective teaching, depends not only on the content knowledge of the instructor, but also on the knowledge of what the students are thinking. The discussions were useful and many students explicitly noted that they had not pondered why accounting for the level of expertise and thinking of their students was important for devising strategies to facilitate learning. Some graduate students noted that they will listen to their introductory students and read their responses carefully.

One graduate student noted that after this discussion he felt that, similar to the difficulty of the introductory students in categorizing the introductory physics questions, he has difficulty in categorizing questions in the advanced courses he has been taking. He added that when he is assigned homework/exam questions, for example, in the graduate level electricity and magnetism course in which they were using the classic book by Jackson, he often does not know how the questions relate to the material discussed in the class even when he carefully goes through his class notes. The student noted that if he goes to his graduate course instructor for hints, the instructor seems to have no difficulty making those connections to the homework. The spontaneity of the instructor's connection to the lecture material and the insights into those questions suggested to the student that the instructor can categorize those graduate-level questions and explain the method for solving them without much effort. This facility is due in part because the instructor has already worked out the questions and hence they have become an exercise. Other graduate students agreed with his comments saying they too had similar experiences and found it difficult to figure out how the concepts learned in the graduate courses were applicable to homework problems assigned in the courses. These comments are consistent with the fact that a graduate student may be an expert in the introductory physics material related to electricity and magnetism but not necessarily an expert in the material at the Jackson level course.

This study raises important issues regarding the content of TA training courses and faculty professional development workshops and the extent to which these courses should allocate time to help participants learn about pedagogical content knowledge in addition to the usual discussions of logistical issues related to teaching. Asking the graduate students and faculty to categorize questions from the perspective of students may be one way to draw instructor's attention to these important issues in the TA training courses and faculty professional development workshops.

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