Development and Application of a Situated Apprenticeship Approach to Professional Development of Astronomy Instructors

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Abstract

Professional development for astronomy instructors largely focuses on enhancing their understanding of the limitations of professor-centered lectures while also increasing awareness and better implementation of learning strategies that promote a learner-centered classroom environment. Given how difficult it is to get instructors to implement well-developed and innovative teaching ideas, even when these instructors are supplied with significant and compelling education research data, one must wonder what is missing from the most commonly used professional development experiences. This article proposes a learner- centered approach to professional development for college instructors, which we call *situated apprenticeship*. This novel approach purposely goes beyond simple awareness building and conventional modeling, challenging instructors to actively engage themselves in practicing teaching strategies in an environment of peer review in which participants offer suggestions and critiques of each other's implementation. Through this learner-centered teaching and evaluation experience, instructors' preexisting conceptual and pedagogical understandings of a particular instructional strategy are brought forth and examined in an effort to promote a real change of practice that positively impacts both their core pedagogical content knowledge and their skills in successfully implementing these teaching strategies. We believe that the adoption of our situated apprenticeship approach for professional development will increase the frequency and success of college instructors' implementation of research-validated instructional strategies for interactive learning.

1. INTRODUCTION: PROFESSIONAL DEVELOPMENT AND THE CENTER FOR ASTRONOMY EDUCATION

Since its inception in 2004, the Center for Astronomy Education (CAE) has been conducting Teaching Excellence Workshops that target instructors who teach the general education introductory college astronomy course for non–science majors (hereafter referred to as Astro 101). Thus far, CAE has conducted nearly 40 workshops in more than half of the U.S. states, Canada, and Puerto Rico, attended by approximately 1,000 Astro 101 college instructors (and many high school and middle school teachers). These workshops aim to improve instructors' pedagogical content knowledge (PCK, which we discuss in Section 1.1; Shulman 1986, 1987) in an effort to help them better implement a learner-centered classroom and, by extension, improve their students' understanding of, and attitudes toward learning, astronomy and science in general.

This article focuses on our learner-centered approach to professional development, which we call *situated apprenticeship* (SA). The term "situated apprenticeship" was initially coined by Tim Slater when conducting workshops with Ed Prather. They used the term to describe their approach to embedding their teaching excellence workshop participants in a more authentic teaching context, in contrast to the presenters simply demonstrating a teaching technique to the participants. A formal definition of SA and detailed discussion of its use is provided in Section 2. Merriam-Webster defines "apprentice" as "one who is learning by practical experience under skilled workers a trade, art, or calling" (Mish 1996, 57). Our SA approach provides instructors with the opportunity to learn firsthand how to effectively implement interactive learning strategies through practical experience and with skilled guidance—within the context of, or situated within, our workshops. For the remainder of Section 1, we discuss our theoretical framework for effective professional development and improvement of instructors' PCK and the results of our external evaluation. Section 2 provides a detailed description of the development of our SA approach and its application to the implementation of think-pair-share (TPS; see Note 1 for a brief history).

1.1 Theoretical Framework: Effective Professional Development and Pedagogical Content Knowledge

In *Designing Professional Development for Teachers of Science & Mathematics* (Loucks-Horsley et al. 2003), the authors state that certain principles must be incorporated into creating "effective professional development" (p. 44) that will meet the "requirements for transformative learning experiences" (p. 45) for the purpose of improving both student learning and instructor competency. That is, effective professional development:

- Is driven by a well-defined image of effective classroom learning and teaching.
- Provides opportunities for teachers to build their content and pedagogical content knowledge and examine practice.
- Is research based and engages teachers as adult learners in the learning approaches they will use with their students.
- Provides opportunities for teachers to collaborate with colleagues and other experts to improve their practice.
- Has a design based on student learning data and is continuously evaluated and improved. (p. 44)

In addition, professional development experiences should:

- Create a high level of cognitive dissonance.
- Provide sufficient time, structure, and support for teachers to think through the dissonance experienced.
- Embed the dissonance creating and resolving activities in teachers' situations and practice.
- Enable teachers to develop a new repertoire of practice that fits with their new understanding. (p. 45)

Pedagogical content knowledge (PCK), as mentioned in the first bulleted list and described in *Examining Pedagogical Content Knowledge* (Gess-Newsome & Lederman 1999), consists of five key elements:

- Orientation toward science teaching
- Knowledge and beliefs about science curriculum
- Knowledge and beliefs about students' understanding of specific science topics
- Knowledge and beliefs about assessment in science
- Knowledge and beliefs about instructional strategies for teaching science (Magnusson, Krajcik, & Borko 1999, p. 97)

The principles outlined above provide the framework that we use to inform how we design our professional development workshops. In particular, these principles help guide our emphasis on improving instructors' PCK as the central focus of our SA approach. Before providing a full description of our SA approach, we discuss the results of the external evaluation of the CAE workshops that led to the need for our SA approach itself.

1.2 Results from Our External Evaluation: Pre- and Postworkshop Surveys Assessing Instructors' PCK

During the period of our external evaluation, our workshops used an "awareness building" and "modeling" approach to helping instructors learn how to implement TPS. We built awareness through discussing the instructional strategy itself, as well as the research results, illustrating a higher level of student learning when using TPS. We modeled the strategy with workshop leaders playing the role of instructor and participants playing the role of students, but we never put the workshop participants in the role of the instructor.

It was our initial belief in designing the CAE workshops that if instructors actively participated as mock students in a setting in which effective instructional strategies were being *modeled* by workshop leaders, it would increase the likelihood that these strategies would then be adopted and implemented effectively in their classrooms.

Our external evaluation provided positive data indicating that the initial CAE workshops did improve instructors' PCK (Dokter 2007; Dokter et al. 2007), especially with respect to their "knowledge and beliefs about instructional strategies for teaching science" (Magnusson et al. 1999, 97), albeit not at the level that the workshop leaders had desired.

In our preworkshop surveys, instructors were asked to state three instructional strategies that they believed would best promote students' learning. With $n = 156$ surveys, we found that instructors' most frequently cited instructional strategy was lecture (31%), whereas specific interactive learning strategies, such as TPS, were cited at the 3% level.

There was a dramatic change in participants' reported beliefs about which strategies would best promote student learning, as stated in postworkshop surveys ($n = 156$)—identification of lecture was down to 6%, and identification of specific interactive learning strategies was substantially higher, at 54%. In both the pre- and postworkshop surveys, instructors were asked to describe how the instructional strategies that they stated helped students learn. To our surprise, on the postworkshop surveys, many instructors lacked the ability to meaningfully articulate in what way, or how, learning took place with a particular strategy, most often saying something consistent with "students talk to each other." Although participants had made improvements toward knowing the names of effective teaching strategies, they did not appear to have made dramatic improvements toward knowing why a particular strategy was pedagogically effective. It is our position that instructors will not be able to effectively implement an interactive learning teaching strategy if they are unable to fully articulate the underlying theoretical framework for why the strategy actually promotes intellectual engagement, critical reasoning, and/or conceptual change (Magnusson et al. 1999).

From the external evaluation, we inferred that our "modeling" strategy had been effective in increasing the likelihood that participants would adopt TPS, with nearly 25% of workshop participants stating that this would be the next step to improve the instruction of their classroom.

Because of the inability of participants to provide detailed descriptions of how the learning occurs with different interactive learning strategies, we decided to make considerable changes to the CAE workshops. These changes were informed by the results of research on effective professional development (Loucks-Horsley et al. 2003) and the results of research on how humans learn (Bransford, Brown, & Cocking 1999). These efforts led to the development of our SA approach to professional development, which is now a central element of the CAE workshops and is the focus of the remainder of this article.

2. DEVELOPMENT OF A SITUATED APPRENTICESHIP APPROACH TO PROFFESIONAL DEVELOPMENT AND ITS APPLICATION TO IMPLEMENTATION OF THINK-PAIR-SHARE

Theoretically, we define situated apprenticeship (SA) as a learner-centered approach to professional development that purposefully engages instructors' preexisting conceptual and pedagogical understandings of a particular instructional strategy and provides a pathway to improving both. Operationally, SA provides workshop participants with the opportunity to actively engage in mock teaching experiences that are designed to help them critically reflect on both their own performances and the performances of others to improve their own knowledge, beliefs, and implementation of interactive learning instructional strategies.

Before reading the rest of this article, the reader may find it useful to have a detailed understanding of TPS. Please read the appendix, entitled "Intellectually Engaging Students Using Think-Pair-Share" and "Revisiting Think-Pair-Share: An Expanded 'How-To' Guide (Forestell et al. 2008)] in the Teaching Strategies section of the Center for Astronomy Education Web site. These resources discuss the pedagogy

behind, and critical implementation steps central to, the CAE approach to implementation of TPS.

2.1 Setting the Stage for Situated Apprenticeship

Before workshop participants can participate in SA, we first lead them through the same awareness-building discussion and modeling of TPS described at the start of Section 1.2. During this time, we use several examples of TPS questions that are (1) appropriate to use with students in their Astro 101 classrooms, and (2) conceptually challenging for the workshop participants. Figure 1 (1a–1c) shows three TPS questions that we use in our workshops for this purpose. Not surprisingly, it can be difficult to create a suite of astronomy questions that meet the two described criteria. To remedy this, we also incorporate questions from scientific disciplines outside physics and astronomy when modeling TPS. These questions provide the participants with a more "authentic experience," which, we believe, gives participants a better perspective on the struggle that students will have when using TPS in their Astro 101 class. Figure 2 (Schneps 1997) is an example of a question from biology about photosynthesis; its target is students at the "Bio 101" level, but it also conceptually challenges our workshop participants.
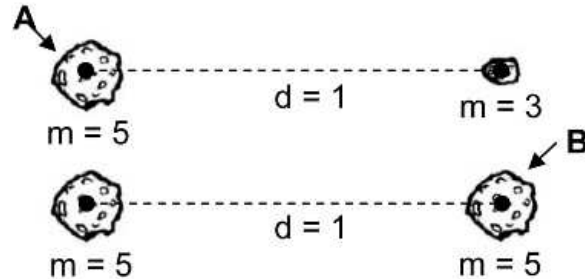
Figure 1a
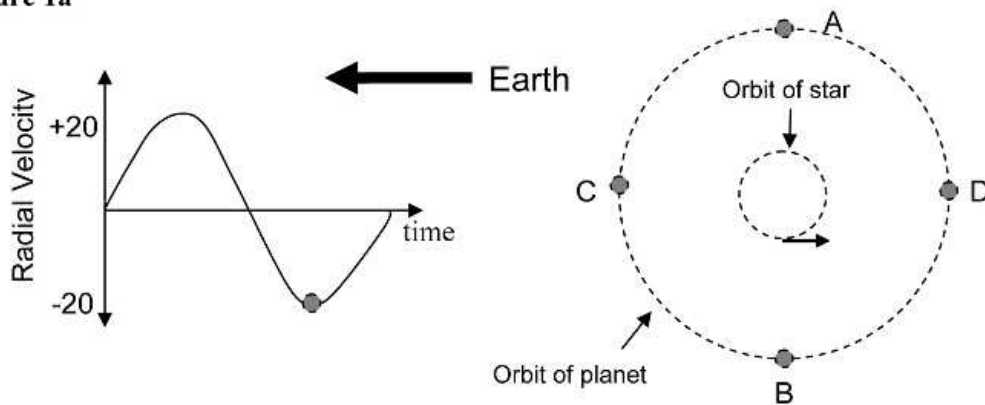
Given the location marked on the star's radial velocity curve, at which location would you expect the planet to be located?

Figure 1b

Which would experience a greater acceleration, as a result of the gravitational force exerted on it, asteroid "A" or asteroid "B"?

A. Asteroid A would experience the greater acceleration.
B. Asteroid B would experience the greater acceleration.
C. The asteroids will experience the same acceleration.
D. Insufficient information to determine an answer.

Figure 1c

Which of the following is true of a binary star system consisting of a Red Giant and a White Dwarf?

    A. You will receive more light when the dwarf is behind the giant than when the giant is behind the dwarf.
    B. The time it takes for the dwarf to pass behind the giant is shorter than the time for the giant to pass behind the dwarf.
    C. The force of gravity exerted on the dwarf by the giant is stronger than the force of gravity exerted by the giant on the dwarf.
    D. The orbital period of the dwarf is shorter than the orbital period of the giant.
    E. None of the above.

Figures 1a–1c. Example of TPS questions both appropriate for Astro 101 students and conceptually rich enough to engage Astro 101 instructors.

Given that a seed grows into a massive tree, where does most of the mass of the tree come from?

    A. From water
    B. From dirt and soil
    C. From the air
    D. It's already in the seed.

Figure 2. Example of a TPS question from biology

2.2 Steps in the Implementation of Situated Apprenticeship

In this section, we discuss key steps (listed below) that frame the implementation of our SA approach to professional development in the context of TPS. The steps are based on our theoretical framework as presented in Section 1.1:

1. Participants critique TPS questions provided by workshop leaders as a whole group.
2. Participants develop TPS questions in collaborative groups.
3. Each group takes a turn practicing implementation of TPS using their question. Remaining participants serve simultaneously as students in a mock class and as a colleague offering a critique of implementation (which we call the "critical friend" role).
4. The remaining participants critique the TPS question itself.

In the remainder of this section, we present difficulties that instructors commonly encounter with each of these steps.

2.2.1 Participants critique think-pair-share questions provided by workshop leaders as a whole group

The first step to successful implementation of TPS is to either create one's own question or borrow one from another source. The question must be a "multiple-choice question that challenges students' thinking and has the ability to foster deep discussion amongst your students" (Forestell et al. 2008). To help workshop participants strengthen their ability to evaluate the potential of TPS questions, we start by presenting them with a series of open-ended questions, which we ask them to rank by considering these criteria: Will the question meaningfully engage students and promote a discussion that makes use of the concept(s) just lectured on? To what degree is the answer simply "declarative"? Would explaining one's answer to the question require multiple steps of cognitive reasoning?

We feel that using open-ended questions helps establish whether participants understand from our modeling that at zero-th order, the questions used must be multiple choice so that students have correct and incorrect answers to vote on; this is essential to the CAE implementation of TPS. When it comes to ranking the questions on their effectiveness in challenging students' thinking and fostering discussion, workshop participants were able to correctly identify questions targeted at the shallowest levels of Bloom's Taxonomy—those requiring only declarative knowledge—but we were surprised by instructors' frequent underranking of questions that targeted Bloom's deeper levels of understanding (Anderson, Sosniak, & Bloom 1994; Brissenden et al. 2002).

Figure 3 shows three sample open-ended questions targeted at shallow, midrange, and deep conceptual levels of difficulty.

Figure 3a: Shallow-level, open-ended question

What is the largest planet in the solar system?

Figure 3b: Mid-level, open-ended question

How do we determine where we are in the disk of the Milky Way Galaxy?

Figure 3c: Deep-level, open-ended question

Imagine that you take two images of two main sequence stars that have the same mass. From your observations, both stars appear to be at the same point in their evolution. From this what possible conclusion could you reach about how their distances (from you) and actual ages compare?

Figures 3a–3c. Sample open-ended questions

2.2.2 Participants develop their own think-pair-share questions in collaborative groups

As the next step in our SA approach for TPS, we ask our workshop participants to work in small collaborative groups to create a TPS question for a topic we provide (e.g., seasons, extrasolar planets, stellar evolution). As a group, they will use the topic and question to model implementation of TPS for the rest of the participants. While groups are working on creating their questions, workshop leaders circulate among the groups, listen to their conversations, answer participant questions, and challenge groups to be critical and realistic about the quality, depth, and appropriateness of their TPS question for Astro 101 students. We have found that the following prompts help guide participants in the development of their questions:

- What could an Astro 101 student realistically understand, at a deep conceptual level, about the topic?
- What could a student say to you that would convince you that he or she understood that concept?
- What is the question for which that student statement is the only answer?
- What are students' common conceptual or reasoning difficulties about the topic?
- What question would motivate a discussion on these difficulties?
- What are the essential ideas that describe or define the topic?
- What question would make use of these ideas?

From this portion of our SA approach, we find that participants emerge with a better appreciation of how challenging it is to actually create appropriate TPS questions. As workshop implementers in a professional development environment trying to create a teachable moment, this is prime time. Much like an instructor in his or her Astro 101 learner-centered classroom will hear his or her students (1) talking about astronomy concepts, (2) exchanging their ideas, (3) creating their own analogies, and (4) integrating their

unconnected bits of knowledge in meaningful self-directed ways, we also hear our workshop participants going through the same transformative experiences during our work regarding their understanding of teaching and learning in the Astro 101 classroom. The workshop participants are highly intellectually engaged in a struggle to come to consensus regarding whether their question meets the essential criteria of being able to engender meaningful student discussions and have only one correct answer that they all agree on. This deliberate implementation of SA creates a rich context that requires collaboration, which promotes the synthesis of our instructors' knowledge of astronomy content with their understanding of the nature of teaching and learning appropriate for Astro 101—development of PCK at its best.

A more detailed discussion of the roadblocks that arise during participants' development (and critique) of TPS questions is provided in Section 2.2.4.

2.2.3 Each group takes a turn practicing implementation of TPS, using their question with remaining participants who serve simultaneously as students in a mock class and as colleagues offering a critique of implementation (the "critical friend" role)

This step of our SA approach to professional development was created to ensure that instructors' understanding of the critical implementation techniques and learning goals of TPS is fully investigated and discussed among our workshop participants. This choice was motivated initially, as stated earlier, by the inability of instructors to meaningfully articulate in what way, or how, learning took place with this instructional strategy. Again, it is our position that instructors will not be able to effectively implement an interactive learning teaching strategy if they are unable to fully articulate the underlying theoretical framework for why the strategy actually promotes intellectual engagement, critical reasoning, and/or conceptual change (Magnusson et al. 1999).

During this step of SA, groups come to the front of the "classroom" of workshop participants one at a time and implement TPS using the question they wrote during the previous step of SA. Each member of the group is responsible for implementing one part of TPS—posing the initial question, asking for students to vote the first time, prompting students to discuss the question with another student, asking for the second vote, and debriefing or providing feedback after the second vote. Note that they are responsible, as a group, for discussing the results of the first voting to decide whether they will prompt the "students" to discuss the reasoning behind their answer with another student. The rest of the workshop participants have the combined role of working as a model Astro 101 class and simultaneously working as the critical friends of the group presenting their TPS question. This complex social environment provides a learner-centered context that allows both modeling of TPS and two-directional metacognition to occur at the same time. During this step of SA, the group presenting and the group of critical friends each have the opportunity to examine and discuss their understanding of the implementation of TPS— thus evolving their PCK—but from different directions (perspectives) occurring simultaneously. All this all occurs with the guidance of experts—that is, the workshop leaders. The type of feedback and the vital role that the participants working as critical friends play when a group is modeling their TPS question are discussed later in this section.

Next, we will highlight roadblocks and difficulties related to the implementation of TPS that commonly occurred during this step of our SA approach. We then offer insights into how these implementation errors serve as teachable moments that are intended to entice the critical friends to participate in the peer

critiquing process. These teachable moments contribute to the mentioned learner-centered environment that helps our participants refine their instructional abilities, with the hope of improving their actual classroom implementation. It may be useful to read the appendix ("Intellectually Engaging Students Using Think-Pair-Share") and "Revisiting Think-Pair-Share: An Expanded 'How-To' Guide" (Forestell et al. 2008).

Reading questions out loud to the students. The students must be able to read the questions themselves for all components of the course, such as quizzes, homework, and exams. They need practice with reading science questions, which foster critical thinking. Further, they must go through all the intellectual tasks related to decoding the question in their own way of thinking and debate the plausibility of the choices offered in the question. All this takes considerable effort and time. Not only are the students engaged at a low intellectual level while being read to, but also, the time spent is really time taken away from the students' learning. Most likely, the student will still need to read the question after you are done, so it is better to provide the question without spending additional time reading it. We have also noticed that instructors sometimes provide clues or insights regarding what the question is about, how students are to reason about the question, or how the question should be answered based on information from the previous lecture. These all represent intellectual tasks that we want our students to undertake; therefore, these should be left as exercises for students to complete without our help or involvement.

Not inquiring about whether the students need more time for either the first or second voting. We have found that if you ask students if they are ready to vote, you will get a response from those students who are ready, but if you ask if anyone needs a little more time, you actually find out if there are students who are not yet ready. A simple method we suggest to help instructors gauge the proper time is to actually read the question to themselves slowly (slower than they think an Astro 101 student might), go through every step of the reasoning needed to disqualify every incorrect choice offered in the question, and reason through the correct choice. We find that using this method ensures that the majority of students are ready to vote once we are done.

Difficulties initiating the voting process. Although it was rare, we did have occasions when instructors would begin by asking for the number of participants who thought A was the correct answer to vote, then those who thought that B was the correct answer to vote, and so on. These instructors clearly did not understand the pedagogical significance of having students vote simultaneously and anonymously, even after we (the workshop leaders) had clearly demonstrated the correct implementation technique when the instructor-participants assumed the role of Astro 101 students. Additionally, we found that several instructors struggled with giving participants clear, easy-to-follow instructions regarding when to vote. Because of their incredible utility and zero risk of failure due to technology problems, we use colored A-B-C-D index cards to help with the voting process in our workshops (and in our own classroom). After some trial and error, we found that simply telling students that we would like them to all vote on the count of three and then simply providing a loud and clear counting of "1, 2, 3, Vote" resulted in all students voting simultaneously—even in classes of 300 students—within only a couple of seconds. Further, when colored index cards are used, the instructor can easily estimate the number of correct votes within only a few seconds of the students voting.

Misjudging the vote. Instructors were reluctant to make judgments regarding the whether enough participants had voted correctly to make it worthwhile for participants to engage in a meaningful discussion about the question asked. It is interesting to note that because we use the colored index cards in the workshop, it is possible for us (the workshop leaders) to ask the instructor and group implementing

TPS to quickly work together to estimate the number of correct votes in real time. Instructors are always surprised at how easy it is to consistently and accurately make this estimate as individuals and as a group. Further, they immediately come to understand how pedagogically *juicy* it is to see which individual students are providing correct and incorrect votes, along with the sea of colors that immediately shows them the overall distribution of the class votes. All this information provided in real time is an unexpected delight and is intellectually invigorating for our implementation group. It is not uncommon to have participants smiling and looking at each other in utter surprise. Welcome to another teachable moment. Some members of the group experience pedagogical dissonance (a necessary component in the development of their PCK) when they notice that particular pockets of participants are all voting incorrectly and in the same region of the class; this can lead to students losing track of thinking about the overall percentage of students who voted correctly. The instructor may struggle regarding what to do next. We have seen instructors start talking with the group of participants who all voted the same incorrect way, completely disregarding the rest of the class and the pedagogical intent of the TPS process. We have seen instructors start to talk to the voting participants about the subtle conceptual underpinnings of their question in an effort to help those they see voting incorrectly. We have seen instructors explain or defend the correct answer. Overall, we find that it takes some coaching for the instructors modeling TPS to become comfortable with and competent in estimating the "sweet spot" of correct answers and providing useful instructions for students that will move the TPS process forward (for a discussion of the sweet spot, see Forestell et al. 2008).

Making sure the "share" portion of TPS is productive. Some instructors felt that it was critical to tell the students about the distribution of their votes (namely, the percent and letter of the correct answer) after their first voting—*before* having them talk to one another. Providing students with this information before they talk to each other and before they are encouraged to defend the reasoning behind their vote has the potential to take the intellectual responsibility off the students and turn the pedagogical value of TPS into a thought-*less* migration toward the most popular vote. The importance of not disclosing to the students the results of their votes at the time of the first voting is critical but does not ensure that the students will engage in a thoughtful discussion of their ideas. We have found that using the verbal prompt, "Find someone with a different answer than yours and convince him or her that you're right" creates the right impetus to evoke immediate, lively discussions among our students and the workshop participants playing the role of Astro 101 students. Of all the verbal prompts we have tried in our classes and in the workshops, this is the one that we have found produces the greatest response and that seems to be most easily adopted by instructors for implementation, though there may be multiple effective prompts. Colored cards are tremendously useful in combination with this prompt. The participants in our workshops who act as Astro 101 students are able to look at each other's votes and immediately find someone who has a different answer from theirs (just as our students do in our classroom).

Not estimating or indicating the appropriate amount of time for the students' discussion. Some groups struggled to gauge the length of time their question would need to be discussed among the participants. We have observed that instructors provided both too little time and too much time. In the case of too little time, the participants were typically quick to voice that they needed more time. Offering too little time to discuss typically stems from the instructor feeling anxious to have the participants vote again, or the instructors underestimating the amount of discussion that is needed to truly explain the reasoning for an answer to their question (which is certainly related to the fact that they were part of authoring the question). The case of too much time is far more subtle for everyone involved. We have had occasions when instructors let the participants talk for a length of time that suggested that participants would be allowed to talk indefinitely. In these cases, we (the workshop leaders) and occasionally the other

participants have asked the instructor group questions along the lines of (1) How much more time are you going to give the participants before you ask them to vote again? or (2) What are you looking for to assess if it is time to have participants vote again? Offering too much time often stems from a sincere desire on the part of the instructor to avoid rushing the participants and hinder their learning. Certainly there will be some questions for which the discussion should take less than a minute, whereas others may take a minute or longer. Because the instructors are also the authors of the question for this portion of SA, we try to encourage them to think about how much time "students" will need to have an authentic Astro 101 discussion of their question. This leads to a more subtle aspect of implementing TPS that is incredibly helpful for ensuring that the discussion between students remains lively and moves forward in a timely manner. When instructing students to start their discussion, we also provide them with the amount of time they will be given for their discussion (e.g., "You've got about a minute to discuss the question. Go!"). Informing the students of a time limit has the effect of motivating them to start immediately and stay on task. We also suggest that while students are in the middle of discussing their reasoning, you state the amount of time they have left to discuss their thoughts before they will vote again (e.g., "You've got about another 30 seconds"). This builds a sense of urgency that helps the students come to consensus and prepare their votes in a timely manner. We also found that some instructors had trouble getting the class to come back together and be aware that it was time for the second voting. We have found that saying "Time!" helps alleviate this difficulty.

We have provided several examples of the roadblocks and implementation errors made by participants and tips for overcoming them. It is essential to this article and to the nature of SA that we also discuss the critiquing process that occurs simultaneously with the implementation of TPS. As discussed, workshop participants who are playing the role of Astro 101 students are also given the role of critical friend for the groups implementing the TPS questions. We found that participants did not easily recognize fundamental implementation mistakes (of the type highlighted previously throughout this section) made during these initial mock TPS sample teaching experiences. In some cases, the workshop participants who have the dual roles of students and critical friends in this portion of SA either "forget" they are supposed to be critiquing the implementation of the TPS and instead are simply reading the question and trying to get it right, or, for reasons of their own, they don't want to offer critiques (these reasons may include feeling like their critique would be interpreted as being unsupportive or judgmental). Further, they might simply miss, or be unsure about, whether the instructor group are making any errors in their implementation. We endeavor to create an environment in which critical examination of each other's implementation is essential to our professional development and something to be sought out rather than something to be fearful of; we are all in the workshop to learn and support each other, and this is a key part of our individual and collective professional growth (workshop leaders included!).

Participants were consistently far more reluctant to engage in and start the critiquing process than we had anticipated. As workshop leaders, we discovered that we had a more critical role than we had anticipated in initiating the multifaceted discussion that we intended to occur between the majority of participants in the critical friends role and the group implementing the TPS question. We found that if we incorporated a simple tool—"the pause button"—into the environment, it helped promote more rapid participant buy-in to the critiquing process and motivated them to be more self-directed and empowered. We first told participants that when they observed something they felt should be identified or talked about, they should feel free to simply say "pause" to the instructor group, in real time, during their implementation. To facilitate this process, when we noticed critical implementation errors that the critical friends did not, we said "pause," which had the effect of freezing the entire mock implementation. We then asked the critical friends participants what the implementation error was that caused us to say "pause." This was followed

by another reminder regarding the role of the critical friend and why it was vitally important to their own PCK development—not to mention the development of the PCK of the group delivering the TPS question—to be critical of the implementation being modeled. They needed to be able to diagnose good and poor implementation if they were to become experts at it (Baxter & Lederman 1999).

We (the workshop leaders) typically only have to use the "pause button" a couple of times before participants start taking control of the critiquing process. After a couple of groups model their teaching of TPS, their peers became much better at providing a meaningful critique of the presentations and explicitly articulating where the most common errors occur. However, a dilemma comes with this improved critiquing, namely that groups start making so few mistakes that there is nothing to critique. We have come up with a way to ensure that the teachable moments continue throughout this portion of SA. While working with participant groups working on creating their TPS question prior to their implementations, we endeavor to discover (1) which groups are further along in their own understanding or ability to properly implement TPS, or (2) which groups have developed a question that is perfect to model an implementation error. We then secretly ask if these groups will agree to model a particular aspect of *poor* implementation to ensure that the rest of the participants have an explicit experience with diagnosing the most typical examples of poor implementation.

For a more complete and hands-on understanding of this critiquing experience of our SA approach, visit a CAE workshop near you—no, really, it will be fun!

2.2.4 Remaining participants critique the TPS question itself

A brief discussion of the difficulties identified during the critiques of the actual TPS question created by each group (as opposed to the implementation of TPS using the question) will be presented in this section. For more information about writing multiple-choice questions of the type appropriate for TPS, the nature of poor versus good questions, conceptual depth of questions, and so on, along with references, we invite the reader to visit the National Institute for Science Education College Level-One Team's Field-Tested Learning Assessment Guide and read the section, Multiple-Choice Tests.

Overall, participants come to understand that writing high-quality TPS questions is quite difficult. The questions created provided a set of typical problems and limitations common to every group that has participated in our workshops since the initial implementation of SA. It is important to note that critiques of questions are provided at two different times during the workshop. First, as the participants are developing their questions, they will often ask the workshop leaders to comment on their question, or they ask for guidance with question development. Second, as the instructor group models its implementation of TPS, the participants in the role of critical friend are asked to provide comments about the group's question following their implementation of TPS. The general difficulties with these questions, identified through both of these processes, can be categorized as pertaining to questions that:

- Are written in language that is too technical or scientific for the Astro 101 population
- Are written at the wrong (too difficult or too easy) conceptual or difficulty level for the Astro 101 population
- Target too many topics at one time
- Target a concept not commonly taught in an Astro 101 course
- Do not have only *one* clear answer

From the standpoint of using TPS to encourage students to engage in an intellectually rich discussion of their ideas, the above question difficulties lead to many limitations. It is difficult to write a question that all readers (including students in the classroom and instructors in the workshop) would agree says or asks the same thing. As a result, poorly written questions cause unnecessary confusion among the students (and our participants) regarding what they are being asked. This all too often leads to guessing (and low first-voting correct response rates) and, more important, limits the students' discussion because they do not understand what the question is asking. When questions were written at too low a conceptual level, participants in the critical friend role were quick to identify that the students in their classes would have very little to discuss with their peers, also noting that these low-level questions did not target the conceptual or reasoning difficulties that their students have with the topic. Our participants also noted that, from their perspective as an instructor, poorly written questions provide little insight into, or mask, what their students are struggling to understand. We tell our workshop participants that these difficulties make it vitally important that they have a critical friend, either from their department or, better yet, from their workshop, carefully read *and answer* TPS questions that the participants create before they try them out on their students. Through this application of SA, participants become much better at identifying those questions that will serve as good TPS questions—questions that challenging students' thinking and foster active and intellectual discussions in the classroom—and come to understand the importance of a critical friend.

3. DISCUSSION

Through our situated apprenticeship approach, we are able to help participants improve their question writing for, and implementation of, think-pair-share. In the end, we have had to increase the amount of time that we allocate to TPS, from about 45 minutes to more than two hours. However, we believe that the improvements we see in participants' performance during the workshop are not simply due to more "time on task." Rather, we are convinced that the process of developing (their own) and critiquing (each other's) questions, along with actually practicing TPS while having peers critique the quality of their implementation, dramatically improves the likelihood that our participants will effectively use TPS in their classrooms. Participants now commonly tell us that they have been to other professional development workshops that promote TPS, but after participating in the CAE teaching excellence workshops, they feel much more confident in their ability to successfully implement this instructional strategy in their own classes. Further, participants have expressed that they find TPS to be a valuable teaching technique, just as they did before we adopted our SA approach, but participants are better able to fully articulate the underlying pedagogical reasons for its use. These participant statements given during the workshop suggest that our SA approach to professional development is successful in meeting our goals of providing participants with the necessary experiences to move beyond awareness of TPS to successful classroom implementation. To lend support to these anecdotes, our next step is to develop a systematic investigation intended to document the efficacy of our SA approach. This investigation will involve both quantitative and qualitative elements, but independent classroom observations will be central.

In retrospect, it should have been more apparent that having the workshop leaders model the teaching technique would be insufficient to promote meaningful increases in the participants' pedagogical content knowledge regarding implementation of TPS, even when the technique is presented clearly and in several contexts. Moreover, it has reminded us, the workshop leaders, that instructor-centered teaching is largely inferior to learner-centered teaching environments.

Note

Note 1. For instructors who teach in a predominantly lecture-based format, think-pair-share represents a relatively low-risk entry point into using interactive learning strategies in their courses. TPS has roots as far back as the early 20th century in literature on teaching using collaborative learning; it was reintroduced in the 1980s by Lyman (1981); it was popularized in the physics community in the 1990s with *Peer Instruction* (Mazur 1997); and it has been shown to effectively improve student learning (Crouch et al. 2004; Crouch & Mazur 2001). In the literature, the terms "think-pair-share" and "peer instruction" are used interchangeably to describe a method of asking students, in class, conceptually rich multiple-choice questions that the students vote on before and after discussing the question with a partner. We will be using the terms "think-pair-share" and "TPS" for the remainder of this article.

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Appendix

Click here for the appendix, "Intellectually Engaging Students Using Think-Pair-Share," in PDF.

Appendix URL: http://aer.noao.edu/auth/prather.brissenden.tps.appendix.pdf