USING ASSESMENT TO INFORM TEACHING IN A PHYSICAL SCIENCE COURSE FOR PRESERVICE ELEMENTARY TEACHERS

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INTRODUCTION

The improvement of undergraduate science courses remains an ongoing concern of university and college faculty. *Blueprints for Reform* (AAAS, 1998) and *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering and Technology* (National Science Foundation, 1997) have recommended changes to the curriculum and instruction of undergraduate science courses to reflect the ways in which scientists work within their disciplines. Reforms have de-emphasized traditional modes of teaching (e.g., lecture and verification-type laboratory activities) in favor of active learning through inquiry-based instruction.

CLASSROOM ASSESSMENT PRACTICES

While changes to curriculum and instruction can improve undergraduate science courses, research demonstrates that along with this, changes in traditional assessment practices must also occur. In their study of an introductory physics course, Dickinson and Flick (1998) depicted how a traditional assessment system could undermine the pedagogical goals of a well-meaning instructor. The fast-paced coverage of material and the instructors' emphasis on scoring the "right answer" on tests, laboratories, and homework assignments resulted in students developing elaborate strategies to obtain passing grades, rather than to develop their understanding of the content.

"Assessment" usually brings to mind tests and quizzes. Because the goal of such traditional assessment has been on determining "whether students know" rather than "what students know," it has been criticized for ignoring the critical role students' prior knowledge plays in the learning process (McDermott, 1991; McClymer & Knoles, 1992; Tobias, 1990). Increasingly, however, college level instructors are utilizing multiple and alternative forms of assessment to develop a clearer picture of what students know and are able to do before, during, and after instruction. Examples include minute papers, one-sentence summaries, and directed paraphrasing (Angelo & Cross, 1993). These classroom assessment techniques (CATs) differ from traditional assessments such as tests or quizzes in that their purpose is course improvement, rather than assigning grades. The primary goal is to better understand student learning and, as a result, to improve teaching. Research demonstrates that classroom assessment can have positive impacts on student achievement when it is used to inform teaching and learning (NRC, 2001). In this way, "assessment is an ongoing process aimed at understanding and improving student learning" (Angelo, 1995, p.7). Heady emphasizes, however, that there is still a "gap between the ideal and the actual use of assessment that should be closed by more research" (2001, p.421).

REFORM THROUGH SCHOLARSHIP OF TEACHING

Action research, one form of scholarship of teaching, has been identified as an effective means of reforming the teaching of introductory college and university science (Chism, Sanders, and Zitlow, 1987; Cross, 1990; Fedock, Zambo, and Cobern, 1996; Schratz, 1990). As the National

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Research Council indicates, “reflection and inquiry into teaching, and the local and practical knowledge that results, is a start towards improved assessment in the classroom” (2001, p. 80).

Through action research, instructors systematically and consciously examine classroom actions and student outcomes for the purpose of improving their practice. Action research studies usually begin with a question generated from a particular problem or concern in the context of one’s own classroom, and involves the development of a systematic plan of action for gathering and analyzing data to inform new actions. In this way, action research differs from traditional research in that it does not end with data analysis, but rather leads to the generation of new questions and new actions (Cross, 1998). The process involving ongoing cycles of generating questions, planning actions, collecting data, reflecting and analyzing data (Hopkins, 1993).

COLLABORATIVE ACTION RESEARCH

Teachers benefit more when action research is carried out collaboratively with other teachers (Feldman & Minstrell, 2000). Research affirms that teachers’ understanding can be deepened by discussion with peers (Atkin, 1994; Cochran-Smith & Lytle, 1999; Elliot, 1987; Hargreaves, 1998). Collaborative action-based research teams involving scientists, science educators, graduate students, and practitioners have been successfully utilized in science courses for education majors at Purdue University (Krockover, Adams, Eichinger, Nakhleh, & Shepardson, 2001).

We employed collaborative action research to examine the implementation and use of CATs in introductory physics courses for elementary education majors. The project represents a collaborative effort between a university physics professor and a science educator jointly appointed in the College of Education and Department of Physics. These instructors were joined by two graduate teaching assistants for the course, both doctoral students in physics, and an undergraduate researcher, a double-major in physics and education. For all members of the team except the science educator (second author) this was a first formalized effort to systematically integrate formative assessment into their teaching.

In this paper, we present our initial evaluations of implementations of CATs into our course. Additionally, we describe how the lessons we learned from our first attempts have continued to shape our use of CATs for subsequent semesters. Though our context is a specialized content course for teachers, we argue that the strategies we employed are easily transferable to other contexts and courses.

THE COURSE: EXPLORING PRINCIPLES OF PHYSICS

Exploring Principles of Physics (Physics 2330) is an integrated lecture-laboratory course designed specifically for elementary education majors. Each semester, we teach two sections with up to 35 students each. Major units in the curriculum include electrical circuits, magnetism, light, and force & motion. Though many laboratory activities are consistent with reform recommendations for inquiry-based instruction, the assessments in the course have primarily consisted of more traditional quizzes and end-of-unit tests. Often, results of these assessments indicated (too late) that students held misconceptions about the concepts. We chose classroom assessment techniques as a way to identify and address these misconceptions through changes in our instruction.

THE ACTION PLAN

Generating questions

With the support of a University research incentive grant we began our project with a pre-semester full-day research retreat in which we developed a shared vision of the course goals using the Teaching Goals Inventory (Angelo & Cross, 1993), and discussed how CATs might help us promote these goals. The equally important teaching goals identified by the group were teaching students facts and principles of physics and helping students develop higher order thinking skills. With these in mind, we formulated the following questions to investigate:

- How do CATs align with our teaching goals?
- What role do CATs play in student learning?
- How can CATs be used to guide instruction?

Planning Actions

CATs were selected based on their fit with the goals of the course. Additionally, a concern was ease of use—we wanted strategies that could be implemented within our existing curriculum. Many of the CATs we used took little time to accomplish and could quickly be analyzed to develop a picture of students' understanding. Figure 1 provides three examples that are typical of our use of CATs during the semester. By using only a few CATs initially, we were able to provide both students and ourselves with the time necessary to feel comfortable with these new techniques.

Reflecting

Each week, the focus of our meetings was directed toward understanding and addressing students' ideas, as assessed through the CATs. This group processing was an important step in monitoring our effectiveness and adjusting our instructional strategies accordingly. As Angelo and Cross (1993) emphasize, following up in response to CATs is critical to their success in improving student learning. For example, after administering a minute paper at the end of class, we realized that students had multiple and conflicting interpretations of the data they had collected during the investigation. In response to this we created a scenario that included a fictitious dialogue between two students about the data (see figure 2). We asked our own students, at the beginning of the next class, to discuss whether they agreed with either of the students and why. The discussion that ensued allowed the students to reason through the evidence for themselves in order to understand the concepts of the investigation.

Collecting Data

To answer our questions, we used a variety of data sources collected throughout the semester in order to capture the perspective of multiple stakeholders (faculty, teaching assistants, students) and to allow for triangulation and validation of themes across data sources. The primary data sources included:

- Research team notes and anecdotal records from class sessions
- Course materials and student responses to CATs
- Transcripts of weekly meetings in which the team planned instruction and assessment

- Interviews with a randomly-selected sample of students (15%) following each of the three modules of the curriculum

Interviews with students were conducted by the undergraduate researcher (first author) on the team, so as to encourage students to more openly share their opinions about the course activities and instructors' use of the assessments (see Appendix A for interview protocol).

Analyzing the Data

Our analysis and evaluation of our action plan were guided by our original questions. To identify emerging themes, two of the researchers (the first and second author) engaged in several rounds of coding, then organized codes into categories to note patterns and trends across data sources (Creswell, 1998). Themes were then peer-debriefed by the remaining members of research team as a validity-check. Four main themes emerged through this analysis, each of which has implications for our continued efforts to implement formative assessment in the course. These themes highlight areas of consistency and discrepancy between the perspectives of students and instructors of the course.

Students began the semester focused on figuring out "what the teacher wants"

On a consistent basis during the semester students questioned what the instructors wanted from them when they were asked to complete open-ended tasks and share their reasoning in class. As one student explained in their interviews:

> *I personally don't really like when we write down what we are still unclear on …I am not sure if I am picking out the right things to understand from the readings.*

This was particularly evident in student responses to tests and quizzes:

> *…I'm not really sure of how much detail [the instructor] wants you to go over or what she wants to include.*

Once students felt they had figured out what the instructor wanted, they became satisfied with their level of understanding, and thus "finished" learning.

> *I got a 100 on the test so I'm good.*

This highlights a discrepancy between the goals of the instructors and the students. While the instructional team viewed both higher-order thinking and knowledge of the concepts as primary goals for our teaching, the majority of students (70%) indicated their primary goal was to "get an A" following a goal-ranking CAT.

Students viewed the purpose of the course as "learning the facts"

Students expressed a "Just the facts, please" attitude in regard to their learning. Students appreciated hands-on activities but expressed displeasure with the amount of time that this approach demanded, and felt it would be quicker to just have the "right answer" explained to them. They viewed the purpose of the course as learning a body of knowledge with the quality of the course being based on the number of facts learned. This was in contrast to the instructors' belief that "less is more" with the number of facts taking a secondary position to the depth of each concept explored.

Students viewed science as a body of knowledge that was to be "accepted" and preferred to move on instead of delving in to explore the concepts in further depth. They desired activities in class that were "more direct and shorter."

> *I would have done so much better if we had said "This is what is right. This is what works. This is how it is supposed to be…" I'm highly annoyed by "Ok, let's try this, now this. Now how does this change? Now let's see why theirs is like this. What did they do different? How come this is like this? "At the end, we all got to the exact same thought processes, exact same objectives. If someone had just said "Here's what you are going to learn. These are the things you need to know and remember forever". I would have done so much better.*

Yet, even students who saw the benefit of class discussions focused on science as a body of knowledge to be memorized:

> *…I think that it is more interesting if you talk about it before you learn it too. So, I think that it's good at predicting and getting us thinking before we actually just learn the facts.*

While there indeed was a body of accepted scientific knowledge (facts, concepts, and theories) instructors wanted students to understand, they intended this to be developed using higher-order thinking skills, rather than rote memorization.

Students believed CATs help them, and instructors, monitor their learning.

As the semester progressed, it became evident that students felt formative assessments were effective in providing both them and the instructors with information about their understanding.

> *I don't feel like she <u>has</u> to use tests to make sure we understand it.*

They indicated there was "ample time" to alert instructors to their confusion, and that assessments helped them monitor their own learning:

> *A lot of those [CATs] really helped to compare what you know and what you didn't know.*
>
> *A lot of the [CATs] and activities showed where we were and what we needed to work on.*

In this way, the timing of assessments allowed students to correct their misconceptions:

> *…[the instructor] breaks down the whole two-hour lesson into smaller parts and she always asks us to draw on our white boards our list of things that we know and if something is wrong with that she will stop and say "Are you sure about this?" and we will discuss it and correct ourselves right then.*

This perspective is consistent with that of the instructors in that they believed CATs provided a snapshot of what students understood at a given moment.

Students felt the combination of instruction and assessment supported their learning.

Students commented on how the changes in their understanding of concepts took place during class and how the activities and discussions helped support this change. The students described how the multiple types of assessment and class work allowed them to look at new ideas and evaluate their thinking. They felt that the material was presented in a logical sequence and was relevant to their future roles as teachers:

> *The hands-on stuff we do probably helps the most because we are actually doing it and learning it for ourselves. But then, I think that my thoughts really come together when we talk about what we did afterwards. I think that it is a combination of the class structure really.*

> *I felt like [the instructor] always started at the basics… and works her way up from that. I think that is really helpful because I could learn more complex things, but you have to know the basics especially if we are going to teach elementary school students.*

There was also evidence that the instructors supported student learning by challenging students' prior conceptions and allowing new ideas to emerge from students' own investigations.

> *We kind of shared at the beginning what we thought might happen and she walked around to all the tables and asked us what we were thinking. Then she didn't say "No, you're wrong" but through the activities we were like "Oh, yeah".*

> *Well, I didn't say "I used to think this and now I think this". It was more like "Well, isn't it this way?" and then I would be corrected and be like "Oh". The change was taking place in class.*

> *With all the demonstrations that we did it proved that the stuff was different than what I thought.*

Instructors' perspectives agreed with that of the students; responses to CATs implemented at the beginning of a unit and throughout the investigations provided a basis for adjusting instructional strategies. Additionally, we compared data from CATs to individual student responses on tests and quizzes to note changes in their conceptions. Thus, we also felt that CATs were useful for fostering conceptual change.

LESSONS LEARNED

In our end-of-semester research retreat, we reflected on the questions that guided our action research, and what we learned about implementing classroom assessment techniques in the course. As a team, we felt the CATs we selected aligned well with our teaching goals, and provided us with valuable evidence of students' understanding of the course material, as well as evidence of our teaching effectiveness. We observed that CATs encouraged critical thinking and fostered students' awareness of their own learning by providing a clear indicator of what they understood and what they did not. This improved their ability over time to ask specific, rather than general questions and seek clarification of the course material. Additionally, we found CATs useful in diagnosing students' difficulty. We benefited from the awareness of alternative conceptions held by students—many of which we did not anticipate. In this way, we were better prepared to address students' prior knowledge more effectively with our instruction.

Several changes were made to our instruction of this course as a result of our efforts to implement CATs. The most prominent change in practice was related to the pace of the course. By using CATs, we shifted our focus from getting through the planned activities to really getting through to our students and impacting their ideas. In some cases, this meant we spent more time on difficult concepts and conducted additional laboratory explorations that would directly challenge students' misconceptions. In other cases, it meant we moved more quickly than anticipated through activities or concepts about which students had little confusion. By using CATs throughout each unit, we were able to continually assess effectiveness of our instruction and make adjustments in strategies. In this manner, our teaching became more responsive to students' learning needs. Overall, we shifted from a more teacher/curriculum centered approach to a more student-centered one.

One advantage of our increased awareness of student ideas was in our ability to redirect students toward applying concepts, versus memorizing algorithms. In particular, we noted that students often solved problems involving Ohm's law without regard to their understanding of the differences between parallel and series circuits. Because we wanted students to use sound reasoning in applying Ohm's law, we developed sample "warm-up" problems in which students were asked to identify faulty reasoning for selection of incorrect responses (see Figure 3).

Our improved understanding of students' comprehension of the course content not only led to novel instructional interventions (such as those illustrated in figures 2 and 3), but it also led to what we feel were improved summative assessment through tests and quizzes that targeted students' previous misconceptions about the content.

RECOMMENDATIONS

Consistent with the cyclical nature of action research, what we learned from this semester has influenced our plans for subsequent semesters in regard to assessment. First, we realize the importance of bringing students on board in terms of our goals and purposes. Student expectations are a powerful influence on their orientation to learning. As such, when students' goals conflict with the purpose and intent of the instructors, progress can be slow. Second, we acknowledge that there may be a "learning curve" for both instructors and students when using CATs, and that using them on a regular basis throughout the semester can help students feel more comfortable sharing and questioning their ideas. Overall, we felt CATs were not just effective at helping the students learn-- they also help the teacher learn about the students. With this information, learning can become a community endeavor in which both sides benefit from a more open environment conducive to learning. Since our students are preservice elementary teachers, we feel this is especially critical in terms of modeling appropriate science pedagogy.

We realize that substantial changes to instruction take time, but feel that the steps we've taken so far are important to continued improvement. The collaborative action-research approach was especially beneficial in guiding and focusing our work. We feel this model is an effective for other faculty hoping to enact change in their courses and instruction, in that it promotes an open dialogue on teaching and learning and an evidence-based means for assessing the impact of instructional interventions.

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Figure 1. Three Examples of Classroom Assessment Techniques Implemented in the Course

Minute Paper
Students are asked to answer two questions: 1) What did you learn today?
2) What questions do you have about what you learned?

Example: Following an investigation of reflection, students responded to these questions at the end of class.

Directed Paraphrasing
Students are directed to explain a concept to a particular audience in their own words.

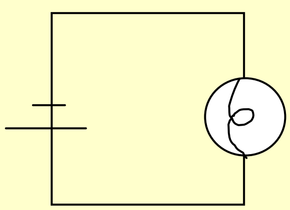
Example: Students were asked to explain the concept of "force" to an elementary student prior to and after the unit.

The Muddiest Point
Students are asked, What has been the "muddiest" point so far in this unit? That is, what topic remains the least clear to you?

Example: Following investigations and discussions of voltage, current, and resistance, students were asked to respond to these questions prior to the upcoming exam.

Figure 2. Example of Student Scenarios Adapted for Discussion in Response to CATs

With which, if either, student do you agree? Why?



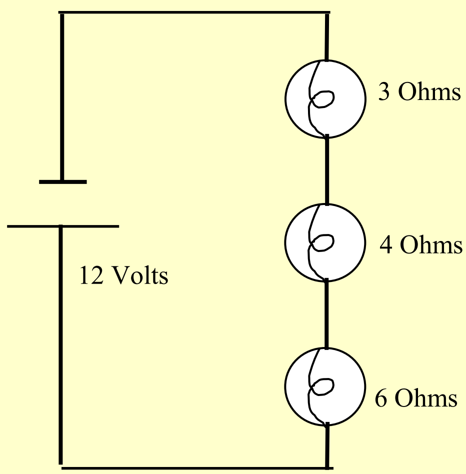
Student 1: *When the bulb is lit, the current flows from the battery to the bulb. There, current is transformed into heat and light.*

Student 2: *When the bulb is lit, the current flows to the bulb and back to the battery. The electrons flowing in the circuit do not get used up..*

Figure 3. Example of Warm-Up Problem Created in Response to CATs

With which response below do you agree? Why?

In the circuit below, what is the current provided by the battery?



1) 9amps, because each bulb has a different resistance:

$I_1 = V/R_1 = 12V/3\Omega = 4A$
$I_2 = V/R_2 = 12V/4\Omega = 3A$
$I_3 = V/R_3 = 12V/6\Omega = 2A$
$I_{total} = I_1 + I_2 + I_3 = 9A$

2) 2amps, because all resistors get the same current, equal to that of the resistor closest to the battery ($I = 12V / 6\ \Omega = 2A$)

3) 0.923amps, because the total resistance is $6\ \Omega + 4\Omega + 3\Omega = 13\Omega$ and $I = 12V / 13\Omega = 0.923A$

4) 3amps, because each resistor gets 4V because the bulbs share the voltage. So,

$I_1 = V/R_1 = 4V/3\Omega = 4/3A$
$I_2 = V/R_2 = 4V/4\Omega = 1A$
$I_3 = V/R_3 = 4V/6\Omega = 2/3A$
$I_{total} = I_1 + I_2 + I_3 = 4/3A + 1A + 2/3A = 3A$

APPENDIX A: STUDENT INTERVIEW PROTOCOL

Pre-Interview
Thank you for agreeing to be interviewed today. The information you share will help the instructors of Physics 2330 improve the quality of their teaching and improve student learning in the course.
Audiotaping this interview will help me remember what you share with me today. I will type up our conversation to share with the instructors, but I will not include your name on the transcript.

- Do I have your permission to audiotape?

I am going to be asking you some general questions about your experience learning the content in the course, but you may also ask questions of me at any time. Do you have any questions before we begin?

Question 1:
This particular content module focused on [topic]. What did you already know about [concept related to topic] before you began the module?

Did you have an opportunity to share these ideas in class? How?
Were your ideas scientifically accurate? How did you know?
Was your instructor aware of your ideas? How did you know?

Question 2:
Did your ideas about [topic/concept] change over the course of the module?

Did you have an opportunity to share your changing ideas in class? How?
What led to the changes in your ideas about [topic/concept]?
Was your instructor aware of your changing ideas? How did you know?

Question 3:
Is there anything that still remains unclear to you about [topic/concept]? Explain.

Did you have an opportunity to share this with the instructors? How?
Was your instructor aware of your misunderstanding about [concept]? How do you know?

Question 4:
How helpful were [specific assessment tools] in helping you learn [topic/concept]?

What was most helpful to you?
What was least helpful to you?
How could your instructor better use the [assessment tool] to support your learning?
How could your instructor change her instruction to better support your learning?

Post-Interview
Is there anything else you'd like to tell me about your experiences during the [topic] module?

Thank you again for your participation in this interview.