Assessing-to-Learn
Formative Assessment Materials for High School Physics

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Executive Summary

Description

The Assessing-to-Learn (A2L) project sought to develop quality formative assessment materials for teaching high school physics and to advance understanding and practice of formative assessment in the teaching of high school science. As originally proposed, the A2L project goal was to create prototype formative assessment materials for use with high school physics curricula. These materials were to be designed with the aim of integrating assessment and instruction, and to be compatible with classroom communication technology. The A2L materials were to serve four educational functions: (1) promote learning (rather than grade student performance), (2) support integrated and flexible use of knowledge across a wide range of problem contexts, (3) provide teachers with a more continuous assessment of students' conceptual understanding and learning progress, and (4) engage a broader cross section of students in classroom learning activities and stimulate greater participation in small group and class-wide discussions. The A2L materials were to be prototypes: quality examples of formative assessment activities for teachers, who would eventually develop their own formative assessment items tailored to their curriculum and the needs of their students.

Lessons learned during the development and pilot testing of formative assessment activities led us to broaden the scope of the A2L project to address significant issues affecting the adoption and implementation of formative assessment practices. Among these are four that we deemed fundamental: (1) teachers vary significantly in many areas affecting the adoption and implementation of formative assessment practices, so a "one size fits all" approach to formative assessment is not feasible; (2) although teachers can (and sometimes do) create their own formative assessment materials, the amount and quality of the materials is usually insufficient to support a comprehensive formative assessment program; (3) although teachers identify with the stated goals of formative assessment, their practice of formative assessment is often inconsistent with these goals; and (4) although teachers and students appear to enjoy doing formative assessment activities and express that the activities are valuable learning experiences, most teachers do not use the information they receive during formative assessment to make real-time teaching decisions.

From our experiences with project teachers, it became clear that while a highly tuned set of formative assessment activities might ultimately be useful for changing the classroom dynamic in significant and productive ways, such materials would likely be insufficient for inducing teachers to adopt authentic formative assessment practices. In response to lessons learned, we broadened the scope of A2L in two noteworthy ways: (1) to identify and elucidate the factors that influence teachers' adoption of formative assessment practices and the kinds of support teachers need to fully implement a program of formative assessment; and (2) to contribute to the pool of educational materials for pre-service and in-service teachers in ways that enhance

teachers' formal understanding of formative assessment and provide practical guidance for initiating and implementing a formative assessment program.

Findings

The results from the A2L project were mixed.

Students and teachers enjoy doing formative assessment activities and believe the activities are helpful for learning. As expected, formative assessment has a dramatic impact on the dynamic of the classroom, especially where active engagement was previously absent. With the introduction of formative assessment, students spend more time working together on learning activities, constructing their own understanding. In general, there is more discussion in both small group and whole-class formats.

Despite the generally positive reactions from participants and the beneficial changes in the classroom dynamic, however, we found a number of impediments to the full implementation of the A2L approach. Teachers view some assessment items as too difficult not a good 'fit' to their curriculum. We believe that some of these judgments stem from a misunderstanding of the goals of formative assessment. Teachers have a tendency to adopt a summative assessment stance (often despite claims to the contrary) in which the correct answer plays a central role. This is contrary to the formative assessment view, in which process matters most and questions are used primarily to focus student attention and to engender interest. As a result, teachers often favored low level conceptual questions they felt they had "adequately covered in class," and stayed away from contextually rich problems they perceived to be "too demanding" for their students. Teachers generally shied away from questions requiring high level analysis and reasoning. The majority of teachers found it difficult to process students' answers in real-time so that information gleaned could meaningfully feed back into instruction. Finally, inability to easily correlate results from different assessment items has limited teachers' ability to examine the responses of individual students and model student progress.

With the exception of the last point, which requires a technological solution, we are addressing these impediments through a sustainable model of professional development integrating the following areas: (1) optimal use of classroom response system technology; (2) teacher development of formative assessment items; (3) new roles for students and teachers in the formative assessment classroom; (4) foundations (goals and practices) of formative assessment; and (5) pedagogical principles underlying the complex decision making necessary for continuous formative assessment. Our work has led us to the concept of "agile teaching," used to describe the perspective, instructional style, and pedagogic techniques for continuously monitoring students' knowledge state through formative assessment and rapidly adjusting instruction to maintain an optimal environment for active, inquiry-based learning. During the project, the evaluation team pilot tested an *action research* model to support teachers' professional development of agile teaching skills. The model has yielded some positive results, and we are now formulating a plan for sustainable professional development centered on agile teaching and action research.

Summary of Products and Contributions

- A web site (http://A2L.physics.umass.edu/) has been created to make much of the project's residue available as a public resource. It is currently being modified to reflect its new role as a public resource, rather than its previous role as a tool for project participants. The site will contain an organized, categorized, searchable database of formative assessment questions appropriate to various physics topics and instructional levels. It will also provide relevant reprints and technical reports. The site will serve three distinct populations: (1) teachers wishing to begin implementing a formative assessment program; (2) persons supporting professional development in the area of formative assessment; and (3) researchers and developers working in the area of formative assessment. A final version of the A2L web site is scheduled to become available to the public by August 1, 2004.

- More than 250 formative assessment items in physics will be made available through the A2L website. (199 are currently available in draft form.) These items will serve as prototypes for the design of formative assessment items in a number of areas (mechanics, electricity & magnetism, fluids, thermodynamics, and modern physics) at a variety of levels (from conceptual physics in the high school to third year physics courses in college) addressing a variety of cognitive goals (e.g., conceptual understanding, analysis and reasoning, and problem solving).

- A resource guide will be available to help teachers take advantage of the resources on the web site. The guide will provide an overview of the site and provide suggestions for how to make optimal use of site resources. It will contain an introduction to formative assessment in general and the A2L approach in particular. It will present examples that highlight a range of assessment items on the site while illustrating different aspects of formative assessment practice. The guide will be available September 1, 2004.

- Using our experiences visiting classrooms to give workshops and collaborate with teachers, together with information gathered via action research by our evaluation team, we will write *Assessing To Learn: A Guide to Classroom Formative Assessment in Introductory Science,* a guide to formative assessment in science. The guide will be aimed at teachers and professional development leaders and will address in detail the five areas of professional development identified above. This resource is scheduled to become available in draft form on the A2L web site by October 1, 2004. We will seek a publisher for printing and distribution. A synopsis and chapter outline are included in the appendix to this report.

- Publications: 9 articles, 5 technical reports

- Presentations: 24

- Workshops: 18

Impact on Future Work

Our work on the A2L project has led us to propose a "contextual project" to NSF/DUE's IERI program. The project is called "Agile Teaching: Sustaining professional development in secondary science instruction through inquiry, technology, and action research", and aims to develop, test, and refine a sustainable model of professional development for secondary school science teachers. The model presumes near-total commitment of a school or district's science department to work with UMPERG researching what works and what doesn't. Teachers are an integral part of the research team.

Professional development will consist of an 84-hour multi-disciplinary science course taught on-site. The course will cover concepts spanning the sciences, such as "systems", "change and transformation", and "scientific models". Pedagogy and math will be interwoven into the narrative, along with numerous classroom techniques for implementing the "agile teaching" approach.

Inquiry will be encouraged using existing NSF curriculum materials. Teachers will work in teams exploring concepts both in and out of their fields of expertise. Technology, in the form of a classroom response system, will be used during professional development to facilitate engagement, interaction, and feedback. Action research will be used to promote reflection and team-building. All three feed directly into the agile teaching approach. Teachers will take these same techniques into their classrooms, and will discuss implementation issues with the rest of the action-research team.

Full Report

1. Project Overview

Assessing-to-Learn (A2L) is a multifaceted project with the primary purpose of advancing our understanding and practice of formative assessment (FA) in the teaching of high school science. The original goal of the A2L project was to create a set of quality FA items (assessment materials that a teacher can use to make decisions about subsequent instruction) to serve as prototypes for use in teaching high school physics. Lessons learned during development and pilot testing of FA activities led us to broadened the project's scope to include other significant issues (i.e., other than the lack of quality FA materials) affecting the adoption and implementation of FA practices. Added research questions include:

- How can one effectively integrate assessment and instruction to meet the wide variation in teaching practices among high school science teachers?
- What factors influence a teacher's adoption of particular FA practices?
- What kinds of support do teachers need to implement a program of FA?
- How do we enable teachers to become authors of FA materials?
- What preparation do teachers need to be effective practitioners of FA?
- What is the effect of FA practices on the classroom dynamic and the way teachers teach?

2. Project Rationale

There has been considerable interest in assessment, especially in view of the goals set forth in reform documents such as the National Research Council's National Science Education Standards. Generally, these goals call for science learning to focus on conceptual understanding, problem solving, and science as inquiry. Most experts agree that a mismatch exists between the goals set forth in national science standards and summative tests used by teachers to rank students. Formative assessment practices provide a better match, but there are barriers to teachers adopting such practices. We would argue that a good first step toward helping teachers adopt a program of formative assessment is the development of simple-to-use formative assessment activities and an efficient process of collecting formative assessment data.

FEW FORMATIVE ASSESSMENT MATERIALS EXIST FOR HIGH SCHOOL SCIENCE, ESPECIALLY FOR PHYSICS. Most assessment tools are summative, used after instruction to gauge student achievement. Students' answers can impact instructional practice in the long term, but the results neither help teachers make decisions about what to do every day, nor help students identify and remedy their own learning difficulties in a timely fashion.

MANY TEACHERS ARE NOT AWARE OF WHAT STUDENTS DO AND DON'T KNOW. Traditional classroom practices are not effective for revealing how well students understand the material.

Consequently, teachers do not give students feedback and teaching that addresses their specific, individual learning needs.

TRADITIONAL FORMATS OF ASSESSMENT CAN BE TIME CONSUMING. Whether the format is pencil-and-paper, a tabulated show of hands, or class-wide discussion, it often takes too much time to collect, organize, interpret, and use the results.

EFFICIENT FORMS OF ASSESSMENT ARE OFTEN NOT REPRESENTATIVE OF THE WHOLE CLASS. Even teachers who use collaborative learning effectively can find it difficult to assess how *all* their students are doing. During a class discussion, the better students often dominate, giving a distorted image of how well the class grasps ideas being discussed. Struggling or confused students are usually unwilling to share their ideas with the whole class and become less and less engaged in the activity.

TRADITIONAL SUMMATIVE ASSESSMENTS ARE NOT LEARNING EXPERIENCES FOR STUDENTS. Students seldom find assessments interesting or fun, since they are intended mostly to assign grades rather than to provide feedback about how each student, as well as the entire class, is doing. Students may or may not know how to answer a particular question, but are rarely provoked into contemplating new ideas or resolving discrepancies in their perspectives.

ASSESSMENT IS OFTEN INDEPENDENT OF CURRICULUM, RATHER THAN INTEGRATED INTO IT. It is often said that "assessment drives curriculum"; one consequence is that most students are motivated to learn only what will help them succeed on tests. To shift the focus of instruction, one must first shift the focus of assessment. This can be accomplished only if formative assessment items are designed in accord with cognitive and educational goals.

3. Detailed Statement of Original Project Goal

We originally proposed a project to develop prototype formative assessment (FA) materials for use with high school physics curricula. These Assessing-to-Learn (A2L) materials were to be designed with the specific aim of fully integrating assessment and instruction, and to be compatible for use with a classroom response system (e.g., Classtalk or PRS).

Experiences with FA at the college level led us to conclude that classroom response systems are a powerful tool for addressing the challenges of FA in a high school setting. Although technology is not essential to make K-12 classes of 20 to 30 students interactive, as it is in large lecture introductory science courses at the college level, we believe that it has great merit for the integration of formative assessment and instruction. We expected the use of classroom response system technology in a high school setting to have many of the same benefits found in introductory college courses, offsetting any class time lost to assessment activities.

- It increases the number of active learning experiences in science classes.
- It makes class time more enjoyable, and therefore more motivating to students.

- It makes assessment activities genuine learning experiences for students.
- It provides a more equitable learning experience for a diverse student population.

Immediate feedback on the results of instruction and activities will impact teachers and students.

- Teachers will become more aware of what their students can and cannot do.
- Teachers often will be surprised how little students have understood their presentations.
- Teachers will become more self-aware of their communication skills.
- Students will become more outspoken and confident when they realize their views are shared by other students.
- Both students and teachers will become aware of the value and importance of formative assessment.

Automatic record keeping of student performance will influence assessment.

- Teachers will be able to see long term patterns of student progress and thus be better able to meet individual student needs.
- Teachers will modify their instructional approach to provide greater emphasis on conceptual development and process skills.
- Teachers will have more time to reflect on the outcomes of their efforts.

4. The Role of Assessment Materials

FORMATIVE ASSESSMENT MATERIALS SHOULD PROMOTE LEARNING RATHER THAN GRADE STUDENTS' PERFORMANCE. They should make students' thinking processes and understandings explicit, so that teachers and students can work together toward developing conceptual understanding and problem-solving skills. FA materials are successful only if students get the message that they should answer questions in terms of how they honestly think, not what they believe their teachers want to hear. It is crucial that FA activities be perceived as learning tools and not as a means for grading.

FA MATERIALS SHOULD PROMOTE INTEGRATED AND FLEXIBLE KNOWLEDGE ACROSS A WIDE RANGE OF PROBLEM CONTEXTS. Research indicates that beginning physics students do not build a self-consistent knowledge base, but rather store in memory pieces of unrelated knowledge that are not linked to contexts of applicability. FA materials should make teachers aware of this existing problem in students' knowledge bases and help students build strategic knowledge elements; that is, students should tie physics concepts to contexts where they can be applied and to the procedural knowledge needed to apply them.

FA MATERIALS SHOULD PROVIDE TEACHERS WITH AN ASSESSMENT OF STUDENTS' CONCEPTUAL UNDERSTANDING SKILLS. They should also assess analysis, reasoning, and problem-solving abilities deemed important by the physics education community. In our work with teachers over the last 14 years, many tell us that they would like assessments that probe for higher level cognitive skills but are frustrated by their lack of time or expertise to develop them.

FA MATERIALS SHOULD ENGAGE STUDENTS AND GENERATE RICH SMALL-GROUP AND WHOLE-CLASS DISCUSSIONS. Few students learn well if they are passive and work in isolation. FA activities should alter the classroom dynamic to make it more student centered. Assessment activities should highlight major physics concepts and problem-solving procedures as a context for discussion among students or between the students and teacher.

5. Broadening the Scope of the A2L Project

The development of a suitable set of prototype FA items remained a significant goal of the A2L project. Nonetheless, work with teachers in the field and with our evaluation team caused us to challenge our original notion that lacking "a comprehensive set of formative assessment items" was the most significant barrier to successful implementation of effective FA practices. We briefly describe selected findings that led us to broaden the scope of the A2L project.

- THERE IS SIGNIFICANT VARIATION FROM ONE TEACHER TO ANOTHER IN MANY AREAS AFFECTING THE ADOPTION AND IMPLEMENTATION OF FA PRACTICES. Although teachers often share certain high level instructional goals, their education, past experiences, instructional style, teaching methods, coverage of content, and beliefs about their students are quite idiosyncratic. Teachers tend to view assessment materials in relationship to their curriculum and perceived capabilities of their students. Teachers want FA materials to closely match their curriculum and what they recognize to be their students' specific needs. We would argue that this perspective — that materials must be tailored to the curriculum and students — is a holdover from the practice of summative assessment. (In the practice of FA it is the teacher's response to students that must be tailored. If the activities themselves are tailor-made for the class, then valuable assessment information will be lost.) In the context of summative assessment, it is "unfair" to test a student on things not covered or that are too hard. In contrast, FA focuses on the boundaries of students' understandings and on the processes students use to analyze and reason about a situation, so materials' "fairness" is not relevant; only their utility is.

- ALTHOUGH TEACHERS CAN AND SOMETIMES DO CREATE THEIR OWN FA MATERIALS, THE AMOUNT AND QUALITY IS USUALLY INSUFFICIENT TO SUPPORT A COMPREHENSIVE FA PROGRAM. Teachers have limited time, and many view FA materials as desirable but not essential. They often lack the background knowledge and skills to create a well-rounded set of FA activities. For example, many teachers will focus on a single cognitive outcome such as "recognizing a concept," failing to address higher order cognitive skills like analysis, reasoning, problem solving, and reflection.

- ALTHOUGH TEACHERS IDENTIFY WITH THE STATED GOALS OF FA, THEIR PRACTICE OF IT IS OFTEN INCONSISTENT WITH THESE GOALS. Some teachers implement FA activities like mini-summative assessments, with each question being a high stakes contest of right and wrong. Some teachers react to the FA context by trying to lead their students to the "correct answer." (Unfortunately, this feeds the dependency of students on the "teacher as authority." FA should provide a teacher with information that allows the teacher to help the students help themselves.) Still, other teachers directly or indirectly stop the FA activity once the correct answer has been identified, with the consequence of losing valuable data. (E.g., were students right for the wrong reason? Did students who answered incorrectly have important and useful insights? Or, simply, why did some students answer incorrectly?).

- ALTHOUGH TEACHERS AND STUDENTS ENJOY FA ACTIVITIES AND EXPRESS THAT THE ACTIVITIES ARE VALUABLE LEARNING EXPERIENCES, MOST TEACHERS DO NOT USE THE INFORMATION THEY RECEIVE TO MAKE REAL-TIME TEACHING DECISIONS. So while many of the classrooms that we observed implementing A2L became more student focused and interactive as a result of using FA activities, the ultimate impact on instruction — making real-time teaching decisions — was not achieved. Flexible teaching, which we consider an essential component of formative assessment, is not natural for teachers. For the most part, teachers continue their instructional plans affected only tangentially by the FA experience.

From our experiences with project teachers, it became clear that a highly tuned set of FA activities might be useful for changing the classroom dynamic, but would be insufficient for inducing most teachers to adopt authentic FA practices. We decided to broaden the scope of A2L in two significant ways.

- Begin to identify and elucidate the factors that influence teachers' adoption of formative assessment practices and the kinds of support teachers need to fully implement a program of formative assessment.

- Contribute to the pool of educational materials for pre-service and in-service teachers in ways that enhance teachers' formal understanding of formative assessment and provide practical guidance for initiating and implementing a formative assessment program.

6. Specific A2L Goals and Objectives

We identified eight tangible goals for the A2L project. Seven of the eight goals are framed in terms of a product that supports some aspect of FA (classroom practice, teacher education, development of assessment materials, etc.). The remaining goal concerns addressing certain research questions related to FA, chosen specifically because we believe that we can make a contribution to these questions given the other goals of the project and the available resources. We list the goals more or less in order of priority.

1. DEVELOP A SET OF PROTOTYPE FA ITEMS AIMED AT INTRODUCTORY HIGH SCHOOL PHYSICS FOR USE WITH A CLASSROOM RESPONSE SYSTEM. This set will serve two purposes: it will provide

a reservoir of items for teachers implementing formative assessment in high school physics, and will also supply exemplars for teachers and developers designing their own FA materials. The FA items address a range of cognitive goals and habits of mind, are based on physics education research, and are designed to have instructional value beyond assessment. We have included items on a variety of topics in introductory high school physics. A2L items target many of the cognitive difficulties identified by physics education research and employ a variety of techniques, such as having students use multiple representations, work in cooperative groups, and carry out hands-on activities.

2. WRITE A GUIDE TO FA IN SCIENCE INSTRUCTION. Based on our work with the A2L project teachers and evaluation team, we have identified a need for teacher education materials on the topic of FA. Using our experiences visiting classrooms, giving workshops, and collaborating with teachers, together with information gathered through action research carried out by our evaluation team, we are authoring *Assessing-to-Learn: A Guide to Classroom Formative Assessment in Introductory*. We imagine two different audiences for this guide. One audience consists of practicing teachers interested in a practical introduction to FA with specific examples and techniques for use in the physics/physical science classroom. The other audience consists of teacher educators who wish to include a component of FA in their teacher education programs, whether college courses, workshops, or online courses.

3. CREATE AN A2L WEB SITE. A web site has been created to make the project's residue available as a public resource; an improved, more useful version will go public by August 2004. The site will contain an organized, categorized, searchable database of FA questions appropriate to various physics topics and instructional levels. It will also provide relevant reprints and technical reports. The site is intended to serve three distinct populations: teachers wishing to begin implementing a FA program, individuals supporting professional development in the area of FA, and researchers and developers working in the area of FA.

4. WRITE A TEACHER RESOURCE GUIDE TO HELP TEACHERS MANAGE THE RESOURCES ON THE WEB SITE. The guide will provide an overview of the web site and provide suggestions for how to make use of the site's resources. It will also contain an introduction to FA and the A2L approach. The resource guide will present a range of examples of FA activities, highlighting a variety of the assessment items while illustrating different aspects of FA practice. The examples will include detailed teacher aids containing a discussion of the purpose of each assessment item, suggestions for classroom implementation, pertinent research on student misunderstandings, and effective instructional strategies for addressing related content. Each aid will contain information relevant to the purpose of its item, such as the specific cognitive goals it targets, tips for fostering useful habits of mind, and hints for anticipating students' answers and reasoning. The teacher aids are intended to be exemplary in the sense of illustrating for teachers the kinds of

information they should consider when using or designing a FA item. We intend this document to help teachers get started using the A2L approach.

5. CONDUCT RESEARCH ON TEACHER ADOPTION OF CLASSROOM FORMATIVE ASSESSMENT. There is a great need to understand teachers' views and practices with regard to FA. Research in the form of classroom observations, surveys, classroom video tapes, and action research was carried out in an attempt to understand if, when, and how FA becomes an integral part of a teacher's practice. Our evaluation team has sought to document changes in teachers' beliefs and expectations, structural changes in the way teachers teach, and changes in the classroom discourse. This research deals with very complex issues and during the course of the project we have only been able to scratch the surface on this important area of investigation.

6. DESIGN A FORMATIVE ASSESSMENT COURSE. As part of writing the guide to FA in introductory science, we are designing the elements of a course on FA. Unfortunately, the institutional resources for teaching such a course are not available at this time. (The University of Massachusetts Physics Education Research Group is submitting a proposal to NSF titled, *Agile Teaching: Sustaining professional development in secondary science instruction through inquiry, technology, and action research*. A significant part of this proposal is a one-year, 84 hour, multi-disciplinary science course taught on-site. We anticipate that the current design effort will support this endeavor.) We envision that the guide to FA described above will serve as the primary text for such a course. The course design elements will include a list of topics, possible readings from the literature, and appropriate references to materials and examples from the A2L web site.

7. FORMALIZE A DESIGN PARADIGM FOR FORMATIVE ASSESSMENT ITEMS. We have documented our design methodology and will make it available on the A2L web site for teachers, teacher educators, and researchers working in the area of FA. Effective design of FA materials requires a deep understanding of the purposes of FA and how various design features of a FA item relate to these purposes. A limiting characteristic of teacher designed materials is the narrow focus of the items, which tend to be restricted to concept recognition or the application of a simple formula. A FA program requires a wider focus to be consistent with the stated goals of national reform efforts in science education.

8. IDENTIFY STRATEGIES FOR CLASSROOM FORMATIVE ASSESSMENT. We have compiled a list of strategies — dos and don'ts — for implementing classroom FA. This list contains a combination of the strategies we have used effectively for doing FA in introductory college level physics courses and of the successful strategies used by A2L project teachers.

7. Research and Educational Activities

The following is a list of the research and educational activities taken as part of the A2L project.

Collaborations: Efforts to achieve the goals of §6 have involved the collaboration of several groups: (a) a development team, (b) industry partners (Better Education, Texas Instruments) (c) an advisory committee (d) an evaluation team, (e) technical support and (f) project teachers and high schools.

Advisory Committee Meetings: We formed an advisory committee consisting of Audrey Champagne (SUNY Albany), Maryellen Harmon (Boston College), and Lillian McDermott (U. of Washington). Meetings between the advisory committee, development team and evaluation team early in the project were instrumental in defining three broad areas needing research: changes in teachers' beliefs and expectations (concerning what their students can or cannot do, what their students know, what constitutes good learning experiences, etc.), structural changes in the way teachers teach (greater use of cooperative group structures, class wide discussion, active learning strategies, etc.) and changes in the classroom discourse (can teachers elicit student thinking, can they induce students to perform deeper analyses, can they make use of student responses to guide discussion and future instruction, etc.).

Development of Formative Assessment Items: The development team consisted of members from the University of Massachusetts Physics Education Research Group. The development team created more than 300 FA items. Approximately 250 of these will be selected as exemplary items for the final A2L website.

Pilot Testing of Assessment Items by Project Teachers: We have had three full years of pilot testing, revision, and new development of FA items. During pilot testing, we required all project teachers to use a common subset of the assessment items. In addition to these required items, each teacher was asked to commit to a small set of items of their own choosing. During the school year teachers were free to use any additional items from the data base, and to create and use their own items as they saw fit. Teachers have shared their items with the development team and these are under consideration for the final A2L website.

Collaboration of A2L Project Teachers and the Development Team: During the second year of the project, the development team initiated a small development effort in collaboration with selected A2L project teachers. The purpose of this effort was to create assessment materials that were more closely related to the A2L teachers' curriculums. The collaboration was used to share perspectives on teaching and assessment between A2L teachers and the development team and to make the development team more aware of issues of concern to teachers. The collaboration was also used to provide teachers with a more in-depth view of FA. The collaboration resulted in quality assessment materials, some of which will be part of the final A2L data base of items.

Development and Pilot Testing of Teacher Aids: We created and pilot tested teacher aids for a subset of items in use by project teachers. Although the teacher aids were generally limited to one page per assessment item, it became clear that teachers had little disposable time to study aids in any kind of depth. It was difficult to discern any impact of the aids on teacher

implementation of FA. However, it was clear that teachers appreciate having an explanation of the physics underlying a FA item. We believe that teachers aids must employ a simple structure capable of communicating needed information economically. To be successful, teachers will need to understand the structure used and the types of information available in the teacher aid. This may require some type of introduction to the teacher aids.

Creation of an A2L Web Site: Our technical support has designed and implemented a preliminary A2L web site. The web site allows teachers to sign up and get access to a database of assessment items and teacher aids. The web site provides users with information about the A2L project, A2L staff, and site news. It also permits the user to search or browse the database of assessment items and teacher aids, and to print items in a format useful for classroom use. The site is set up with an online discussion forum; however, shortage of resources has prevented us from taking advantage of this feature. The site offers several administrative features such as report functions, management of volunteers and users, and group email. It makes available a document we have written about FA. The site has allowed non-project teachers to sign up for access to FA items. Approximately 75 teachers volunteered to try out items from the web site. During the third year, we posted a survey on the web asking teachers about their views of FA and their use of the A2L items, but the response rate was only about 25%.

Documents on FA: The development team created a document that expresses fully its view of FA. The resulting document, *ASK•IT/A2L: Assessing Student Knowledge with Instructional Technology*, has been posted on the A2L web site and has served as a useful reference to project teachers and others who have used A2L items. This document will be the starting point for writing a guide to FA. We have also written two other documents on FA. "Assessing-To-Learn: Reflective Formative Assessment Using a Classroom Communication System" was written as a contribution to the NSF funded international conference "Pathways To Change 2002" and is published in the conference proceedings. "Assessing-to-Learn: Formative Assessment in Physics Instruction" was written as an introduction to FA for high school physics teachers and is accepted for publication in *The Physics Teacher*.

Classroom Visits: The development and evaluation teams made many visits to project high schools to observe the use of FA items. We also observed classrooms when no FA items were in use. All of the A2L project teachers used a classroom response system (Classtalk or PRS) provided to them by the development team. Some of the classroom technology was donated to the development team by the vendors participating in the collaboration. The development team provided teachers with technical support and made observations to evaluate the effectiveness of items used by teachers. Following a visit, development team members would debrief teachers and discuss with them alternative ways to use the assessment items and what additional assessment items might be needed. The evaluation team made observations to assess the impact of FA on teachers, students, and the classroom dynamic.

Workshops for Project Teachers: During the first two summers of the project, we held a two-day workshop for teachers. The workshops provided teachers with background information on FA. Teachers were also engaged in a series of activities to help them become familiar with the existing formative assessment items, to plan their use of items for the coming school year, and to share ideas and discuss concerns with their peers.

Workshop for Beta Teachers: During the third year of the project, we invited a new group of teachers not local to the University of Massachusetts to join the project. We refer to these as "beta teachers." They were given a workshop, and then were essentially on their own to implement FA in their schools except for email contact. The design of the beta teachers workshop was the joint effort of the development team, evaluation team, and project teachers. The workshop dealt with the theory of FA, the development of FA items, strategies for implementing FA, and practical issues associated with implementation. The A2L project teachers contributed to the workshop both as participants and presenters.

Other Workshops: Members of the development team have given numerous workshops addressing issues in FA to teachers outside the A2L project. The primary purpose of these workshops has been to raise teacher awareness of the value of FA in the teaching of science.

Pre-Post Interviews: The evaluation team conducted pre- and post-project interviews with project and beta teachers and with the development team. These interviews explored subjects' views concerning the nature of FA and the goals of the A2L project. A pre/post format was used to examine how participation in the A2L project impacted teachers.

Pre/Post Surveys: The evaluation team also conducted pre- and post-project surveys with project and beta teachers. The purpose of the surveys was to get more detailed information about each teacher's teaching goals and practices.

Pre/Post Evaluation of Student Learning: Since a goal of the project is the development of assessment items that constitute good learning activities, the evaluation team attempted to evaluate student learning in a couple of isolated cases. The evaluation team gave a small group of students an activity prior to a series of FA items. The students were asked to work together on a problem while the evaluation team videotaped the students. Following normal classroom use of the designated FA items, the students worked on the problem a second time.

Videotaping Classroom Practice of FA: Although generally we did not videotape classrooms during classroom visits, the evaluation team did collect video in a small number of instances after obtaining the appropriate permissions. This video will be used to more critically analyze the impact of FA on the classroom practice of teachers.

Collaborative Teacher Action Research: The evaluation team served as facilitators of an action research group consisting of a subset of the A2L project teachers. The method of action research that was used is referred to by the evaluation team as *enhanced normal practice*, which

consists of anecdote-telling, the trying out of ideas, and systematic classroom inquiry. This participating group of teachers had two main goals: to improve the use of A2L in their own classrooms and to develop ways for other teachers to learn how to use A2L.

8. Data Collection and Observations

Data collection and observations were described above as part of the activities of the project. In this section we provide a complete list of these particular activities.

Data Collected

1. Which A2L items teachers used.
2. Interview data examining teachers' beliefs about FA.
3. Surveys and questionnaires examining teachers' educational goals and practices.
4. Teachers' written answers to selected A2L items.
5. FA items created by teachers.
6. FA items created jointly by the development team and selected teachers.
7. The development scheme used by the development team.
8. Survey results on FA practice of teachers using the A2L web site.
9. Video tape of classroom FA practice.
10. Notes from collaborative teacher action research meetings
11. Interview data examining developers' beliefs about FA
12. Teacher comments on A2L items used in class.
13. Student performance data on selected items.
14. Video of a small groups of students solving a problem pre- and post-classroom FA.
15. Notes of classroom visits made by the development and evaluation teams.

Observations

1. Classroom FA activities: observations by the development team.
2. Classroom FA activities: observations by the evaluation team.
3. Teacher action research meetings: observations by the evaluation team.
4. A2L-sponsored workshops: observations by the evaluation team.

9. Publications and Presentations

Publications

Leonard, W.J., Gerace, W.J. & Dufresne, R.J. (2001). Questions First (Q1st): The challenges, benefits, drawbacks, and results of asking students questions prior to formal instruction. In S. Franklin, J. Marx & K. Cummings (Eds.), Proceedings of the 2001 Physics Education Research Conference (pp 41–44). Rochester, NY: Rochester Institute of Technology.

Dufresne, R., Gerace, B., Leonard, B. & Mestre, J. (2001). Creating an item for in-class formative assessment. The Interactive Classroom [Newsletter for Interactive Classroom Teaching and Learning], 1,3.

Gerace, W.J. (2001). Problem Solving and Conceptual Understanding. In S. Franklin, J. Marx & K. Cummings (Eds.), Proceedings of the 2001 Physics Education Research Conference (pp. 33–36). Rochester, NY: Rochester Institute of Technology (2001).

Dufresne, R.J., Gerace, W.J. & Leonard, W.J. (February 2001). Springbok: The physics of jumping. The Physics Teacher, 39(2), 109–116.

Dufresne, R.J., Leonard, W.J. & Gerace, W.J. (March 2002). Making sense of students' answers to multiple-choice questions. The Physics Teacher, 40(3), 174–180.

Leonard, W.J., Gerace, W.J. & Dufresne, R.J. (2002). Resolutión de Problemas Basada en el Análisis. Hacer del análisis y del razonamiento el foco de la enseñanza de la física [Analysis-Based Problem Solving: Making analysis and reasoning the focus of physics instruction]. Enseñanza de las Ciencias [Science Teaching], 20(3, November), 387–400.

Gerace, W.J. & Beatty, I. (2002). "Probing physics students' conceptual knowledge structures through term association". American Journal of Physics, 70(7, July), 750–758 (2002).

Dufresne, R.J., Gerace, W.J., & Leonard, W.J. (2002). Assessing-To-Learn (A2L): Reflective Formative Assessment Using a Classroom Communication System. Invited workshop paper available online at http://stemtec.org/pathways/Proceedings/Papers/Dufres-p.pdf; also available on a CD-ROM assembled by STEMTEC. Also available as a University of Massachusetts Physics Education Research Group Tech. Rep. PERG-2002#05-APR#1-15pp.

Dufresne, R.J., Gerace, W.J. & Leonard, W.J. (2004). "Assessing-To-Learn: Formative assessment in physics instruction". The Physics Teacher, 42(6), 109–116

Technical Reports

Gerace, W.J., & Leonard, W.J. (1999) . "A Demonstration of Kinematics Principles,". University of Massachusetts Physics Education Research Group Tech. Rep. PERG-1999#07-JUL#2-v.2-10pp (1999).

Dufresne, R.J., Gerace, W.J., & Leonard, W.J. (1999). "Using technology to implement active learning in large classes," University of Massachusetts Physics Education Research Group Tech. Rep. PERG-1999#11-NOV#2-22pp.

Leonard, W.J., Gerace, W.J. & Dufresne, R.J. (1999). "Concept-Based Problem Solving: Making concepts the language of physics,". University of Massachusetts Physics Education Research Group Tech. Rep. PERG-1999#12-NOV#3-18pp (1999).

Leonard, W.J., Gerace, W.J. & Dufresne, R.J. (2000). "ASK IT / A2L: Assessing Student Knowledge with Instructional Technology,". University of Massachusetts Physics Education Research Group Technical Report PERG-2000#09-SEP#1-28pp.

Leonard, W.J., Gerace, W.J., & Dufresne, R.J. (2001). Analysis-Based Problem Solving: Making analysis and reasoning the focus of physics instruction. University of Massachusetts Physics Education Research Group Tech. Rep. PERG-2001#12-AUG#3-v.2-23pp.

Presentations (Development Team)

Gerace, W.J., "Promoting Active Learning Through the Use of Technology." Invited interactive seminar presented to the math, science and engineering faculty of the University of Strathclyde, Glasgow, SCOTLAND, November 25, 1998.

Gerace, W.J., "Electronic Classroom Communication Systems: Past, present, and future." Invited seminar for the Science, Technology, Engineering and Mathematics (STEM) Education Institute, University of Massachusetts, Amherst, MA, October 5, 1999.

Gerace, W.J., Mestre, J.P., Leonard, W.J. & Dufresne, R.J. Assessing to Learn (A2L): Formative assessment for high-school physics. AAPT Announcer, 29, #4 (December), Contributed Paper DF1, p. 88 (1999). Presented at the Contributed Session on PER: Assessing Methods of Instruction, for the Winter Meeting of the American Association of Physics Teachers, Kissimmee, FL, January 15–19, 2000.

Leonard, W.J., Gerace, W.J., Mestre, J.P. & Dufresne, R.J. Multiple-Choice Questions: Searching for some answers. AAPT Announcer, 29, #4 (December), Contributed Paper FB2, p. 99 (1999). Presented at the Contributed Session on PER: Basic Research and Tool Analysis, for the Winter Meeting of the American Association of Physics Teachers, Kissimmee, FL, January 15–19, 2000.

Gerace, W.J., "Classroom Communication Systems: A comparison of Classtalk and the Personal Response System." Invited presentation given for the Science, Technology, Engineering, and Mathematics Teacher Education Collaborative (STEMTEC), University of Massachusetts, Amherst, MA, February 12, 2000.

Mestre, J., Gerace, W., Dufresne, R. & Leonard, W. Assessing to Learn: Formative assessment materials for high school physics. Poster presented at the Physics Education Research Conference, Guelph, Ontario, CANADA, August 2–3, 2000.

Mestre, J.P., Dufresne, R.J., Gerace, W.J. & Leonard, W.J. The multidimensionality of assessing for understanding. AAPT Announcer, 30, #4 (Winter), Contributed Paper EG01, p. 118 (2000). Presented at the Contributed Session on PER Assessment, Part I, for the Joint Winter Meeting of the American Association of Physics Teachers and the American Astronomical Society, San Diego, CA, January 6–11, 2001. (Presented by J. Mestre.)

Dufresne, R.J., Gerace, W.J., Mestre, J.P. & Leonard, W.J. Assessing to Learn (A2L): Research on teacher implementation of continuous formative assessment. AAPT Announcer, 30, #4 (Winter), Contributed Paper EG03, p. 119 (2000). Presented at the Contributed Session on PER Assessment, Part I, for the Joint Winter Meeting of the American Association of Physics Teachers and the American Astronomical Society, San Diego, CA, January 6–11, 2001.

Beatty, I., Dufresne, R.J. & Gerace, W.J. ConMap: Investigating Computer-Based Approaches to Assess Conceptual Knowledge Structure. AAPT Announcer, 30, #4 (Winter), Contributed Paper HA01, p. 133 (2000). Presented at the Contributed Session on PER Web-Based Assessment, for the Joint Winter Meeting of the American Association of Physics Teachers and the American Astronomical Society, San Diego, CA, January 6–11, 2001.

Leonard, W.J., Gerace, W.J. & Dufresne, R.J. Questions First (Q1ST): The challenges, benefits, drawbacks, and results of asking students questions prior to formal instruction. AAPT Announcer, 31, #2 (Summer), Invited Paper FF02, p. 137 (2001). Presented at the Invited Session on Studying Student Learning Through Classroom Behaviors, for the Summer Meeting of the American Association of Physics Teachers, Rochester, NY, July 21–25, 2001.

Gerace, W.J., "Problem Solving and Conceptual Understanding." Presented at the 2001 AAPT Physics Education Research Conference, Rochester, NY, July 25–26, 2001.

Dufresne, R.J. Developing A2L assessment items. Presented at the Assessing-to-Learn Physics Workshop, Amherst Regional High School, Amherst, MA, July 13, 2001.

Dufresne, R.J. & Gerace, W.J. Interpreting student responses to questions. Presented at the Assessing-to-Learn Physics Workshop, Amherst Regional High School, Amherst, MA, July 13, 2001.

Dufresne, R.J. & Gerace, W.J., "Mock classroom and A2L philosophy." Presented at the Assessing to Learn Physics Workshop, Amherst Regional High School, Amherst, MA, July 13, 2001.

Dufresne, R.J. & Gerace, W.J., "Interpreting student responses to questions,". Presented at the Assessing to Learn Physics Workshop, Amherst Regional High School, Amherst, MA, July 13, 2001.

Dufresne, R.J. & Gerace, W.J. "Interpreting student responses to questions," Presented at the Assessing to Learn Physics Workshop, Amherst Regional High School, Amherst, MA, July 13, 2001.

Dufresne, R.J., Gerace, W.J., & Leonard, W.J. (2002). Assessing-To-Learn (A2L): Reflective Formative Assessment Using a Classroom Communication System. Invited workshop paper available online at http://stemtec.org/pathways/Proceedings/Papers/Dufres-p.pdf; also available on a CD-ROM assembled by STEMTEC. Also available as a University of Massachusetts Physics Education Research Group Tech. Rep. PERG-2002#05-APR#1-15pp.

R.J. Dufresne & W.J. Gerace. "Classroom Communication Systems: Getting beyond the one-man show." Abstract submitted for the Winter Meeting of the American Association of Physics Teachers, Austin, TX, January 11–15, 2003.

"Classroom Communication Systems: Getting beyond the one-man show," (with R.J. Dufresne). AAPT Announcer, 32, #4 (Winter), Contributed Paper DJ07, pp. 88–89 (2002). Presented at the Winter Meeting of the American Association of Physics Teachers, Austin, TX, January 11–15, 2003.

Presentations (Evaluation Team)

Feldman, A., and Capobianco, B. (2002). *Formative Assessment Action Research: A Study of Teacher Learning by Using Technology*. A paper presented at the Annual Meeting of the National Association for Research in Science Teaching, April 2002, New Orleans, LA.

Feldman, A., Capobianco, B., Pedevillano, E. and Weiss, T. (2002). *Culture and Identity in a Science Teacher Education Reform Project*. A paper presented at the Annual Meeting of the American Educational Research Association, April 2002, New Orleans, LA.

Feldman, A. (2001). *Formative assessment action research*. Invited seminar. Hebrew University, Jerusalem, Israel. December 19, 2001.

Feldman, A., and Capobianco, B. (2002). Formative Assessment Action Research: Teacher Learning in Action. Annual meeting of the Association of Educators of Teachers of Science. January 2003, St. Louis.

Feldman, A., and Capobianco, B. (2003). Real-Time Formative assessment: A study of teachers' use of an electronic response system to faciliate serious discussions about physics concepts. A paper presented at the Annual Meeting of the American Educational Research Association, April 2003, Chicago, IL.

Presentations (A2L Project Teachers)

We point out that several of the teachers who participated in the A2L project (both our alpha and beta teachers) have made their own presentations on formative assessment at workshops and professional meetings. These presentations were initiated by the teachers and were carried out independent of the A2L project.

Workshops (Development Team)

Assessing-To-Learn (A2L): Reflective Formative Assessment Using a Classroom Communication System (R.J. Dufresne & W.J. Gerace). Workshop presented for STEMTEC (Science, Technology, Engineering, and Mathematics Teacher Education Collaborative), Amherst, MA, September 21, 2002.

Assessing-To-Learn (A2L): Reflective Formative Assessment Using a Classroom Communication System (R.J. Dufresne W.J. Gerace & W.J. Leonard). Workshop presented at PATHWAYS TO CHANGE: An International Conference on Transforming Math and Science Education in the K-16 Continuum, Arlington, VA, April 21, 2002.

Assessing-to-Learn Physics (R.J. Dufresne, W. Gerace, C. Emery, A. Kropf & V. Veneman). Two-day workshop given at Amherst Regional High School, Amherst, MA, July 13–14, 2001.

Learning vs. Teaching: Changing Perspectives in Science Instruction (R.J. Dufresne W. Gerace & W. Leonard). Workshop given for the Institutional Research and Academic Development Awards Program Workshop, Tucson, AZ, October 27–28, 2000.

"Physical Puzzles: Do you ever wonder why things behave the way they do?" (W. Leonard).Two interactive discussions with high school students, given for Career Day at Frontier Regional High School, South Deerfield, MA, March 23, 1999.

"Bring Your Brain! Demonstrations of science using common, household items," (W. Gerace & W. Leonard). 8 sets of demonstrations, given for the students in grades 1–8, St. Vincent de Paul School, Long Hill Township, NJ, March 25, 1999.

"Active Learning: How to engage students, increase motivation, and encourage learning," (W. Gerace & W. Leonard). Invited, interactive mini-workshop, given for elementary and middle school teachers at St. Vincent de Paul School, Long Hill Township, NJ, March 25, 1999.

"Bring Your Brain! Demonstrations of science using common, household items," (W. Gerace, I. Beatty, D. Lee & W. Leonard). 4 sets of demonstrations, given for about 90 children of ages 3–18, Anchor Village, St. Philomena's Children's Home, Sydenham (Durban), South Africa, August 16–17, 1999.

"Bring Your Brain! Demonstrations of science using common, household items," (W. Gerace, I. Beatty, D. Lee & W. Leonard). 3 sets of demonstrations, given for about 100 pupils in standards 7–10 (grades 9–12), Naauwpoort School, Rustenburg, South Africa, August 20, 1999.

"Promoting higher order thinking skills," (W. Gerace & W. Leonard). Workshop given at the request of Chicopee Public Schools, Chicopee, MA, October 25, 1999.

"Assessment in the service of instruction," (W. Gerace & W. Leonard). Workshop given at the request of Chicopee Public Schools, Chicopee, MA, November 1, 1999.

"Relating communication and learning skills," (W. Gerace & W. Leonard). Workshop given at the request of Chicopee Public Schools, Chicopee, MA, November 8, 1999.

"Developing Effective Classroom Practices. Session 1: Promoting higher order thinking skills / Session 2: Assessment in the service of instruction / Session 3: Emphasizing structuring and communication," (W. Gerace & W. Leonard). Workshops (3) given at the request of Springfield Public Schools, Springfield High School of Science & Technology, Springfield, MA, December 6, 1999; January 28 & March 6, 2000.

"FUN·damental Physics: Amusing musings," (W. Gerace & W. Leonard). Mini-courses (2) given for the Teachers As Scholars program of the Five College/Public School Partnership, University of Massachusetts, Amherst, MA, March 28 & April 6, 2000.

"FUN·damental Physics," (W. Gerace & W. Leonard). Workshop given for the Chicopee Public Schools, Chicopee, MA, April 4, 2001.

"FUN·damental Physics: Amusing musings," (W. Gerace & W. Leonard). Mini-courses (2) given for the Teachers As Scholars program of the Five College/Public School Partnership, Amherst College, Amherst, MA, April 6 & 27, 2001.

"Strategic Tutoring in Science," (W. Gerace & W. Leonard). Five-day workshop, given for the Quantitative Skills Center/Summer Science Program, Amherst College, Amherst, MA, July 30–Aug 13, 2002.

Workshops (Evaluation Team)

NSTA 2003-03-28 - 14:00 - 15:00 - Formative Assessment Action Research: Using Technology to Increase Student Learning [Workshop, Phys] Presenter(s): Allan Feldman (University of Massachusetts, Amherst, MA); Earl L. Carlyon (Farmington High School, Farmington, CT); Aaron Kropf (Amherst Regional High School, Amherst, MA); Val Veneman (Amherst Regional High School, Amherst, MA).

10. Other Contributions and Products

An A2L website (http://A2L.physics.umass.edu/) has been created to make the project's residue available as a public resource; an improved, more useful version will go public by August 2004. (See goal number 3 in §6 for additional comments.)

More than 250 formative assessment items in physics will be available on the final A2L website. The set of items will provide exemplars for a variety of topics (mechanics, electricity & magnetism, fluids, thermodynamics, and modern physics) at a variety of levels (from conceptual physics in the high school to third year physics courses in college) addressing a range of cognitive goals (e.g., conceptual understanding, analysis and reasoning, problem solving.) Many A2L items are available in draft form on the current version of the A2L project website: http://A2L.physics.umass.edu/. (See goal number 1 in §6 for additional comments.)

A teacher resource guide to provide an introduction to FA and to help teachers manage the resources on the A2L site. Available September 1, 2004. (See goal number 4 in §6 for additional comments.)

Assessing To Learn: A Guide to Classroom Formative Assessment in Introductory Science – a guide to formative assessment. Available on the A2L site October 1, 2004. (See goal number 2 in §6 for additional comments.)

11. Summary of Findings

Results to date have been mixed. Teachers and students generally like the A2L approach and the use of the classroom response system technology. Teachers find the histogram of student responses useful and their consensus is that students find it useful as well. The teachers claim that the A2L process is useful for stimulating class wide discussion and this is also our experience based on our many observations. Students seem to enjoy working on the items, and delight in seeing how their answers stack up against those of their classmates. Teachers claim they would use more items if enough 'good' items existed.

Despite the generally positive reactions to the A2L approach, however, we see some impediments to a full implementation. Teachers view some assessment items as too difficult, or not a good 'fit' to their curriculum. We believe that some of these judgments stem from a misunderstanding of the approach. Specifically, teachers adopt a summative assessment approach (despite claims to the contrary) in which the correct answer plays a central role. This is contrary to the formative assessment view, where process matters most and questions are used primarily to focus students and engender student interest. As a result, teachers tend to favor low level conceptual questions, and generally shy away from questions involving higher level analysis and reasoning. Some teachers find it difficult to process student's answers real-time so that information gleaned can meaningfully feed back into instruction. Finally, the inability to easily gather the results from different assessment items has limited teachers' ability to look at the progress of individual students in order to take student progress into account.

With the exception of the last point, which requires a technological solution, we are seeking to address these impediments directly through professional development materials. We believe that to successfully use the A2L model of formative assessment, teachers must build requisite knowledge and experience in several areas.

- If teachers are using a classroom response system they must develop familiarity with the response system technology. This involves not only learning basic user information, but also understanding the different ways that response system technology can be used to obtain assessment information and foster desired learning goals.
- Teachers must have access to quality formative assessment items that are suitable for their students. The A2L model demands that teachers respond real-time to students' needs. No set of preexisting, sequenced items can do the job. Teachers must be able to select assessment items based on need, and when necessary, they must create the questions themselves.
- Formative assessment requires students to take on new more demanding roles in the classroom. The transition for students is not a natural one. Teachers need to understand these new roles and actively coach students through this transition.
- Formative assessment focuses on process. Students are engaged in activities often in small groups. The teacher must interact with individual students, with small groups and with the class as a whole. The teacher supports students, leads class discussion, makes assessment decisions on the fly. Teachers must have a pedagogy that supports the complex decision making involved in the formative assessment process.
- It takes teachers a considerable amount of time to understand formative assessment and make it an integral part of their practice. It requires expertise in several areas. If teachers are using classroom communication technology, they must understand how the technology works and feel comfortable employing the technology as needed. They must also learn how to manage the classroom dynamic, which is changed dramatically with the introduction of technology. Teachers need to learn how to create items as needed, and then to modify instruction based on the information they receive while engaged in formative assessment activities. None of this is easy or natural for teachers. Their success may depend in large part on their own conceptual understanding of formative assessment.

Many of these issues are still under investigation by the evaluation team. There is still considerable data to be analyzed. In the mean time, the development team has turned its attention toward the development of educational materials for teachers, with the hope that a solid conceptual foundation on the topic of formative assessment will complement teachers experiences as they attempt to improve their practice of formative assessment.

12. Impact on Future Work

Agile Teaching: Sustaining professional development in secondary science instruction through inquiry, technology, and action research

Our work on the A2L project has led us to the concept of *agile teaching*, used to describe the perspective, instructional style, and pedagogic techniques needed to use formative assessment for monitoring students' knowledge state and rapidly adjusting instructional experiences to maintain optimal stimuli for active, inquiry-based learning. During the A2L project, the evaluation team pilot tested an *action research* model as a way to support teachers' professional development of agile teaching skills. The model has yielded some positive results, and we are now formulating a plan for sustainable professional development around agile teaching and action research.

We are preparing a proposal to the National Science Foundation (NSF) to develop, test, and refine a sustainable model of professional development for secondary school science teachers. The model presumes near-total commitment of a school or district's science department to work with UMPERG researching what works and what doesn't. Teachers are an integral part of the research team.

Professional development will consist of an 84-hour multidisciplinary science course taught on-site at participating schools. The course will cover concepts spanning the sciences, such as "systems," "change and transformation," and "scientific models." Pedagogy and math will be interwoven into the narrative, along with numerous classroom techniques. The professional development course will be taught by a Master Teacher steeped in the agile teaching approach, skills, and methodologies. The Master Teacher will visit teachers' classrooms, offer feedback and advice, and monitor action research. Master Teachers will be trained via a second, higher level professional development course delivered at the University of Massachusetts by the PIs.

Our model of sustainability applies to two different levels and scales. At the district level, after the professional development course is taught, agile teaching will be sustained within a school by having a Master-Teacher-in-residence serving as a highly available resource to teachers and helping to maintain the action research team. At the regional level, agile Teaching will be sustained through ongoing training and certification of Master Teachers, who will then offer professional development courses to teachers in their own school systems or become Master-Teachers-in-residence.

Inquiry-based learning will be encouraged using existing NSF curriculum materials, so teachers will work in teams exploring concepts both in and out of their fields of expertise. Classroom response system technology will be used during professional development to facilitate engagement, interaction, and feedback. Action research will be used to promote reflection and team-building. All three feed directly into the agile teaching approach. Teachers will take these same techniques into their classrooms.

Each of these three strands is essential to optimal implementation of agile teaching. They also complement each other, with each playing a critical role in supporting the other two. For instance, response system technology gives teachers the opportunity to collect the wide range of responses generated by inquiry-based materials and the class-wide feedback needed to engage fully in action research. Action research methodology aids implementation of new approaches and classroom practices, such as those needed with inquiry-based materials and instructional technology.

Appendix

Assessing To Learn:
A Guide to Classroom Formative Assessment in Introductory Science

13. Purpose

This guide will support the professional development of teachers in the use of classroom formative assessment techniques. It will be designed for teachers working in small to medium-sized groups, with or without a facilitator. The guide contains enough material for 12 to 14 meetings distributed over two-semesters, at a rate of approximately one chapter per meeting. Each chapter will contain sections for individual work by each teacher and sections for group work and discussion.

14. Chapter Structure

Each chapter will conform to the following structure.

I) Paradigm Examples

Introduce the chapter's main point or issue through examples.

II) Pre-Questions and/or Pre-Activities

Direct teachers to reflect on their own teaching, to try some activities in the classroom, and to make observations.

III) Exposition/Principles

Present background information and raise important questions. Provide a theoretical perspective. Discuss pedagogy. Refer to relevant literature.

IV) Practical Examples

Present various formative assessment activities that exemplify the chapter's principles and ideas.

V) Discussion Points (for community of teachers)

Raise issues that require analysis and consideration of context, and that cannot simply be stated in the exposition. Have teachers share classroom experiences.

VI) Important Lessons and Reflections (for groups)

Raise the exposition to the meta-level. Have teachers reflect on their own practice and consider what changes might be warranted.

VII) Follow-Up (for individual teachers)

Encourage teachers to try activities in their classroom based on what they have learned, and to report back to their peers.

15. Contents Outline

Meta-communication as a tool for improving self-awareness

Part 2: Designing Formative Assessment Activities

Chapter 6: The Goals of Formative Assessment

Targeting components of the student model
Targeting process and habits of mind
Targeting different cognitive levels

Chapter 7: Assessment Activities as Learning Experiences

Assessment without evaluation
Identifying the lessons behind the assessment
Assessment in the midst of learning
Going with the flow: maintaining a flexible agenda

Chapter 8: Designing Formative Assessment Items

Example assessment items
The connection to cognitive goals and habits of mind
Question sets and learning activities
Elaborate forms of formative assessment

Chapter 9: Questions Within Questions: Multiple Levels of Assessment

How an item can address multiple levels and goals
The "it's too difficult" myth
It's not the item so much as what you do with it.

Chapter 10: Structuring Formative Assessment Activities in the Classroom

Components of Formative Assessment
The Learning/Assessment Cycle
Building in efficiency
Individual vs. group work
Roles of the teacher & students

Part 3: Putting Formative Assessment to Work

Chapter 11: Mining Assessment Information: The Role of Dialogue

Teacher small-group interactions
Histogram data
Whole-class discussion

Chapter 12: Interacting with Students: Do's and Don'ts

Actions counterproductive to formative assessment
How to avoid coaching students to the right answer
It's not about the right answer!

Chapter 13: Interpreting Assessment Information: What Do Your Students Know?

The pitfalls of over-interpretation and micromanagement
Creating a process rather than *fixing* problems.

Back to basics: model and goals
Students need to be a part of figuring out what needs attention

Chapter 14: Making Use of Formative Assessment Data

No magic bullet, no ideal curriculum, no perfect response
Keeping instruction and learning activities relevant and effective
Building on what students know
Student language as a bridge to formal language

Chapter 15: Role of the Teacher

Weaving a coherent whole from the pieces

Chapter 16: Role of the Student

The student as independent learner
Student self-assessment
Getting students to meta-communicate
The strategic learner: helping students take control