2006-1683: USE OF FORMATIVE ASSESSMENT TO PROBE STUDENT CONCEPTIONS OF THE LEVER RULE

Chrysanthe Demetry, Worcester Polytechnic Institute

Chrys Demetry is Associate Professor of Mechanical Engineering in the Materials Science and Engineering Program at Worcester Polytechnic Institute. Her teaching and research interests include use of educational technology, influence of learning styles on teaching and learning, and K-12 engineering outreach. She received the ASM Bradley Stoughton Award for Young Teachers in 2000 and WPI’s Trustees’ Award for Outstanding Teaching in 2002.

Use of Formative Assessment to Probe Student Conceptions of the Lever Rule

Introduction

Scientific studies of learning have revealed that student misconceptions are more likely to be addressed by teaching practices that emphasize formative assessment in addition to summative assessments like graded homework and exams.[1,2] In other words, students benefit from frequent assessment *for learning* instead of exclusive assessment *of learning*. In this context, the term *formative assessment* shares much in common with the term *classroom assessment* used by Angelo and Cross in the 1990s:[3] learning activities conducted in the classroom that are designed to probe and advance student understandings.

Integrating formative assessment into a large enrollment course is an overwhelming prospect for many instructors, but educational technologies are making classroom-based assessment activities much more feasible. In the last several years action research on the use of web-based course management systems and electronic response systems, also known as student response systems, classroom communication systems, audience response systems, electronic voting systems, or more colloquially as "clickers," has been spreading into science and engineering classrooms. In the Physics teaching community, for example, these instructional technologies have facilitated the implementation of Peer Instruction[4] and Just-in-Time Teaching,[5] pedagogies that focus on interactive engagement and the importance of prior knowledge in the learning process and that have been shown to enhance student learning outcomes.[6] Web-deployed assessments and use of clickers in the classroom offer the potential to implement key elements of effective formative assessment:[1] gathering information about learners' current states of understanding and making adjustments in instruction to close the gap between those states of understanding and learning goals.

This paper is part of an ongoing inquiry into use of educational technologies to facilitate formative assessment in large-enrollment offerings of Introduction to Materials Science. Previous work explored students' reactions to assessment activities and their perceptions of learning gains.[7,8] Students reported that use of these technologies promoted learning and recommended their continued use. More recent work has sought to probe beyond student perceptions and explore more directly the extent to which these formative assessment activities, and the feedback and instruction that follows, are associated with learning gains.[9] This paper focuses on formative assessment activities related to phase equilibria that were intended to reveal student conceptions of components, phases, amounts and compositions of phases, and their understanding and application of the lever rule. These particular concepts were of interest based on the frequency and persistence of student misunderstandings observed in more than a decade of teaching introductory materials. In addition, concepts of phase equilibria are included in the "Materials Concept Inventory" developed recently by Krause and Griffin.[10-12] This paper offers further insight into student conceptions of the lever rule that were revealed by formative assessment activities, and shows the challenges associated with designing activities and feedback that will effectively probe and advance those conceptions.

Description of Formative Assessment Activities

The focus of this study is one offering of Introduction to Materials Science in Fall 2004 at Worcester Polytechnic Institute. Ninety-five students from a range of engineering and science majors were enrolled in the course. Formative assessment activities, including instructor feedback, typically occupied at least one-half to two-thirds of each class period, with the remainder typically spent on "mini-lectures." Students were asked to prepare for class by reading the textbook and lecture notes and then taking a "preparation assessment" via Blackboard™. The open-ended questions in these assessments were intended to reveal student misconceptions at a formative stage in the learning process. Fifty-minute class periods were then planned to bring these misconceptions to the forefront. A feedback/voting technology called Classroom Performance System™ (CPS) was used to pose questions and problems to students and provide them with immediate feedback on their understanding. Figure 1 summarizes the sequence of student preparation, assessments, and mini-lectures for each class period. The following paragraphs describe details of implementation and assessment questions specific to phase equilibria concepts.

Preparation Assessments: A key strategy in enabling integration of classroom formative assessment was to move as much "information transfer" as possible *out* of the class meetings, so that face-to-face time could be used primarily for assessment and feedback. Toward that end, more responsibility was placed on students to prepare for class by doing the assigned reading in the textbook[13] and by reviewing lecture notes, which were supplied in advance as .pdf files on a Blackboard™ site. Before each class, students were asked to complete a "Preparation Assessment" prepared and deployed using the *Test Manager* feature in Blackboard. Each assessment was designed to address the learning goals for that class period and consisted of two open-ended conceptual questions and an optional "Muddiest Point" question. Table 1 shows three preparation assessment questions that focused on basic concepts of binary phase diagrams and the lever rule. (Subsequent questions on microstructure development are not included in this analysis.)

A TA graded student responses using a three-point rubric that focused on completeness and clarity of thought rather than whether it was correct, in keeping with the formative nature of the assessment. In order to provide some incentive for completion, however, the preparation assessment points contributed 10% to the overall course grade.

The instructor reviewed approximately 25% (N≈23) of the students' responses to the assessment questions prior to each class and looked for any patterns of confusion. The fifty-minute class periods were then designed using a "Just-in-Time" approach[5,14-16] to bring those misconceptions to the forefront. In addition, example responses were distributed and discussed in each class period, showcasing good responses, alternate conceptions, and common misconceptions without revealing the identity of the student authors. With the exception of those students whose

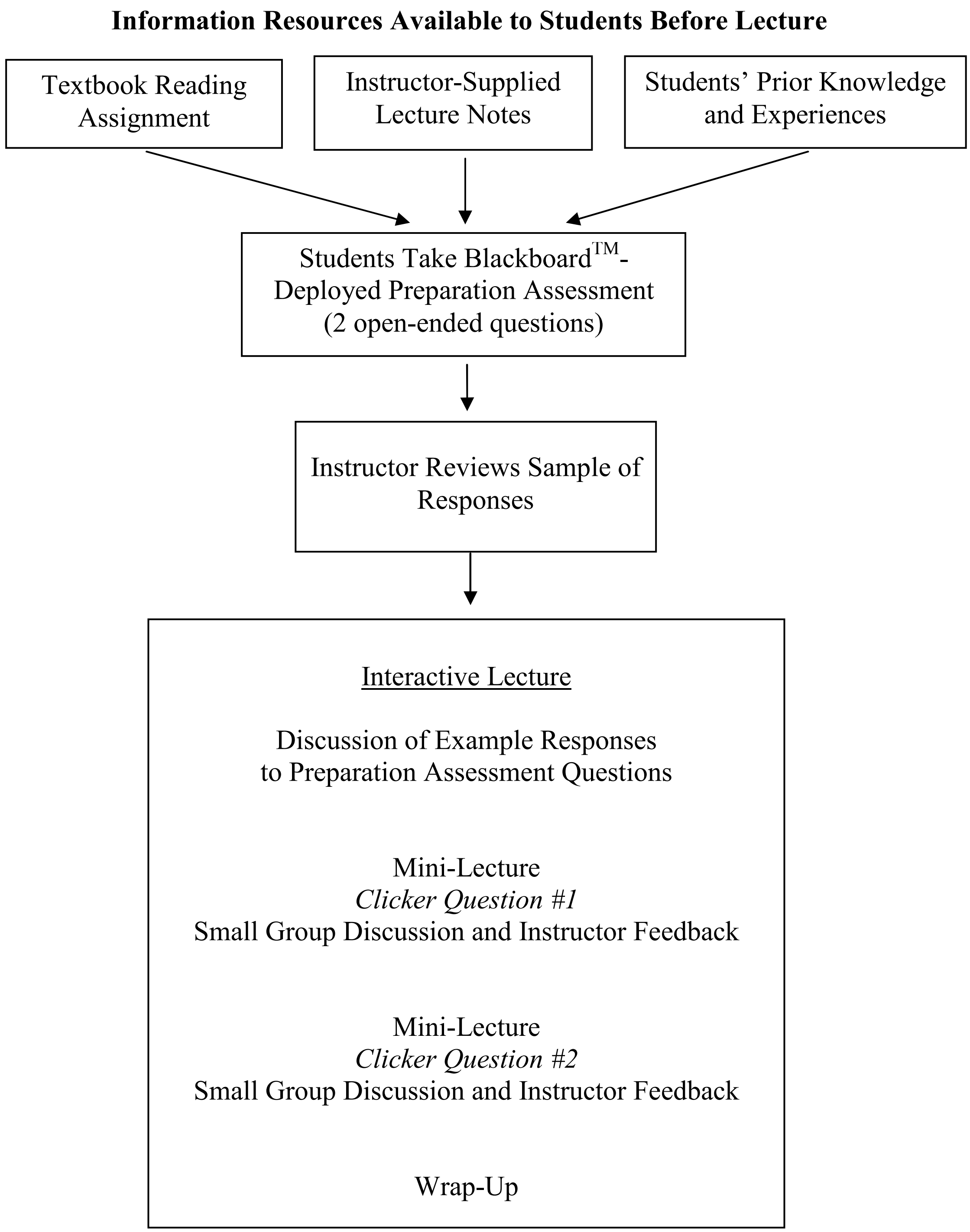

Figure 1. Diagram showing sequence of activities leading up to each class meeting and the typical structure for each 50-minute lecture period.

Table 1. Preparation Assessment Questions on the Basics of Phase Diagrams	
Prep 1-1*	Referring to the phase diagram in Figure 10.2(a) [Ni-Cu], what are the **components** of the system? Also, what **phase or phases** would be present for a 50wt%Ni alloy at 1300ºC? Explain your answers.
Prep 1-2	Referring to Figure 10.2(b): For a 35wt% Ni alloy at 1250ºC, a mixture of solid α (alpha) and liquid is present. What is the **composition of the liquid phase** in that solid-liquid mixture? (Note that this is different than figuring out the *amount* of the liquid phase that is present!) Explain how you determined the composition of the liquid phase from the phase diagram.
Prep 2-1	Yesterday in class we discussed various ways to understand and apply the lever rule. For example, you can use the see-saw or lever-arm analogy to figure out which phase you should have more of, or use the heuristic "opposite segment of the tie line over the whole." Or you can do out a mass balance calculation to see how the overall amount of a component in the material is distributed between the two phases of different compositions. Or you can use common sense (hopefully) to see which phase composition you're closer to in the two-phase region, which means that you must have more of that phase and thus use the larger segment of the tie line. Which one of these ways of thinking, or some other one, makes the most sense to you and will you use to apply the lever rule correctly? *Explain your thinking.*
**Day-Question #* is the signifying notation. For example, Prep 1-2 refers to the second question that was asked in preparation for the first day of class on the topic of phase diagrams.	

responses were selected for discussion, students did not receive individualized feedback on their preparation assessment responses.

Use of an Electronic Response System for In-Class Problems: Additional formative assessment and feedback was provided during class periods through use of the Classroom Performance System™ (CPS),[17] which is a wireless response technology. All students signed out a response pad ("clicker") at the start of the course, and their response data were automatically recorded. Typically one to three multiple choice questions, intended to reveal common misconceptions, were posed each class period. A "think-pair-share" cooperative learning method was used in which students were asked to think about the question on their own, then turn to a neighbor, explain their response, and try to come to a consensus. Students then individually "clicked in" their responses, which were projected in the form of a histogram for all to see. (Responses of specific students are available privately to the instructor, but student responses remain anonymous on the display.) Thus, students' collective thinking becomes visible to both instructor and students.

The "clicker questions" that relied on application of the lever rule are shown in Table 2. While the preparation assessment questions were more conceptual in nature or asked students to glean information from the phase diagram, most clicker questions required the students to perform calculations. (This was not true of all topics in the course; see References 8 and 9 for more discussion of different types of assessment questions.) Typically, the distracters in the multiple choice questions were designed using experiential knowledge of common misconceptions observed in more than 10 years of teaching introductory materials. Therefore, particular incorrect answers could be connected to specific misconceptions, which were discussed when giving

Table 2. Nature of Clicker Questions Asking Students to Apply the Lever Rule	
CQ 1-1*	Determine the amount of liquid for a particular alloy and temperature that lies in the liquid+solid region of an isomorphous phase diagram (Al_2O_3-Cr_2O_3)
CQ 2-1	Determine the amount of primary phase that has formed immediately prior to the eutectic temperature (Al-Si system)
CQ 2-2	Determine the composition of an alloy given the amount of primary phase and the amount of a eutectic constituent (reverse lever rule)
CQ 3-1	Given a plain carbon steel composition in wt%C, determine the amount of pearlite formed upon very slow cooling through the eutectoid temperature.
*Same notation as in Table 1.	

feedback. One distracter for all questions requiring use of the lever rule was the common mistake of applying it in a "backwards" fashion: in other words, using the wrong segment of the tie line in the numerator of the calculation. In this case, a feedback event might proceed as follows: "For those of you who chose the answer B, you are probably applying the lever rule backwards, in other words using the incorrect segment of the tie line in the numerator of the calculation…" Alternative ways of understanding and remembering how the level rule is applied were then re-explained and sketched. Whenever possible, students were asked to explain their reasoning to the whole class to get more insight into how they were attempting to construct knowledge.

As an incentive for attendance and class participation, students were graded on these clicker questions, but again in keeping with the formative nature of the assessment, they received full credit if they entered a response; it did not matter if their answer was correct. Participation in clicker questions contributed 10% toward the overall course grade.

Research Methods

The following research questions were of interest in this study:

1) Do students who use particular heuristics (e.g., "opposite segment over the whole") develop a better understanding of the lever rule?
2) To what extent can preparation assessment and/or clicker questions responses be used as a predictor of summative mastery of the material?
3) How effective was the feedback associated with clicker questions in helping students with initial misunderstandings apply the lever rule correctly in subsequent applications?

For research purposes, student responses to formative assessment questions were scored for comprehension. This process was straightforward for clicker questions, since they were multiple choice questions with one correct answer. A limitation, however, is that a correct response may not always indicate comprehension if a student merely guessed arbitrarily or entered a particular response at the suggestion of a peer. Preparation assessment responses were analyzed according to the rubric presented in Table 3, which is an adaptation of the SOLO (Structure of the Observed Learning Outcome) Taxonomy.[18] An initial review of students' responses showed that three levels of learning were the maximum that could be distinguished.

Table 3. Rubric for Evaluating Comprehension in Preparation Assessment Responses	
Rating	Description
3	Describes a valid conclusion or provides an explanation using relevant data or concepts. Terminology need not be sophisticated or perfect, but clarity of thinking is evident.
2	Identifies some (if not all) relevant data or concepts, but cannot quite relate them together to provide a lucid explanation or arrive at a valid conclusion. The student's response may be valid, invalid, or somewhere in between.
1	Draws upon irrelevant data or concepts, or only one when several are called for. Either arrives at an invalid conclusion or none at all.

As suggested by the first research question in the listing above, a goal was to determine whether particular heuristics or ways of knowing the lever rule were associated with greater summative mastery. Toward this end, each student's response to preparation question 2-1 (Table 1) was classified into one of five categories. The categories were suggested in the wording of the question, and only a few students described alternative ways of thinking. In future work, it would be interesting to see how students would respond if no particular heuristics were described by the instructor.

Scores on a homework assignment and on exam questions were used as summative measures of learning. The homework assignment consisted of five questions involving interpretation of binary phase diagrams, application of the lever rule, and equilibrium microstructure development in eutectic systems. Three questions on an exam also focused on the same topics and were similar in nature.

Possible associations between formative comprehension levels and summative mastery, and between effects of lever rule heuristic on summative mastery, were investigated using analysis of variance (ANOVA). In cases where data were not normally distributed, the Kruskal-Wallis test was used, which is the non-parametric equivalent of ANOVA that compares ranks within a population rather than means.

Ways of Knowing the Lever Rule: Influence on Learning Outcomes

Table 4 provides some examples of students' explanations of how they understood and would remember the lever rule, grouped into five categories. These responses have been chosen to illustrate the wide range of comprehension within most heuristic categories. Table 5 summarizes student performance on clicker questions, homework, and exam questions, grouped according to the heuristic category described in the preparation assessment. Comprehension evident in responses to clicker questions did not differ as a function of heuristic choice, but statistical tests indicated significant differences between homework scores and marginally significant differences between exam scores. Post-hoc multiple comparisons showed that the contrast between the mass balance and opposite-over-whole groups was the primary contributor to the difference in performance between the groups as a whole.

Many students who identified the mass balance heuristic showed low levels of comprehension in their response, which may be connected to their low summative performance. Table 6 confirms

Table 4. Example Student Responses to Preparation Assessment Question 2-1 for Each Lever Rule Heuristic Category		
Category	Unedited Student Response	Rating*
Mass balance	The mass balance way seems to be the most basic concept and easiest to use. Basically you look at each component separately. First you have to say that the mass of one phase plus the mass of the other phase will equal 100 percent of the solution. Next we can say that the percentage of mass of each of the two phases can be multiplied by the composition of the component at that phase and added together with the same procedure for the other phase to equal the composition at the point that we are looking for; W(a)C(a) + W(l)C(l) = C(point of interest). Then you can solve the two equations to get the mass percentages which are the W's at each of the phases.	3
	I would use the mass balance calculation because it's alot easier not to get things confused if you use math instead of common sense.	1
Opposite over whole	For me, it is easiest to do the opposite segment of the line over the whole strategy. The denominator for the composition equation is the same for both solid and liquid phases. Once I knew this value, it was apparent that the numerator would pose more problems. To clarify the distinction, I have just thought about it as excluding whatever composition value that I don't need. For instance, if I was asked to find the liquid phase composition, I know that the C-subL value would be eliminated from the numerator.	3
	I think i like the idea of using the opposite segment of the tie line over the whole because I like being able to relate things to picture or graphs in order to see whats going on. I think using the tie line over the whole is most closely related to the lever rule as well. I would not choose to use common sense because I am not alwasy sure of what would be best and therefore might misinterpret something. Using the tie line seemed very straight forward whereas using the the balance equation leaves room for confusion and error.	2
Observe position in two-phase region	There is the most of whichever phase the point of the total compositon is closest to. If it is closer to the liquid phase line there will be more liquid in the system and if it is closer to the solid line there will be more solid in the solution. If it is closer to the liquid line then when you divide you want the longer segment length to relfect that there is more liquid over the lenght of the entire segment.	3
	I think that the easiest for me to remember would be to use the common sense using the graph. The other methods get me confused and you have to remember an equation to use. This method simply involves the use of the graph and a little analization. Much simpler for me.	1
See-saw or lever arm analogy	The seesaw analogy and the lever rule together make the most sense to me because the Co is like the pivot point of the lever and to balance this bar on the pivot point I am going to need more force on the side that the pivot is closer to. So, that side will have more Weight fraction.	3
	The method that seems the easiest to follow and help with my understand of the lever rule would be the analogy of the see-saw or lever arm. This makes the most sense because it gives a good picture of which component should have the higher composition at the given point. From this analogy I can work out the mathematics behind the general concept	1
Other/ Unclear	I use the lever line and extend to the end of the region, draw lines down to the bottom for both sides, and read the compositions. The compositions are then x wt% and 100-x wt % and do the same for the other side.	1
	I like the method of looking at different segments of the tie line and using the segments to apply the lever rule. It is more conceptual to look at the segments and think of dividing up the pieces over the whole.	1
**Ratings were made by the author according to the rubric outlined in Table 3.*		

that students who chose that heuristic were less able than others to explain their choice clearly and with relevant concepts. Four of the seven students identified similar reasons for the appeal of the mass balance: that there were "actual numbers in the calculations" and that they preferred "numbers over theory." It is possible that these students thought that they could "plug-and-chug" through a mass balance without wrestling with interpretation of the phase diagram or identifying tie lines and phase compositions.

This result does not suggest that the underlying notion of the lever rule as a mass balance should be eliminated from instruction. The group of students that seemed to grab onto the mass balance as something more mathematical and less demanding than the lever rule was relatively small,

Table 5. Comprehension of Phase Diagram Concepts Shown by Groups of Students Adopting Different Heuristics for Understanding the Lever Rule

Heuristic Category	N	# of Correct Clicker Questions, Mean Rank	HW Score, Mean Rank	Exam Questions, Mean
Mass balance	7	49.4	19.9	63.1
Opposite over whole	20	34.6	47.1	84.3
Observe position in two-phase region	26	36.0	40.6	79.6
See saw or lever arm analogy	18	43.4	42.2	78.0
Other/unclear	7	40.4	26.6	79.3
Significance*		.437	*.037*	*.094*

*The significance value is the probability p of acceptance of the null hypothesis that there is no difference between the groups. $p < .05$ is generally taken to be significant, and $p < .10$ is sometimes designated as "marginally significant" in the social sciences.

Table 6. Number of Responses in Each Comprehension Rating for Different Choices of Heuristic Category

Heuristic Category	Comprehension Rating for Heuristic Explanation* (from Table 3)		
	1 (Little/None)	2 (Some)	3 (Good)
Mass balance	5	0	2
Opposite over whole	1	9	10
Observe position in two-phase region	9	7	10
See saw or lever arm analogy	3	3	12
Other/unclear	4	2	1

*A chi-square test gives a significance value of p=.007 that this distribution of counts is due to chance alone and it is possible or likely that their choice of the mass balance from the suggested list of possible heuristics was a symptom rather than a cause of confusion that in many cases persisted. Rather than eliminate discussion of mass balances, information from this or similar assessment questions could be used to intervene with those students who seemed to be viewing the mass balance as a calculation that would enable them to avoid coming to terms with the underlying concepts.

Predictors of Summative Mastery of Phase Diagram Concepts

While the results in Table 5 seem to suggest that promoting use of the “opposite over the whole” mnemonic may be beneficial to students, there is also evidence that clarity of thinking is just as important or more important than heuristic choice. The comprehension evident in students’ explanation of their heuristic choice was associated with summative mastery, regardless of heuristic category. Mean exam scores were 72.4, 78.3, and 83.4 for students whose heuristic explanations were rated 1, 2, and 3, respectively. Those differences are marginally significant (p=.062). For homework scores, the differences were greater: mean ranks of 27.1, 40.7, and 46.6 for students whose explanations were rated 1, 2, and 3, respectively (p=.006).

For the other two preparation assessment questions shown in Table 1, there were also significant positive associations between comprehension evident in the responses and students’ homework scores (p=.038 and p=.031 for Prep 1-1 and 1-2, respectively.) While there were also positive associations with exam scores, they did not reach a level of statistical significance. Regardless, there is ample evidence to suggest that using these types of assessment questions—asking students to write about phase diagram concepts, and about lever rule heuristics in particular—and using comprehension as a predictor of summative mastery, could be an effective means of identifying students who could benefit from additional intervention. Some representative examples of students’ responses to preparation assessment questions 1-1 and 1-2 are shown in Tables 8 and 9 at the end of this paper. As anticipated, these questions were helpful in making visible students’ struggles with terms like components, phases, phase compositions, and amounts of phases, and their responses were used as starting points for discussion in each class period.

Students’ responses to clicker questions were not as strong a predictor of summative mastery of phase diagram concepts. There was no pattern of association between number of correct clicker questions responses and exam scores. There was a positive association between number of correct responses and homework scores, with mean ranks of 30.4, 37.2, 44.1, 54.2, and 58.5 for students who answered 0, 1, 2, 3, and 4 clicker questions correctly (p=.079). The stronger association between comprehension evident in preparation assessment responses and summative mastery is noteworthy since the clicker questions were much more similar to homework and exam questions than were the preparation assessment questions. This result is consistent with much of the evidence in the literature that attention to conceptual understanding often results in better problem solving abilities (see Reference 19, for example.)

Effectiveness of Feedback in Advancing Student Conceptions of the Lever Rule

The positive association between summative measures of learning and the comprehension evident in formative assessment responses seems quite intuitive and may be useful in identifying students who would benefit from intervention. At the same time, one can argue that if the feedback and instruction that followed the formative assessment activities were highly effective, students who initially had misconceptions would be redirected and ultimately show similar learning gains as students who were able to learn the material more readily. In that case one would expect there to be no relationship between formative assessment results and summative measures of performance, except for the positive effect of participation regardless of initial comprehension. This issue is complex and is discussed more fully elsewhere.[9] Regardless, there is another type of evidence suggesting that the instructional feedback following formative assessment activities may not have been as effective as one would hope.

The distracters in the multiple choice clicker questions offer the opportunity to track particular misconceptions. As mentioned previously, applying the lever rule in a backwards or inverse fashion is a common mistake since in some sense the correct use of the lever rule is counter-intuitive to many novice learners. Each clicker question described in Table 2 had a distracter that could be tied to performing the lever rule backwards. Table 7 shows the percentage of students who chose the "backwards" distracter for each of the four clicker questions. Note that the cohort of students in attendance was somewhat different on each of the three days that these questions were posed, and that students moved in and out of the group choosing this particular distracter. In addition, each question got a bit more complex, involving concepts of microstructure development in addition to basic application of the lever rule. Fifty percent of the students chose the backwards distracter at least once. Focusing on the second class period when two clicker questions using the lever rule were posed, 11 of the 17 students who chose the backwards distracter for the first question did not choose it for the second question. However, 14 students who did *not* choose the backwards distracter for the first question did choose it for the second question, and four students chose the backwards distracter for both questions. Yet after the first question was posed and the histogram of results was projected, feedback about the backward distracter was emphasized since that was the most common mistake. While 100% success is not a realistic goal, these results are somewhat sobering and show in a tangible way how fragile student understandings are in the formative stages of the learning process and how difficult it may be to provide truly effective feedback. In addition, the results indicate that correct responses to clicker questions cannot always be interpreted as indicative of a robust understanding.

Table 7. Formative Assessment Results Showing Little Change in Students' Choice of a Particular Type of Distracter

Clicker Question	% Choosing "Backwards" Distracter
1-1	14.9%
2-1	19.5%
2-2	20.7%
3-1	17.2%

The literature on formative assessments offers some insight into the challenges that instructors face in providing effective feedback to very large groups of students.[1,2] One conclusion is that providing students with feedback about their understanding without adjusting instruction or giving individualized guidance on how to improve may not produce substantial learning benefits. While instructional adjustments were made and alternative ways of thinking were offered, it is unlikely that each student's current state of understanding was anticipated and addressed.

Furthermore, even with several years of experience using clickers in the classroom, it is extremely difficult to judge how much time to spend on feedback when close to 75% of the class *appears* to have achieved understanding of the topic. Individualized, tailored instruction is impossible with the type of formative assessment activities described in this paper. Intelligent tutoring systems may offer more promise in that regard.[1]

Another point that is emphasized in the literature is the important role of the learner in formative assessment. If formative feedback is entirely owned by the instructor, the development of independent learning abilities in students is likely to be diminished.[1,2] This issue of "who owns the feedback" is not often discussed among users of electronic response systems. Clearly, it isn't sufficient to show histograms of results, identify the correct answer, and view that as effective, timely feedback. But in this study, even the fairly extensive post-mortem participatory discussion of the clicker questions was not as effective as one would hope. It may be that more peer-centered forms of feedback, where each student can talk instead of merely listening, would be more effective. Certainly, research in the physics teaching community[4,6,19] shows the benefits of peer interaction, and that has not likely been refined sufficiently in the formative assessment activities described in this paper.

Another challenge in providing effective feedback may be the absence of a model of cognition in the materials science domain. A major emphasis in the literature is that a cornerstone of effective assessment should be a model of cognition and learning that is based on empirical studies of how learners represent knowledge and develop competence in a particular subject domain.[1] Ideally, these models should take a developmental approach, showing common pathways that learners take as they proceed toward competence. With knowledge of cognition in a particular subject area, teachers are equipped with a more robust and informed set of instructional strategies that enable them to accelerate transitions from a student's current level of competence toward the next, higher phase of learning.[1] Further refinement of the Materials Concept Inventory and related research on conceptual development may help in that regard.

Summary and Conclusions

Conclusions of this research and implications for teaching can be summarized as follows:

- The level of comprehension evident in students' written explanations of their way of understanding and applying the lever rule is positively associated with summative measures of learning. Therefore, developing students' ability to describe their lever rule heuristic clearly and with relevant concepts is likely to be more important and beneficial than encouraging the use of a particular heuristic. Furthermore, teaching interventions might well be targeted at those students who can't explain concepts well in writing.
- Students who reported affinity for the mass balance as a means of applying the lever rule seemed attracted by the mathematical way in which it was presented. These students on average showed lower homework and exam scores than students who identified other heuristics.
- The quality of student responses to open-ended preparation assessment questions was a better predictor of summative measures of learning than the correctness of their responses to clicker questions. Therefore, open-ended and/or conceptual questions may

have more value than calculation questions as a diagnostic and development tool in learning about phase diagrams.

- More refinement of strategies for effective feedback and accompanying classroom research is needed to fully realize the benefits of formative assessment in advancing student understandings of the lever rule and of other topics in materials science.

Bibliographic Information

1. Pellegrino, J.W., Chudowsky, N., and Glaser, R., Eds., *Knowing What Students Know: The Science and Design of Educational Assessment,* Washington, D.C.: National Academy Press, 2001.
2. Black, P., and Wiliam, D., "Assessment and Classroom Learning," *Assessment in Education*, Vol. 5, No.1, 1998, pp. 7-73.
3. Angelo, T.A. and Cross, K.P., *Classroom Assessment Techniques: A Handbook for College Teachers,* 2nd Ed., San Francisco: Jossey-Bass, 1993.
4. Mazur, E., *Peer Instruction: A User's Manual*, Upper Saddle River, NJ: Prentice Hall, 1997.
5. Novak, G., Patterson, E.T., Gavrin, A.D., and Christian, W., *Just-in-Time Teaching: Blending Active Learning with Web Technology,* Upper Saddle River, NJ: Prentice Hall, 1999.
6. Hake, R.R.., "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *American Journal of Physics*, Vol. 66, No.1, 1998, pp. 64-74.
7. Demetry, C., "Use of Educational Technology to Transform the 50-Minute Lecture: Is Student Response Dependent on Learning Style?" *Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exhibition* (CD-ROM), Portland, OR.
8. Demetry, C., "Technology-Assisted Formative Assessment in an Introductory Materials Course," *Proceedings, Materials Science & Technology 2005 Conference* (CD-ROM), September 25-28, 2005, Pittsburgh, PA.
9. Demetry, C., "'Clickers' and 'Warm Ups' Are Not a Panacea: Challenges of Assessment and Feedback in Large Lectures," submitted to *Journal of Engineering Education*, 2006.
10. Krause, S., Decker, J.C., Niska, J., Alford, T., and Griffin, R., "Identifying Student Misconceptions in Introductory Materials Engineering Classes," *Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition.*
11. Krause, S., Decker, J.C., and Griffin, R., "Using a Materials Concept Inventory to Assess Conceptual Gain in Introductory Materials Engineering Courses," *Proceedings, 2003 Frontiers in Education Conference,* Boulder, CO.
12. Krause, S., Tasooji, A., and Griffin, R., "Origins of Misconceptions in a Materials Concept Inventory from Student Focus Groups," *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition.*
13. Callister, W.D., Jr., *Fundamentals of Materials Science and Engineering: An Integrated Approach*, 2nd Ed., John Wiley, 2005.
14. Marrs, Kathleen A., Blake, Robert E., and Gavrin, Andrew D., "Web-Based Warm Up Exercises in Just-in-Time Teaching: Determining Students' Prior Knowledge and Misconceptions in Biology, Chemistry, and Physcis," *Journal of College Science Teaching*, Vol. 31, No. 1, 2003, pp. 42-47.
15. Gavrin, A., Watt, J. X., Marrs, K., and Blake, R.E. Jr., "Just-in-Time Teaching (JiTT): Using the Web to Enhance Classroom Learning," (*Web) Proceedings, 2003 American Society for Engineering Education Annual Conference & Exhibition.* Online at *http://www.asee.org/ acPapers/ 2003-26_Final.pdf.*
16. Eschenbach, E.A., and Cashman, E.M. "Introduction to Air Resources—Just in Time!" (Web) *Proceedings, 2004 American Society for Engineering Education Annual Conference & Exhibition.* Online at *http://www.asee.org/acPapers/2004-2109_Final.pdf.*
17. Classroom Performance System, McGraw-Hill eInstruction Corporation. Online at *http://www.einstruction.com/*.
18. Biggs, J.B., and Collis, K.F. *Evaluating the Quality of Learning: The SOLO Taxonomy (Structure of the Observed Learning Outcome)*, New York: Academic Press, 1982.

19. Crouch, C.H., and Mazur, E., "Peer Instruction: Ten years of experience and results," *American Journal of Physics*, Vol. 69, No. 9, 2001, pp. 970-977.

Table 8. Example Student Responses to Preparation Assessment Question 1-1

Unedited Explanation	Rating
A component is a pure metal or compound that makes up an alloy. For the copper-nickel example that we are looking at in 10.2a the components are copper (Cu) and Nickel (Ni). The phases that would be present for a 50wt%Ni alloy at 1300ºC would be both liquid and solid alpha. The solid (alpha) phase will begin melting at about 1280 degrees C, but will not be in the complete liquid stage until around 1320 degrees C. Therefore, at 1300 C the alloy will have both alpha and liquid phases at equilibrium.	3
The components of the system are copper and nickel. The phase at 50%Ni and 1300 C would be a+L or the material/liquid phase.	2
The components of the system are the three regions: liquid, solid and liquid-solid phases. Liquid and liquid-solid regions are separated by the liquidus line. Solid and liquid-solid regions are separated by the solidus line. These three regions are displayed on a temperature versus weight percent composition of nickel. A 50 wt% Ni alloy at 1300 degrees C, would be in the liquid-solid phase.	1
The two components of the system are liquid and solid. The phase is alpha and liquid.	1
The Components of the system are tempriture and the compisition of Ni. At 50wt% Ni and at 1300° the compisituion wil be both liquid and solid.	1

Table 9. Example Student Responses to Preparation Assessment Question 1-2	
Unedited Explanation	Rating
The composition in the liquid would be about 31 wt% Ni - 69 wt% Cu and the composition of the alpha solid solution is about 42 wt% Ni - 58 wt%Cu. This is found by drawing a straight horizontal line that touches the solidous and liquidoues lines on the graph. Where this line intersects the lines on the graph a perpendicular line is drawn down to the concentration values on the graph. Where these perpendicular lines meet the values is what wt% the nickel is in the liquid and alpha phases.	3
The composition of the liquid phase in the solid-liquid mixture is approximately 31 wt%. I used a tie line to discover this. I drew the line across two phase regions and drew them until they intersected the single phase regions. The intersection of the tie lines with a single phase region tells the composition of that region.	2
I'm not sure how to determine which side of the tie lines to use for liquid and solid, but I think that the composition of the liquid phase in the mixture is about 32 wt% using the intersection of the tie lines and the composition axis.	2
The composition of the liquid phase is .32 in that solid liquid solution. This is determined by using the lever rule. Here one would take the distance from the point to the liquidus line on the same temp value. Then divide that %wt buy the total horizontal distance from the liquidus line to the solidus line going throughout the present condition. This will give you the compostion of liquid phase.	1
Using the lever rule, the liquid phase is about 18% liquid copper and 82% is solid nickel. Copper has a lower melting point, so it is the liquid. The lever rule gives the percent composition.	1
The composition of the liquid phase would be that is contains alpha-liquid, and beta liquid, which signify solid solitions.	1
The composition of the liquid phase at point B is 68%. To get this you first must draw the tie line which is a horizontal line passing through the point in question. Where the line intersecs both the liquidus line and solidus line, the compositions at those points are taken. Now there are three points along the compostion line that we are concerned with. The difference between the highest point and the middle point is divided by the difference between the mid point and the lowest point. This value is the percent composition of the liquid phase.	1