Characterizing and Addressing Student Learning Issues and Misconceptions (SLIM) with Muddiest Point Reflections and Fast Formative Feedback

Prof. Stephen J Krause, Arizona State University

Stephen J. Krause is professor in the Materials Program in the Fulton School of Engineering at Arizona State University. He teaches in the areas of bridging engineering and education, capstone design, and introductory materials science and engineering. His research interests include strategies for web-based teaching and learning, misconceptions and their repair, and role of formative feedback on conceptual change. He has co-developed a Materials Concept Inventory for assessing conceptual knowledge of students in introductory materials engineering classes. He is currently conducting research on web-based tools for teaching and learning, misconceptions and strategies and tools to promote conceptual change in materials courses.

Dr. Dale R Baker, Arizona State University

Dr. Adam R Carberry, Arizona State University

Adam R. Carberry, Ph.D., is an Assistant Professor at Arizona State University in the Fulton Schools of Engineering. He earned a B.S. in Materials Science Engineering from Alfred University, and received his M.S. and Ph.D., both from Tufts University, in Chemistry and Engineering Education respectively. Dr. Carberry was previously an employee of the Tufts’ Center for Engineering Education & Outreach.

Dr. Terry L. Alford, Arizona State University

Casey Jane Ankeny PhD, Arizona State University

Casey Ankeny is a lecturer in the School of Biological and Health Systems Engineering at Arizona State University. Her research focuses on the effect of student-centered strategies on attitude, achievement, and persistence.

Dr. Milo Koretsky, Oregon State University

Milo Koretsky is a Professor of Chemical Engineering at Oregon State University. He received his B.S. and M.S. degrees from UC San Diego and his Ph.D. from UC Berkeley, all in Chemical Engineering. He currently has research activity in areas related engineering education and is interested in integrating technology into effective educational practices and in promoting the use of higher-level cognitive skills in engineering problem solving. His research interests particularly focus on what prevents students from being able to integrate and extend the knowledge developed in specific courses in the core curriculum to the more complex, authentic problems and projects they face as professionals. Dr. Koretsky is one of the founding members of the Center for Lifelong STEM Education Research at OSU.

Dr. Bill Jay Brooks, Oregon State University

Bill Brooks is a postdoctoral scholar in the School of Chemical, Biological, and Environmental Engineering at Oregon State University. His Ph.D used written explanations to concept questions to investigate technology mediated active learning in the undergraduate chemical engineering classroom. He current interests involve using technology to enhance educational practices in promoting conceptual understanding. He is the primary programmer of the AIChE Concept Warehouse and his current focus is on its continued development, specifically creating and integrating Interactive Virtual Labs.

Dr. Cindy Waters, North Carolina A&T State University

Cindy K. Waters is an Assistant Professor in the Mechanical Engineering at NCA&T State University. She received her B.S. and M.S from Virginia Tech in Materials Science and Engineering Department and a 2004 PhD in Mechanical Engineering, from NCA&T. Her research is in the development and characterization of novel syntactic foams and various porous metals via powder metallurgy and foam casting. She is also significantly involved in engineering education research in the areas of assessment
studies of classroom material science pedagogical implementations; case studies in various engineering disciplines and; engineering faculty barriers to adopt evidence-based (or nontraditional) teaching methods. She serves as the College of Engineering liaison to ASEE and advises the Society of Women Engineers student chapter and leads the students in developing and implementing yearly outreach events for the K-8 female community. She is author of many peer-reviewed conference proceeding for the ASEE Annual Meetings and the FIE meetings.

Prof. Brady J. Gibbons, Oregon State University

Dr. Brady Gibbons is an Associate Professor of Materials Science in the School of Mechanical, Industrial, & Manufacturing Engineering at Oregon State University. His research specializes in structure-process-property relationships in multifunctional thin film materials. His group focuses on processing, novel instrumentation development, and integration science; new dielectric, superconducting, semiconducting, and pyroelectric materials for energy conversion and energy storage; ferroelectric and piezoelectric thin films for microelectromechanical systems; scanning probe and x-ray diffraction characterization methods; and spectroscopic ellipsometry. Specifically he is interested in developing novel integration science strategies to combine material functionalities that result in significantly enhanced, or even new, properties. Prior to arriving at OSU he spent eight years at Los Alamos National Laboratory (LANL) as a postdoctoral researcher and member of the technical staff. There, his research on 2nd generation superconducting wire led to an R&D 100 Award in 2004. He received his Ph. D. in Materials from the Pennsylvania State University in 1998. Dr. Gibbons is a 2012 NSF CAREER awardee, as well. That program is designed to develop new environmentally benign piezoelectric materials, which can be used for a variety of sensing and actuation applications including sonar, ultrasound, energy harvesting, and microelectromechanical systems.

Mr. Sean Maass

Currently pursuing a Masters Degree in Materials Science and Engineering. Passionate about enhancing Engineering Education across the globe as well as continuing to learn more about Materials, Design, Manufacturing, Data Mining and Analysis, and Statistics.

Prof. Candace K Chan, Arizona State University

Candace K. Chan is an assistant professor in Materials Science and Engineering in the School for Engineering of Matter, Transport and Energy at Arizona State University. She teaches introductory materials science to undergraduate engineering majors and is exploring the role of frequent, formative feedback and web-based teaching and learning on student engagement and understanding of materials concepts. Dr. Chan also teaches an advanced course on electrochemical energy conversion and storage and leads a group of undergraduate, graduate, and postdoctoral researchers focused on the design and characterization of novel materials for batteries and photoelectrochemical applications.
Characterizing and Addressing Student Learning Issues and Misconceptions (SLIMs) in Materials Science with Muddiest Point Reflections and Fast Formative Feedback

Abstract

Well-designed formative feedback has the potential to enhance both instructor teaching and student learning. Initially, developing a formative feedback process takes some effort, but once established, requires little effort. The process includes four steps: 1) acquiring data from student reflections; 2) assessing and characterizing student responses in order to diagnose the learning issues that can impede students from achieving their learning goals; 3) designing and synthesizing the type and mode of formative feedback that best addresses the learning issues; and 4) selecting a formative feedback delivery method that quickly communicates to students the information and/or resources that they can use to enhance progress toward their learning goals. Over time, feedback to students on their performance and reflections on topical content has been divided into two general types - one is outcome feedback and the other is information or process feedback. Outcome feedback basically describes whether an outcome of a task is correct or incorrect, which only provides limited guidance for the student. In particular, with traditional lecture-and-test pedagogy, instructors communicate outcome feedback to students that is mainly composed of assessment by grading of homework, quizzes and tests as to whether the work is correct or incorrect. As such, instructors often assume that students can use this limited information to subsequently improve their knowledge and understanding of the content. On the other hand, information or process feedback from data analysis and synthesis of directed feedback provides rich and insightful information to address issues related to students’ learning processes. It helps students monitor their construction of knowledge and contributes to the self-regulation that leads to deeper conceptual learning and the achievement of their learning goals.

There are many methods for acquiring student reflection responses, but in this paper we will focus on the steps of the feedback process when using end-of-class “Muddiest Point” (MP) student reflections. These arise from a class topic for which students are monitoring the learning issues that arise in the course of class instruction and may impede their understanding of content. The first step in the process is data collection, which is now automated with Concept Warehouse (CW), cw.edudiv.org, a web-enabled resource developed by Milo Koretsky at Oregon State University. The second step is using the responses to characterize and diagnose student learning issues. There are a variety of types of Student Learning Issues and Misconceptions (SLIMs) that impede learning. Some of these include knowledge gaps, vocabulary gaps, (misunderstood, misused, incorrect or missing words) and skill gaps which can include missing or faulty skills in problem calculations, analysis, computation, and graph construction, reading and interpretation. The third step is to address the nature of the type of learning issue and synthesize the formative process feedback response using the most suitable mode (verbal, visual, videos, graphical, tabular, etc.). This helps facilitate self-regulation of their learning by monitoring, assessing, and adjusting their learning strategies to achieve their desired learning goals. The fourth step is to communicate the feedback response with a simple delivery method, such as next-class slides, email, Blackboard, or the web. In this paper, an example of MP-generated SLIMs related to the introductory materials science topic of eutectic phase diagrams will be given as an example, along with strategies for addressing them. Results on effectiveness and impact of such formative process feedback for a whole materials course will also be presented and discussed.
Introduction

Well-designed formative feedback has potential to enhance both instructor teaching and student learning and is sometimes referred to as "two-way" feedback\(^1\). Initially, developing a formative feedback process takes some effort, but once established, requires limited effort. Over time, feedback to students on their performance and/or reflections on topical content has been divided into two general types - one is outcome feedback and the other is information or process feedback\(^2\). Outcome feedback basically describes whether an outcome of a task is correct or incorrect, which only provides limited guidance for the student. In particular, with traditional lecture-and-test pedagogy, instructors communicate outcome feedback to students that is mainly composed of assessment by grading of homework, quizzes and tests as to whether the work is correct or incorrect. As such, instructors often assume, on shaky ground, that students can use this limited information to subsequently improve their knowledge and understanding of the content. On the other hand, information or process feedback provides much richer and more insightful information which addresses issues related to students’ learning processes. It helps students monitor their construction of knowledge and contributes to the self-regulation that leads to deeper conceptual learning and the achievement of their learning goals\(^2\). Another benefit of conducting the formative feedback process is that instructors can also use their knowledge of student learning issues and misconceptions (SLIMs) to benefit their teaching by adjusting their instruction to better address the SLIMs as well as create student in-class and out-of-class learning resources to promote self-regulation for more effective learning.

The Muddiest Point (MP) student reflection responses utilized in this NSF-sponsored JTF (Just-in-Time-Teaching with Interactive Frequent Formative Feedback) are actually used in "two-way" feedback\(^3\). That is because the students provide the feedback of their thoughts on what their learning issues are to the instructor and the instructor, in turn, provides to students the feedback on their learning issues to facilitate progress on their learning. The JTF project first used a tedious process of MP student response end-of-class card data collection, compilation in Excel, and subsequent analysis. This process has now been improved and transformed by a powerful tool, the Concept Warehouse (CW), cw.edudiv.org\(^4\). It is a web-enabled resource developed by Milo Koretsky at Oregon State University. It has automated MP data gathering and analysis capabilities in which anonymous MP responses are submitted to CW via smart phone, tablet or laptop. CW then automatically outputs response data to the instructor in tabular quotation format, with a student MP intensity scale of 0-5 for each response. It also creates a Word Cloud with word size proportional to its frequency that allows fast identification of key words for MP SLIMs. This assists instructors in characterizing types of student learning issues and which leads to the synthesis of formative process feedback to be communicated to students with quick delivery methods such as email. Addressing learning issues as quickly as possible with formative process feedback can be very effective for motivation and self-regulated learning.

In this paper an example for a particular topic in a materials course of eutectic phase diagrams will be used to illustrate the MP-based SLIMs feedback process. This includes the steps of collecting data, characterizing issues, synthesizing responses, and communicating the feedback. Assessment of results and impact of this two-way formative process feedback will also be presented and discussed.
Background

Formative Feedback

One of the goals in engineering education, as included by ABET\(^5\) into its accreditation criteria, is to promote practices that teach students how to become lifelong learners, or "learning how to learn". Yet, the majority of classes in engineering are still taught by lecturing, or the "transmission" mode of teaching. In the past, student learning in higher education has been conceptualized as a simple process of acquisition of knowledge based on transmission of information by instructors. Today, however, research-informed conceptualization of learning views it as a process by which students actively construct their own knowledge\(^6\). In this model, students interact with topical content in different settings, including social engagement with other students, and connect with prior knowledge to build a conceptual framework of retrievable knowledge and understanding of the new content\(^7\). This change in conceptualization of how students learn has been referred to as a shift from "instructor-centered teaching" to "student-centered learning". In effect, this means that the responsibility and management of learning is shifted from the instructor to the student.

In spite of the shift in attitude about how learning is conceptualized, approaches to teaching have lagged and most engineering classes are taught and students assessed by traditional lecturing and testing. In fact, with traditional teaching, students have little input or control of the content, its delivery, learning resources, or assessment of their learning. As such, instructors "transmit" feedback to students mainly with assessment by grading of homework, quizzes and tests as to whether the work is correct, or incorrect. Instructors often assume that students can use this limited information to subsequently improve their knowledge and understanding of the content. However, if such feedback, or formative assessment, is controlled only by the instructor, it seems a difficult proposition to think that students can develop the skills of lifelong learning such as defining goals, monitoring progress, and diagnosing and addressing learning issues that arise along the pathway to goal achievement\(^6\). These are the metacognitive skills that compose characteristics of the learning strategies used in the process of self-regulation by expert learners\(^2\).

The relationship between feedback and self regulation was discussed in a recent review by Nicola and McFarlane-Dick\(^6\) who discussed some important issues. Effective self-regulation requires that students target goals against which performance can be measured and assessed. Feedback is the information about how the student’s present state (of learning and performance) relates to these learning goals. Internal feedback in self regulation helps students to monitor and assess progress toward goals with respect to either success or possible difficulties with learning activities and tasks. More effective self regulation produces better feedback. External feedback from external resources such as students, teachers, interactive web sites, etc., can contribute to the self-regulated learners' assessment of progress toward goals as well as provide assistance in overcoming impediments in progress towards their learning goals. Student Muddiest Point reflection responses give instructors authentic, rich insights and information on student learning issues they can effectively use to synthesize external formative feedback. Such feedback can then be used by students to assess and monitor progress and overcome learning issues.

The overall benefits of good feedback practice have been summarized by Nicola and McFarlane-Dick\(^6\) and are described in the list below:

1. Helps clarify the nature and criteria of students learning goals;
2. Facilitates the development of reflection and self-regulation in learning;
3. Delivers high quality information to students about their learning;
4. Encourages teacher and peer dialogue around learning;
5. Encourages positive motivational beliefs and self-esteem;
6. Facilitates opportunities to close the gap between current and desired performance toward desired learning goals;
7. Provides information to instructors to help them adjust their teaching strategies and practice.

Muddiest Points and the Reflection Process

Critical class reflections on “Muddiest Points”, i.e. the content students struggle to grasp most, provide real-time feedback to an instructor who can provide feedback and strategize to adjust his/her teaching and pedagogy to address issues specific to a given class. In a Muddiest Point Reflection an instructor solicits from students a brief, anonymous written comment about difficult concepts or other issues that arose during the class. The Muddiest Point method allows students to reflect on their own learning over a whole class and highlight difficulty with specific issues or concepts. The critical class reflections also provide a clear and easy way to track the attitudes, understanding, and learning approaches of the students in the class. Addressing student learning issues with formative process feedback is an important part of effective teaching. The Muddiest Point two-way feedback process can be thought of as consisting of four steps. As describe below, they are: 1) acquiring data from student reflections; 2) assessing and characterizing responses to diagnose the learning issues; 3) designing and synthesizing the type and mode of formative process feedback that best addresses the learning issues; and 4) selecting a delivery method that quickly communicates to students the information and/or resources that they can use to enhance progress toward their learning goals.

Muddiest Point Data Acquisition

The first step is acquiring data from student reflections that are anonymous and usually collected shortly after the end of class. Anonymity is critical for authentic, honest, and unbiased feedback. In order to determine intensity or difficulty of a learning issue, it is useful to include an intensity scale (e.g. 1-5) in the reflection request. If responses are anonymous with no incentive, an instructor is relying on the goodwill of students for a reflection. If so, participation may drop off as a semester progresses, down to 25% or less by semester end. Another factor that will decrease participation is not rapidly responding to students with instructor feedback before, or no later than, the beginning of the next class. Greater participation can be promoted with incentives like extra credit or using MPs as part of the class grade. When using these approaches participation increases to 75% to 90% across the whole semester. To give credit participants have to be identified and yet must have their comments remain anonymous. At the present time there are two approaches to accomplish this. One is by using the automated Muddiest Point data collection at Concept Warehouse (CW) cw.edudiv.org for which all participants names are dissociated from their MP responses. Another method used has been a signoff sheet used by students when they turn in their Muddiest Point reflection card or sheet. Another factor that improves participation and the quality of comments is to remind students at the beginning of class to think about their learning issues. Also, participation and comment quality are improved if data is not collected at the very end of class, but either 5 or 10 minutes before the end or an hour or two after the class. Otherwise, at class-end many students will be getting ready to rush to their next class, which degrades participation and quality of comments.
In end-of-semester metareflections on a semester of reflections, students have occasionally commented that one impact of the reflections is to help them think over the entire class about what conceptual issues need to be addressed for them to more effectively learn the topical content. Another important impact of the reflections is the feedback to the instructor about the quality of the class, including aspects of mini-lectures, activities, and engagement. Instructors using Muddiest Point reflections have mentioned that some comments are on class quality for issues such as poor handwriting, talking softly or too fast, too many PowerPoints covered, and other similar issues. Comments are not necessarily negative and instructors have also received compliments on quality of lecture, activity, learning, engagement, and so on. Overall, the Muddiest Points promote self-regulation for both instructors and students and in effect open up a trusted channel of communication between them that does not exist in traditional classrooms.

Assessing, Characterizing and Diagnosing Muddiest Points

The second step in the Muddiest Point process is that of assessing and characterizing student responses in order to diagnose the learning issues that can impede students from achieving their learning goals. An important problem with learning issues is that course instructors can exacerbate learning issues or be the underlying cause of learning issues. Every instructor makes assumptions about what students know and can do when they enroll in a class. The assumptions may be correct, partially correct, or totally incorrect. These assumptions are often tied to expectations of competent knowledge, concepts and skills acquired from prior courses and/or prerequisite courses. An example is that, one instructor assumed that sophomore engineering students could read, interpret, understand, and create graphs which related material processing to material properties. Yet Muddiest Point responses demonstrated that, at least a quarter of the class was having trouble with the graphs ("The graphs are confusing"). Graphing skills are used throughout an introductory materials course as well as many other courses in all engineering disciplines. It is difficult to understand many concepts without such skills, but it is possible to devise simple interventions for this type of a learning issue which will have positive impact on future technical work of students with these issues. There is considerable value of the two-way formative process feedback MP reflections for both instructors and students.

We will now consider the nature of the general term of SLIMs or Student Learning Issues and Misconceptions. There are a variety of resources available for assessing student work in order to comprehend the nature and origin of misconceptions and learning issues. These can include Muddiest Point reflection responses, homework, quizzes, tests, and classroom discussion, dialogue, problem solving, etc. Although there are always sets of specific issues and misconceptions associated with given topical content, it often turns out that such issues fall into more general categories. Once the learning issues and misconceptions are assessed and characterized into larger categories, it is often possible to diagnose the general nature of a problem with a specific type of learning issue or misconception. If such a problem is correctly diagnosed, it is likely that there are also general approaches or interventions that can be used to "cure" or remedy the problem or repair the misconception. Although a specific learning issue or misconception may not directly appear in an MP reflection, there may be responses that reflect symptoms of a problem that can be used to diagnose the issue and understand its underlying causes. To illustrate the nature of such signs, symptoms, and issues, examples that arose in a materials course will be given.
One issue that can impinge upon student learning is availability of the functional knowledge or 
skills required to solve a problem or complete a task at hand. If the required knowledge is 
missing, unused, misunderstood, misapplied or misused, the difficulty of completing a task is 
increased or may be impossible. All of these missing or flawed types of knowledge can inhibit or 
impede learning. Taber\(^8\) has created a classification scheme of origins for different types of 
learning "impediments", some of which are misconceptions. A null deficiency impediment is 
missing information or knowledge that a student never acquired. A null transfer impediment is 
missing or unused information or knowledge that was learned at one time, but did not transfer or 
was not activated for use in the new task or problem. A substantive experiential impediment 
refers to a faulty concept model that was acquired from personal experience in the real world. 
This is generally referred to as a misconception but could also be thought of as misunderstood 
knowledge due to personal experience. A substantive pedagogic impediment refers to a faulty 
concept model that was acquired from an academic course learned in school. This is also 
generally referred to as a misconception but could also be thought of as misunderstood 
knowledge due to academic experience. A substantive misinterpretive impediment refers to a 
faulty concept model that misinterprets new knowledge in a task or problem. This is also 
generally referred to as a misconception but could also be thought of as misused knowledge or 
new knowledge used in the wrong way. One possibility that was overlooked by Taber is 
misapplied knowledge, would effectively choosing the wrong concept model for a given 
situation. It may be that this is the first use of a classification scheme of student issues and 
misconceptions in terms of functional knowledge and five types of non-functional knowledge, 
although the classification scheme draws heavily on the work of Tabor, Chi, and others.

Some examples will now be given of classification of student learning issues with respect to five 
categories of non functional knowledge that include missing, unused, misunderstood, misapplied 
or misused knowledge. If we consider the important topic of atomic bonding in a materials 
course, examples of learning issues and misconceptions would include the following\(^9\): an 
example of missing knowledge is that a significant fraction of students in an introductory 
materials course, who have already taken a chemistry course, often identify the bonding type in 
metals as ionic (rather than metallic) because metallic bonding was not discussed in the 
chemistry course. This could be also referred to as vocabulary gap. An example for the majority 
of students in an introductory materials course of unused knowledge is van der Waals bonding, 
which they have never heard of because the terminology for the same phenomena in chemistry is 
the term London dispersion forces. This could also be also referred to as vocabulary gap. A closely related issue is that some students had heard of van der Waals bonding in chemistry but 
did not recall or activate the concept in the materials course. An example of misunderstood 
knowledge is that the model for ionic bonding as sharing of electrons between atoms (which is 
the model for covalent bonding). This is a misconception due to confusion between bonding 
models. An example of a misused model is of macroscopic phenomena of solids to behavior of 
atoms at the atomic level such as soft atoms, hard atoms, brittle atoms or atoms rubbing, 
snapping or swelling. An example of misused knowledge is attributing thermal expansion of 
solids due to larger oscillations of atoms in a potential energy well rather than larger asymmetric 
oscillations of atoms in a potential energy well. This is a misconception due to not including the 
asymmetry in the potential well model of atom vibration. These are some examples of the types 
of learning issues that can arise in Muddiest Point reflections and need to be classified and 
diagnosed so an appropriate response or intervention to the learning issue can be synthesized.
Designing and Synthesizing Formative Process Feedback from Muddiest Points

The type and mode of formative process feedback that will best address student learning issues will depend on how the learning issue or misconception was revealed, characterized and diagnosed. The instructor needs to synthesize appropriate process feedback which is directed toward topical learning goals. Such feedback is highly valued by students and has the potential to increase motivation and perseverance in achieving the goals. There are a variety of approaches to creating the process feedback. It can be flexibly directed toward students, in-class or out-of-class, with multimodal (verbal, written, visual, graphical, video, pencast etc.) and multi-dimensional interactions (faculty-student, student-self, student-student, and student-web). A basic strategy question is what type of corrected model can be used to address the learning issue and what type of medium should be used for communication. One principle for providing formative process feedback is that it is easier for students to relate it to an abstract concept if it is tied to a concrete real world application. Another principle is that for abstract concepts it is always good to use multiple representations of a model. For example, ionic bonding could be represented visually showing a transfer of atoms. It could be described in writing as the transfer of electrons between atoms. It could be parametrized as the equilibrium of attractive and repulsive forces or as minimum energy in a potential bonding well. It could be described and sketched in a pencast or produced in a screencast video. An alternative strategy is to direct students toward other student learning resources on ionic bonding, such as a YouTube video (Google key words: MaterialsConcepts Bonding), a wikipedia site, or a web based materials vocabulary site such as Quizlet.com (Google key words: MatSciasu).

Communicating and Delivering Muddiest Point Process Formative Feedback

A formative process feedback delivery and communication method should be selected such that the feedback is quickly provided to students with the information and/or resources that they can use to enhance progress toward their learning goals. In a more practical sense this could refer to solving homework problems or studying for a quiz or a test. Input from instructors using Muddiest Points indicates that, if possible, the formative process feedback should be communicated to students no later than the beginning of the next class, the one that follows from the class where the Muddiest Point responses were generated. This serves at least multiple goals. One goal is that it allows students to use the feedback for homework, quiz, or test preparation. However, an equally important function of the rapid feedback is that it helps prepare students for the upcoming class and addresses potential learning issues and misconceptions that may need to be resolved to make good progress in the topic delivered in the following class. This rapid feedback is well appreciated by the students and may be critical to resolving SLIMs for the upcoming class. One delivery method is to discuss a slide of a limited number of Muddiest Points at the start of the next class. If this approach is used it is important to use not summarized issues or misconceptions, but actual student quotes, which are authentic, and in the student voice. Students also like to see their own quotes used in the slide and students also like to see what other students have to say. It is a very good warm-up for the upcoming class and also serves the purpose of activating the prior knowledge from the previous class, which will contribute to more effective learning. Other methods of delivering the feedback could include email, Blackboard, and the web. As previously discussed, students could also be directed to learning resources, which could include specific pages in the text or the web sites mentioned previously like YouTube, Quizlet.com, and Wikipedia.
Participants and Methods

The example we will use to demonstrate the Muddiest Point process will be on Eutectic Phase Diagrams from a section of the Fall 2013 introductory materials science class at a large southwestern university. There were 39 students enrolled in this broadly subscribed introductory materials science and engineering class. The class was composed of 1 freshman, 12 sophomores, 12 juniors, 13 seniors, and 1 graduate student. The disciplines in which the students were enrolled were 1 in aerospace engineering, 1 in biomedical engineering, 4 in chemical engineering, 5 in industrial engineering, 2 in materials science and engineering, 24 in mechanical engineering, 1 in physics, and 1 in elementary education.

The twice weekly, 75 minute class ran for a 15-week semester. The Student Reflection of Most Interesting Point and Muddiest Point was given for each class with the automated Concept Warehouse with a deadline of six hours after the end of the class. The students were given 1/5 of a point extra credit for each response with a maximum total of 5 points added in to the final grade total of 100 points (before extra credit). The participation rate across the semester was about 75%.

Results and Discussion

An example of a typical set of results from the Concept Warehouse from the Fall 2013 materials course will be presented for the topic of Eutectic Phase Diagrams. Figure 1 shows the tabular format of anonymous student quotes on their reflection of the Most Interesting Point as well as the Muddiest Point, along with the intensity of a comment scaled from 0-5. The data in Figure 1 show about half of the student responses that were submitted but are representative of the main points from both Interesting and Muddiest Points. Figure 2 shows the word clouds associated with the Most Interesting and Muddiest Points from the student reflection. Figure 3 shows the Excel spreadsheet word frequency numbers for the Most Interesting and Muddiest Points and it can be seen how well the highest words correspond with the largest words in the word clouds.

The Student Reflection Point of Interest allows students to think about and convey parts of content and the classroom experience that they find most interesting and intriguing. They begin to recognize topics and activities that interest them which promote future appreciation of knowledge. Requesting Interesting Point information also gives the students potential motivation to view the class positively since they are alerted to look for things that may relate to their personal interests. This also allows the instructor to identify with the learner and see what information sparks interests in the students’ thoughts. This feedback helps the instructor devise strategies and approaches to teach more effectively as well as improve the classroom experience.

The Interesting Point comments in Figure 1 had an overall average intensity of 4.1 / 5.0, which is unusually high both because of the interesting content of phase diagrams as well as the three YouTube videos that were shown in conjunction with the content. It can be seen that there are two most frequent items in the Interesting Points. One is about the primary content of the class, the phase diagram and the amount of information about metal alloy phases that is available as a function of composition and temperature. This is reflected by the quote, “I think that the phase diagrams were most interesting. It's weird how you can get so much info from them and all the different phases that appear." The other, most frequent Interesting Point related to the three one-minute YouTube videos that were played about phase transformations that occurred for water-
based solutions that were supercooled, superheated, and supersaturated. The video of the superheated water at the site [http://www.youtube.com/watch?v=2FcwRYfUBLM](http://www.youtube.com/watch?v=2FcwRYfUBLM) with temperature far above the boiling point in a microwave caused an explosion when the water almost instantly transformed from liquid to gas vapor steam. The supercooled water at [http://www.youtube.com/watch?v=lISK1YFcZBM](http://www.youtube.com/watch?v=lISK1YFcZBM) in a plastic Fiji bottle had been placed in a freezer for a couple hours and was removed with a temperature of about -15°C. When it was tapped lightly on a counter ice crystals nucleated near the cap and initiated rapid phase transformation of the liquid water into solid ice. The supersaturated solution of sodium acetate in water at [http://www.youtube.com/watch?v=1y3bKIOkcmk](http://www.youtube.com/watch?v=1y3bKIOkcmk), had a grain of the material dropped into the top of a 4-liter beaker, whereupon long white crystals grew at a moderate rate over about 40 seconds into the solution until they impinged on its sides and bottom. This is also reflected by comments such as, “I enjoyed learning about supersaturated solutions, as well as supercooling and superheating.” It should be commented that showing and discussing these videos in conjunction with the topical content of phase diagrams positively impacted student learning in the area of conceptual knowledge of solutions and solubility of phases as shown with pre and post concept tests. The positive student reaction and high learning gains triggered by the use of short videos suggests that this effect deserves further study and could significantly impact learning in other engineering disciplines, as well as other areas of materials courses.

<table>
<thead>
<tr>
<th>What was the most interesting point in lecture today?</th>
<th>How interesting was it?</th>
<th>What was the muddiest point in lecture today?</th>
<th>How muddy was it?</th>
</tr>
</thead>
<tbody>
<tr>
<td>The videos and nucleation.</td>
<td>5</td>
<td>Fractions of alpha and beta</td>
<td>2</td>
</tr>
<tr>
<td>Sodium Acetate example.</td>
<td>4</td>
<td>Calculating % phase with the plt</td>
<td>3</td>
</tr>
<tr>
<td>Super saturated liquids</td>
<td>5</td>
<td>Nucleation sites and how to calculate the percentage of what phase</td>
<td>5</td>
</tr>
<tr>
<td>supercooling</td>
<td>5</td>
<td>different saturation points are still a little confusing</td>
<td>3</td>
</tr>
<tr>
<td>the videos</td>
<td>5</td>
<td>scratched and unscratched, supersaturated, saturated and supersaturated</td>
<td>3</td>
</tr>
<tr>
<td>I enjoyed learning about supersaturated solutions, as well as supercooling and superheating.</td>
<td>4</td>
<td>Understanding the phase diagrams took a bit of effort to understand</td>
<td>2</td>
</tr>
<tr>
<td>the difference is saturated and how it pertains to the liquid not the solid</td>
<td>4</td>
<td>understanding what the alpha, beta states actually represent</td>
<td>5</td>
</tr>
<tr>
<td>Watching the videos depicting super saturated compounds</td>
<td>3</td>
<td>Do two metals that you alloy always have a liquid phase?</td>
<td>4</td>
</tr>
<tr>
<td>Learning about Phases visually with the graph</td>
<td>3</td>
<td>Understanding the phase diagram and terminology seems like alot of memorization.</td>
<td>5</td>
</tr>
<tr>
<td>The most interesting part was seeing the different types of solutions, heated, iced, ex</td>
<td>5</td>
<td>The hardest part was understanding the table we did in class with alpha and beta</td>
<td>3</td>
</tr>
<tr>
<td>I think the phase diagrams were the most interesting. Its weird how you can get so much info from them and all the different phases that appear</td>
<td>5</td>
<td>I also think that the phase diagrams can be difficult to read.</td>
<td>3</td>
</tr>
<tr>
<td>The crystallization of the supersaturated water was really interesting</td>
<td>4</td>
<td>How to read the phase diagram, what exactly does Alpha and Beta represent?</td>
<td>4</td>
</tr>
<tr>
<td>The video about supersaturated solution is really interesting</td>
<td>4</td>
<td>The phase graph makes a little bit confusion</td>
<td>1</td>
</tr>
<tr>
<td>How supersaturated mixtures respond to nucleation points</td>
<td>4</td>
<td>Why does a eutectic reaction exist in mixtures?</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 1. Concept Warehouse tabular output of student responses on the topic of Eutectic Phase Diagrams for the Fall 2013 class showing student comments and associated intensities for reflections on the topic’s Most Interesting Points and Muddiest Points
The Muddiest Point comments in Figure 1 had an overall average intensity of 3.7 / 5.0, which is somewhat high on average but typical for this subject since the topic of phase diagrams incorporates many new concepts, terms, and types of calculations. In characterizing the nature of the content of the comments it appears that there are three areas where student issues exist. (“Understanding the phase diagram and terminology seems like a lot of memorization.”) One issue is with all of the features and their meaning, significance and terminology. The second issue is related to characteristics of nature of phases, phase transformations, and phase reactions. (“What exactly does alphas and beta represent?”) The third issue is related to the means by which phase chemical compositions are determined and how the fractions of phases are calculated. (“Fractions of alpha and beta.”) What strategies can be used to address the wide breadth of issues that were revealed here? Similar responses arose in previous sets of Muddiest Point comments in previous semesters on the topic of Eutectic Phase Diagrams, so it was decided that tutorial YouTube videos (Google key words: MaterialsConcepts Phase Diagrams) would be made to address the broad swath of student issues that arise while progressing through content on phase diagrams. As such, five YouTube videos were created during the Fall 2012 semester and since that time those five videos have received more than 75,000 views. The impact of these videos on student learning on the topic of phase diagrams was quite positive also, as will be discussed later.

Another significant milestone is that Wiley Publishing has adapted over two dozen short Muddiest Point videos into the Wiley Plus student learning resource site that are linked to the latest 9th edition of their best-selling introductory materials textbook by Callister and Rethwisch, Materials Science and Engineering: An Introduction. The tutorial videos are denoted in the textbook with “margin concept cues” that inform the student that a short tutorial video is available to clarify and remedy Muddy Points on a particular topic. It will be interesting to see the effects of this innovation on instructor teaching and student learning in materials science.

Figure 2. Most Interesting Points and Muddiest Points Word cloud images of word frequency (seeFigure 3) for the topic of Eutectic Phase Diagrams.

<table>
<thead>
<tr>
<th>Interest Pt words</th>
<th>Times Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>video</td>
<td>5</td>
</tr>
<tr>
<td>water</td>
<td>4</td>
</tr>
<tr>
<td>supersaturated</td>
<td>4</td>
</tr>
<tr>
<td>Interesting</td>
<td>3</td>
</tr>
<tr>
<td>unsaturated</td>
<td>3</td>
</tr>
<tr>
<td>phase</td>
<td>3</td>
</tr>
<tr>
<td>solution</td>
<td>3</td>
</tr>
<tr>
<td>saturated</td>
<td>3</td>
</tr>
<tr>
<td>nucleation</td>
<td>2</td>
</tr>
<tr>
<td>super</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Muddiest pt words</th>
<th>Times used</th>
</tr>
</thead>
<tbody>
<tr>
<td>phase</td>
<td>11</td>
</tr>
<tr>
<td>diagram</td>
<td>4</td>
</tr>
<tr>
<td>beta</td>
<td>4</td>
</tr>
<tr>
<td>alpha</td>
<td>4</td>
</tr>
<tr>
<td>saturated</td>
<td>3</td>
</tr>
<tr>
<td>unsaturated</td>
<td>3</td>
</tr>
<tr>
<td>read</td>
<td>3</td>
</tr>
<tr>
<td>transmission</td>
<td>3</td>
</tr>
<tr>
<td>supersaturated</td>
<td>3</td>
</tr>
<tr>
<td>fraction</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 3. Phase Diagram word frequency tables for Most Interesting and Muddiest Points.
Communicating and Delivering MP Formative Process Feedback to Students

One delivery method is to discuss a slide of a limited number of Muddiest Points at the start of the next class. If this approach is used it is important to use not summarized issues or misconceptions, but actual student quotes, which are authentic, and in the student voice. Students also like to see their own quotes used in the slide and students also like to see what other students have to say. It is a very good warm-up for the upcoming class and also serves the purpose of activating the prior knowledge from the previous class, which will contribute to more effective learning. Other methods of delivering the feedback could include email, Blackboard, and the web. As previously discussed, students could also be directed to learning resources, which could include specific pages in the text or the web sites mentioned previously like YouTube, Quizlet.com, and Wikipedia.

![Reflections - Phase Diagrams I: Solubility & Eutectic PD](image)

**Points of Interest (4.1)**
- “I enjoyed learning about supersaturated solutions, as well as supercooling and superheating.”
- “The video about supersaturated solution is really interesting.”
- “How supersaturated mixtures respond to nucleation points.”
- “I think the phase diagrams were the most interesting. It’s weird how you can get so much info from them and all the different phases that appear”

**Muddiest Points (3.7)**
- “What is nucleation”
- “How to calculate the fraction of what phase”
- “What is the difference when the container or beaker is scratched or unscratched when talking about unsaturated, saturated, and supersaturated material.”
- “Understanding what the alpha, beta states actually represent”
- “Do two metals that you alloy always have a liquid phase?”
- “Why does a eutectic reaction exist in mixtures?”
- “The hardest part was understanding the table we did in class with alpha and beta”

Figure 4. Class start slide of selected student responses on the topic of Eutectic Phase Diagrams for the Fall 2013 class showing student comments and average intensities for reflections on the topic’s Most Interesting Points and Muddiest Points.
Impact of Muddiest Points & Engagement on Student Attitude Achievement & Persistence

Motivation can be increased when students receive frequent feedback by Muddiest Point activities so they recognize and identify with a course's relevance, significance, and possible value to their own future. When students are learning to bridge ideas from concrete contexts of a material with the familiar they also recognize their own relationship to these concrete contexts. When they reflect through Muddiest Points with situations related to these contexts, students can be better motivated to learn and continue in engineering. This is directly reflected in the affective portion of the exit survey for the Fall 2013 introductory course as shown above in Table 1, for Student Evaluation of Instructional Strategies and Personal Impact. It shows student’s perceptions of teaching strategies and also personal impact for the semester. The results were used to evaluate student attitudes about different components of the student engagement teaching strategy and their personal impact on students. Generally, the instructional strategies averaged a relatively high value of 78% for students felt items were supportive or very supportive. Similarly, the personal impact of the class also averaged a relatively high value of 83% for students who agreed or strongly agreed with the items. A brief discussion below of all results focuses on the far right summary column.

Table 1. Student Evaluation of Instructional Strategies and Personal Impact Exit Survey for a Fall 2013 introductory materials science class

Impact of Muddiest Points on Student Attitude - Support of Student Learning Survey
Instructional Strategies

1. Team based problem solving – A continuing high rating to 92% felt this is valuable to their learning the content.
2. Team report-out of solution to activity – Remained a relatively high value of 80% helps students articulate concepts and opportunity to listen to others articulating concepts.
3. Hands-on classroom activities – Increased even more in popularity to 93% indicating that more kinesthetic activities have potential to further improve attitude and achievement.
4. Contextualized Mini-Lectures – Remained a relatively high 79% as content is refined and class time and activities are better managed.
5. Muddiest Point YouTube videos – Relatively high value of 83% indicates good support for this learning resource that will hopefully be expanded in the future.
6. Daily Reflections Interesting Point – Relatively low at 54%, but increased slightly over time, maybe suggestions should be solicited for approaches to further increase interest in class.
7. Daily Reflections Muddiest Point – The ratings increased to 77%, possibly as a result of informing student of the value of MPs as a self-regulation learning tool.
8. In-class YouTube videos – High rating of 89% indicates students highly value the videos for illustrating concepts and applications – will be expanding use of these to more classes.
9. Class-start discussion of prior class Muddiest Point – Relatively high value of 82% shows strong support for formative process feedback for facilitating clarity and performance.
10. Homework preview problem for preparing students for next class – moderate support of 69% which could possibly be increased with better resources for solving concept map quizzes.
11. Undergraduate Teaching Assistant – High value of 97% demonstrates high regard for role of UGTA in class to support student learning – hope to continue success here.
12. Quizlet.com web materials vocabulary resource – modest value of 54% indicates resource needs to be improved and students made more aware of value of resource.

Personal Impact of 250 Class on Student

1. Class increased interest in remaining in own major – continuing high value of 85% demonstrates value of engagement pedagogy and contextualization of concepts.
2. Consider taking more classes in materials science – Moderately high value of 74% indicates enhanced interest in discipline of materials science and associated courses.
3. Material valued in career or grad school – Continuing high value of 86% indicates value to students’ future demonstrated in course content and learning.
4. Instructional strategies more motivating than other courses – Moderately high value of 71% indicates desire of students to see some instructional strategies of 250 more broadly adapted.
5. Helped students see relevance of engineering to real-world needs – Continuing very high value of 91% demonstrates value of frequent use of real world examples to show relevance.
6. Use Instructional Strategies in Other Courses? – Relatively high rating of 86% shows strong preference for more engagement in curriculum.
7. Would you recommend course to a friend? – Strong rating of 91% of ultimate endorsement of course indicates strong interest of students to share experience with friends.

Some highlights of the teaching strategies section of survey results include the following. Students have a very positive attitude about engagement pedagogy as seen by an 89% average of
the first three items of team based and hands on active learning. A second highlight is the importance of Muddiest Points in the teaching strategies is highlighted by the fact that 83% of students supported or strongly supported Muddiest Point discussions as well as Muddiest Point YouTube videos. Motivation and self efficacy are promoted with the Muddiest Point activities and accounts in part for the 93% persistence rate of students in the Fall 2013 class. A third highlight is the use of in-class YouTube videos which has a rating of 89%, indicating that this is innovation used in a few classes has impact and should be expanded. A fourth highlight how highly valued for support of student learning the undergraduate peer mentor is with a rating of 97%. This is consistent with results from prior semesters and is a strategy that could positively impact other engineering courses and disciplines. The major highlight of the personal impact section of survey is the high overall average of 88% of the future value in item 3 and real-world relevance in item 5 of the contextualized Muddiest Point and engagement teaching strategies.

Impact of Muddiest Points and Engagement on Student Achievement

The impact of the impact of the Muddiest Point process and engagement on student achievement is shown in Figure 5 which shows for the three hourly exams the positive slopes over time of the trend lines for upper, median, and lower quartiles test scores. The time frame is from Spring 2009 to Fall 2012. It also shows that when new student resources, such as Muddiest Point videos for phase diagrams, became available that the tests scores in the second exam for Fall 2012 were an average of 8 points higher than the trend lines of upper, median, and lower quartiles over time. The updated results beyond the Fall 2012 term will be presented at the conference.

Figure 5. Trend lines for core materials classes for Tests #1, #2, and #3 for the Fall 2012 semester. Average differences between F12 scores and the prior years’ trend lines were 1 point for T#1, 8 points for T#2, and 2 points for T#3.

Summary and Conclusions
This paper showed the theoretical framework for student reflections and formative process feedback. It also described the nature of the four steps in the two-way Muddiest Point feedback process consisting of: 1) acquiring data from student reflections; 2) assessing and characterizing student responses in order to diagnose the learning issues that can impede students from achieving their learning goals; 3) designing and synthesizing the type and mode of formative process feedback that best addresses the learning issues; and 4) selecting a formative feedback delivery method that quickly communicates to students the information and/or resources that they can use to enhance progress toward their learning goals. One feedback method cited was with Class Warm-ups, which consist of a slide or two for discussion at the beginning of the next class which can help clarify confusing or difficult-to-grasp concepts. Another method shown was to create Muddiest Point YouTube tutorial screencasts, such as the ones at www.youtube.com/user/MaterialsConcepts, which could be viewed by students to help resolve difficult concepts and also assist in solving homework problems. Positive impact on student achievement Muddiest Point and engagement pedagogy showed long term positive slope in the exam score trend lines for upper, median and lower quartiles over seven semesters. This includes a positive response for content for which a Muddiest Point YouTube Tutorial screencast on Eutectic Phase Diagram Calculations had been created. A final supplemental approach was to incorporate Word Clouds in any of the feedback methods in which students' most significant issues can be highlighted with the Muddiest Point frequency of a given word as revealed by the size of a word in the Word Cloud. Overall, this paper showed the very positive potential impact of incorporating Muddiest Point formative process feedback strategies in teaching and learning for positive gains for student attitude, achievement and retention.

Acknowledgement

The authors acknowledge the support of this work from NSF Grant #1226325.

Bibliography
