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Effect of Implementation of JTF Engagement and Feedback Pedagogy On Faculty Beliefs and Practice and on Student Performance

Dr. Stephen J Krause, Arizona State University

Stephen Krause is professor in the Materials Science Program in the Fulton School of Engineering at Arizona State University. He teaches in the areas of introductory materials engineering, polymers and composites, and capstone design. His research interests include evaluating conceptual knowledge, misconceptions and technologies to promote conceptual change. He has co-developed a Materials Concept Inventory and a Chemistry Concept Inventory for assessing conceptual knowledge and change for introductory materials science and chemistry classes. He is currently conducting research on NSF projects in two areas. One is studying how strategies of engagement and feedback with support from internet tools and resources affect conceptual change and associated impact on students' attitude, achievement, and persistence. The other is on the factors that promote persistence and success in retention of undergraduate students in engineering. He was a coauthor for best paper award in the Journal of Engineering Education in 2013.

Dr. Dale R Baker, Arizona State University

Dale Baker is a science educator, Her research focuses on equity issues as well as teaching and learning in science and engineering. She is a fellow of the American Educational Research Association and of the American Association for the Advancement of Science. She was the 2013 recipient of the NARST distinguished Contributions to Science Education Through Research award. This is the most prestigious award given by this international science education organization.

Dr. Terry L. Alford, Arizona State University

Dr. Alford holds the rank of professor in the School for the Engineering of Matter, Transport, and Energy. He currently integrates JTF tools and concepts into his on-line course delivery.

Dr. Casey Jane Ankeny, Arizona State University

Casey J. Ankeny, PhD is lecturer in the School of Biological and Health Systems Engineering at Arizona State University. Casey received her bachelor's degree in Biomedical Engineering from the University of Virginia in 2006 and her doctorate degree in Biomedical Engineering from Georgia Institute of Technology and Emory University in 2012 where she studied the role of shear stress in aortic valve disease. Currently, she is investigating cyber-based student engagement strategies in flipped and traditional biomedical engineering courses. She aspires to understand and improve student attitude, achievement, and persistence in student-centered courses.

Dr. Adam R Carberry, Arizona State University

Dr. Adam Carberry is an assistant professor at Arizona State University in the Fulton Schools of Engineering Polytechnic School. 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 and manager of the Student Teacher Outreach Mentorship Program (STOMP).

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. As an undergraduate he studied hardware, software, and chemical engineering. He ultimately received his Ph.D. from Oregon State University in Chemical Engineering. He is currently interested in the development of technology to study and promote STEM learning.

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

Dr. Cynthia Waters is an assistant professor in the Mechanical Engineering and she specializes in porous metals for biological and transportation applications, and engineering education. Dr. Waters' research expertise is in the creation and characterization of metallic foams and porous metals for the future of applications ranging from space exploration to biomedical implants. These metals display a high density to strength ratio and improved ability for energy absorption, which leads to usefulness in many applications. She gets excited in a classroom whether introductory or advanced courses and she has been told that she can make a difficult concept seem easy and that her excitement is contagious Waters believes that we must become 'facilitators of learning'. She works alongside the students to groom their own metacognative processes and help produce a lifelong learner. Several of her currently funded NSF grant deal with facets of engineering education. These include 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.

Prof. Brady J. Gibbons, Oregon State University

Effect of Implementation of JTF Engagement and Feedback Pedagogy on Change of Faculty Beliefs and Practice and on Student Performance

JTF (Just-in-Time-Teaching with Interactive Frequent Formative Feedback) is an NSF TUES Type 2 project which is implementing student-centered pedagogy with eight instructors at four collaborating institutions. Key features of the pedagogy are web-enabled classroom engagement as well as two-way formative feedback to inform instructors of student learning issues so they can adjust instruction and create adaptive resources to facilitate student learning. For instructors, the anonymous student formative feedback opens for them a window on student thinking which can reveal learning issues such as misconceptions, skill gaps (like charting), difficult concepts, vocabulary ambiguities, etc. This helps instructors develop and build their pedagogical content knowledge so they can adjust their instruction and more effectively deliver content, concepts and skills in light of their reflective knowledge of students' means of understanding and learning the material. With *JTF* web-enabled engagement and feedback pedagogy instructors' attitudes and approaches to teaching shift toward student-centered learning with resultant change in classroom practice to make instruction more effective. This was evidenced by improvements in student performance. The process of shifting beliefs and practice of eight collaborating faculty employed an implementation strategy that utilized a faculty change model and an organizational model of characteristics of sustainable innovation. As such, the research question addressed in this paper is, "What is the effect of *JTF* engagement and feedback pedagogy on change of faculty beliefs and classroom practice and on associated student performance across diverse settings."

In the *JTF* collaborative project the eight faculty have been participating for the last three years. They have set up web-enabled daily or weekly formative feedback mechanisms for acquiring "Muddiest Point" student anonymous reflections through Blackboard or Concept Warehouse survey tools. The instructors reflect on the responses and provide immediate feedback to students in the next class and/or via Blackboard postings. Results from a Fall 2013 survey of JTF faculty showed the following. Eight out of eight faculty said that, in the last two years of using *JTF* pedagogy, their classroom practice had "changed somewhat or changed significantly." One quote illustrating this change was, "I teach using full engagement strategies.... previous classes were much more lecture-centric." Another question showed that 7 of 8 felt that their views about teaching had changed "somewhat or significantly." One quote showing this change was, "Muddiest Point items are a powerful tool that shows a teacher where students are not understanding all information." The shift in the views and actions of teachers also resulted in positive outcomes in student performance. For student attitude, results from a Student Impact Value Survey (SIVS), based on expectancy/value theory, showed positive results of average 64% for Interest / Attainment Value and high values of 85% average of Utility Value, and also 84% agreeing that the Cost of Effort was low. Results for student persistence showed that, across collaborating institutions, persistence was 97% for 227 students in four classes in Fall 2013 and 95% for 311 students in five classes in Spring 2014. For student achievement, one instructor's final exam scores showed a shift in mean from 69% in Fall 2009 to 75% in Fall 2011 to 79% in Fall 2013. This is a shift upward of a full letter grade over four years. Overall, the faculty survey results and student performance outcomes demonstrate the effectiveness of *JTF* engagement and feedback pedagogy. Shifting faculty beliefs and classroom practice from instructor-centered teaching toward student-centered learning resulted in positive outcomes of student attitude, achievement and persistence.

Introduction

In this *JTF* (Just-in-Time-Teaching with Interactive Frequent Formative Feedback) project, reflection, engagement, and assessment tools developed in an earlier successful project were used and adapted to an interactive, web-enabled environment. This can facilitate the strategies, practices, and assessments that use two-way formative feedback to improve student attitude, learning, and achievement. Well-designed frequent formative feedback has potential to enhance both instructor teaching and student learning.[13, 34] For the *JTF* project, the process enables more effective instruction with instructor Just-in-Time-Teaching tools and student learning with Just-in-Time-Learning resources, as catalyzed by faculty-student interactions through two-way frequent formative feedback mechanisms. The instructor feedback helps students monitor their construction of knowledge and define the knowledge gaps that exist between their understanding of a topic and their achievement of the learning goals of the topic. Students can then strategize which resources to select, including those described in this paper, in order to reduce or ultimately close that knowledge gap. This metacognitive strategy contributes to self-regulation that leads to deeper conceptual learning and the achievement of learning goals. The ease-of-implementation, impact, and effectiveness of the *JTF* pedagogy for enhancing student performance are being tested in collaboration with faculty in diverse settings at four institutions of higher education.

In the *JTF* project the guiding principles were based on the research findings described in the book, How People Learn (HPL).[4] The book discusses how cognitive processes act to achieve learning through conceptual change based on three major principles, which include the following. For more effective learning, instructors need to: 1) elicit students' prior knowledge to inform instruction; 2) engage students to promote conceptual change so they can construct deep knowledge organized in a conceptual framework; and 3) encourage metacognition to build habits of expert learners who define their learning goals and monitor their own progress. The positive impact of the three evidence-based HPL principles on student learning is strongly supported in the literature and their application in practice in *JTF* pedagogy is now discussed.

In the *JTF* project faculty needed to know and understand both the abstract, evidence-based-instructional-strategies (EBIS) principles as a foundation for more effective teaching, as well as how they are used by showing concrete examples of their implementation in practice. In that light, we illustrate how this was done in the *JTF* for the three HPL principles. The first principle, eliciting prior knowledge, can reveal students' misconceptions and learning issues that may potentially be repaired by adjusting instruction and modifying materials. In prior work, two examples of such methods are formative feedback in Just-in-Time-Teaching[26] and concept quizzes in Peer Instruction.[25] Similar approaches were adapted to the *JTF* project to adjust instruction and give feedback to students.[20] The second principle, promoting conceptual change through "interactive-engagement", has been well demonstrated by many researchers[11, 12, 29] and has been utilized in *JTF* with contextualized activities for classes in materials courses taught by *JTF* faculty.[19] The third principle, promoting metacognition, is effective for improving self-reflective learning and motivation[34] and has been implemented by all *JTF* faculty through class-end reflections in which students reflect on and describe their own learning issues in terms of "Muddiest Points."[7, 16] Such issues are quickly addressed in the next class by *JTF* instructors in the two-way formative feedback process.[21]

A key factor in facilitating ease-of-use of *JTF* methods has been their implementation with web-enabled tools, which were readily used by *JTF* faculty in their practice. The impact of application of the HPL principles by *JTF* project collaborators has been reflected in changed faculty attitudes and by improvements in their students' attitude, achievement and persistence.[24]

While implementing these principles was effective, it has been important to understand how the principles of the web-enabled, engagement and feedback pedagogy were scaled to eight instructors at four institutions. In this project, results are being reported from the research question of, "What is the effect of *JTF* engagement and feedback pedagogy on change of faculty beliefs and classroom practice and on associated student performance across diverse settings." To better understand the approach to this question and the activities, interactions, and results of the *JTF* faculty collaboration, the background section will discuss the topics of characteristics of effective scaling of education innovation and of the change process in diffusion of education innovation that occurs as faculty are changing their beliefs and classroom practice.

Background

What are the Characteristics of Effective and Sustainable Scaling of Innovation? There are various methods of scaling education innovation used across STEM disciplines,[3, 14] but one that is frequently used is the "develop-disseminate model". In this model, an individual or a small group develops and tests an education innovation for a given setting and then, based upon the efficacy of that innovation, makes it broadly available to instructors who teach in a variety of settings. However, this model has been criticized by some researchers. Elmore[10] states that such a strategy assumes that its success is independent of setting, and suggests that the strategy is misguided because the innovation is not modified or altered to fit a given local setting, nor are necessary resources usually provided to support implementation. Adelman and Taylor[1] stated that, when innovation is implemented without modification or support, it is usually abandoned with little change in practice. Coburn[8] critiqued such innovation efforts as overly simplistic and needed to account for other factors. She proposed a model with four characteristics found in effective, sustainable innovation scaling: 1) *Depth;* 2) *Sustainability;* 3) *Spread*, and 4) *Shift of Innovation Ownership.* Dede[9] discussed means of improving Coburn's model for greater flexibility and durability of the four factors and Kezar[17] demonstrated how Coburn's model, as applied to K-12 innovation scaling, could also be applied to undergraduate STEM education. With this background, Coburn's four factors will be discussed with respect to the *JTF* project.

The first factor, *Depth*, refers to need for faculty change in beliefs at a deep level, which should then be reflected in classroom practice. This shows the need for faculty change, which was a major part of the *JTF* project. The second factor, *Sustainability*, means that an innovation must be robust and have the flexibility to be sustainable and adaptable to differing or changing contexts. For the *JTF* project, this meant that the *JTF innovation* worked in *different institutional settings* in the project. The third factor, *Spread*, refers to how the innovation is spreading with change in underlying beliefs, norms, and principles, for individuals and across the organization of the *JTF* collaborators. In the context of the *JTF* project, this means building a sustainable community of practice (CoP) to provide collaborative support for materials science faculty at four diverse institutions who have a common set of professional interests in the materials science discipline. The fourth factor, *Shift of Innovation Ownership*, refers to shift in ownership of an innovation, from an external facilitator to internal ownership through its adaptation by individuals and their associated institution. In the *JTF* project this would refer to the development of ownership of the *JTF* innovation by faculty of the materials science CoP through supported implementation of the *JTF* innovation. The four factors in Coburn's model of effective scaling of educational innovation are now discussed in more detail.

Facilitating Depth of Change of Faculty Beliefs toward Student-Centered Learning

Different models of change processes that represent faculty development in engineering education have been discussed by Borrego et al.[3] in a recent article that talks about the benefits and issues associated with the different change models. One model is *diffusion of innovation (DOI)*, based on a book of the same title published in 1962 by Rogers,[31] now in its 5th edition.[32] It is a theory which models adoption of innovation across a spectrum of fields such as electronics, public health, and agriculture, and has been shown to be relevant to innovation in education. The approach has been summarized with a framework of a five stage model of adoption of innovation. The stages include:

1. Knowledge or Awareness - occurs when an individual is exposed to an innovation and its functioning

2. Persuasion or Interest – occurs when interest is growing and an individual seeks additional information

3. Evaluation and Decision – occurs when an individual decides to adopt or reject an innovation

4. Implementation or Trial – occurs when an innovation is tested by putting it into use

5. Confirmation or Adoption – occurs when use of an innovation is continued and sustained

Borrego et al.[3] cite findings of other researchers that change agents, who have used this model for faculty development strategies, have been successful at the first two stages of *awareness* and *interest*, but are not as successful at the *trial* stage, which they say can lead to discontinuing use of an innovation or changing it in ways that decrease its effectiveness.[2, 15] However, they also cite evidence that suggests that, providing support for implementing innovation in the third and fourth *decision* and *trial* stages, with personal or small group interactions, can provide a more successful progression to the higher stages of diffusion of innovation.[30]

Recently, Pimmel et al.[27] have used a virtual community of practice (VCP) implementation of Rogers'[32] *DOI* model for faculty development using the internet. It was delivered with a two-tier, "train-the-trainer" model which was comprised of a first tier group of faculty leader pairs who received a half semester of training. After that, each of five faculty leader pairs then, in turn, trained a second tier of 20 – 30 faculty participants in evidence-based instructional strategies, methods, and examples, for a half semester. With this training, faculty participants progressed through the first and second stages of *awareness* and *interest* in Rogers' *DOI* model.[32] Potential issues of discontinuance in the third and fourth stages of *evaluation* and *implementation* of the *DOI* model were then addressed with a semester of supported classroom implementation by the faculty leader pairs. They led discussions of VCPs across the internet on topics of implementation successes and barriers and strategies to overcome them. Positive results for the VCP model for about 100 faculty in two cohorts were described at a sponsored session at the 2014 ASEE conference.[28] These results can be related to both Coburn's[8] Effective Characteristics of Scaling Innovation Model and Rogers'[32] DOI model.

In Coburn's[8] scaling model of characteristics of sustainable innovation, she says change in *faculty beliefs at a deep level should change* and also be reflected in classroom practice with pedagogy that shifts from instructor-centered teaching to student-centered learning, which was achieved in the Pimmel et al.[27] VCP with supported classroom instruction. Likewise, the *DOI* change model also shows that the supported instruction in the Pimmel et al.[27] VCP took participant faculty through the five stages of innovation to the *confirmation* or *adoption* level as evidenced by the faculty changes in classroom practice. This approach is now applied for *JTF*.

Facilitating Sustainability through Adaptability of Innovation and Depth of Belief Change

As previously mentioned, innovation must be robust and have the flexibility to be sustainable and adaptable in differing or changing contexts. In the *JTF* project this means that the web-enabled, engagement and feedback pedagogy should have the flexibility to fit the differing cultures of the faculty at four institutions. Additionally, innovation relies upon the depth-of-belief change of faculty in those programs. Coburn[8] says innovation that is implemented superficially in scaling may fall into disuse. Therefore, determining the extent to which faculty beliefs have changed can be a measure of the extent to which an innovation can potentially be sustained. In the *JTF* project regular project meetings, surveys, and workshops have been used to promote adaption of the *JTF* pedagogy and will be discussed in the results section.

Facilitating Spread of Innovation in an Organization with a Community of Practice

A community of practice (CoP) is defined by Wenger et al.[35] as a unique combination of three elements: a *domain of knowledge* given by a set of issues; a *community of people* who care about this domain; and the *shared practice* in which they are engaged in learning and improving in their domain. In a panel session in FIE in 2003,[33] *Communities of Practice in Engineering Education*, a question that was posed was, "How does a member of an organization gain the *insider knowledge* to learn how to act, talk, and think like a successful practitioner?" Brown and Duguid[6] suggest that, "Learning that is informal, social, and focused on meaningful problems helps create *insider knowledge*." Gaining *insider knowledge* is a major part of becoming a member of a CoP. For the *JTF* project, the materials science CoP was overseen by experienced faculty who were the *insiders* that had successfully implemented student-centered learning in their own classroom practice. They facilitated discussions of the *JTF* faculty on their implementation successes, issues, and strategies to improve effectiveness of implementation of EBIS and *JTF* pedagogy. So they came together to create a new level of organization--a *new* community with novel ways of practicing and interacting by being pragmatic in working together to solve critical implementation problems in teaching, assessment, and evaluation. This promoted the *spread* of innovation across the CoP. At the same time, the CoP promoted *deeper change in faculty beliefs* and potential for *sustainability of innovation*.

Shifting Innovation Ownership from External Facilitator to Internal Practitioners

Coburn[8] stated that, in scaling a reform innovation, ownership over the innovation must shift so that it is no longer an "external" innovation, controlled by a facilitator, but rather becomes an "internal" reform with the authority for the reform held by, in this case for the *JTF* project, the materials science faculty and the organization of the CoP. Although ownership of an innovation may be internal, it must be expressed explicitly by faculty whose beliefs and strategies are reflected and manifested in student-centered materials, activities, and classroom interactions. As such, there needs to be evidence that faculty have progressed to Rogers[32] fifth stage of innovation change of *confirmation* or *adoption*. The evidence that shows that this has occurred for the *JTF* project is discussed in the results section.

Results and Discussion

Facilitating Depth of Change of Faculty Beliefs toward Student-Centered Learning

In Coburn's[8] scaling model of characteristics of sustainable innovation, she says change in faculty beliefs at a deep level should also be reflected in classroom practice with pedagogy that shifts from instructor-centered teaching to student-centered learning. Collecting evidence on characteristics of classroom practice was done mainly by regularly surveying *JTF* participants every semester over the past two years of the *JTF* project.

The results from a Fall 2013 *JTF* faculty survey showed the following. Since starting in *JTF*, seven of eight faculty said "their views on teaching had changed somewhat or changed significantly." Additionally, eight of eight faculty said their "classroom practice had changed somewhat or changed significantly." One said, "Muddiest Point items are a powerful tool that shows a teacher where students are not understanding all information." For the *impact of JTF on* *student performance*, persistence across all universities was 97% for 227 students in four classes in Fall 2013 and 95% for 311 students in five classes in Spring 2014. One instructor reported that, over three classes, the percentage of females in a materials class receiving A's or B's increased from 34% to 65% when reflections on Interesting and Muddiest Points were used. The results show potential of *JTF* for impacting student performance. Additionally, JTF faculty showed their level of involvement by creating two new surveys to characterize student attitude, a Student Resource Value Survey (SRVS)[24] and a Student Impact Value Survey (SIVS).[7]

On a Spring 2014 one open-ended survey one question was: "How do you view your role in the classroom now as compared to before joining *JTF*?" The responses to this question were:

- "More as a coach and encourage and guide the students to do the necessary mental gymnastics to improve their comprehension and mastery of the topics."
- "More of a guide now."
- "More of a coach than a 'lecturer'."
- "I've always taken a role in class as a mentor/coach rather than a lecturer."
- "I realize even more that I am the guide and they must take on the learning."
- "Since using *JTF* the Muddy Point feedback has allowed me to give daily feedback to the students and to create better activities for engagement."
- "Before I felt as if I just spoke to the class and wrote on the board. Now I feel like, in addition to those, I am asking questions of EACH student during lecture. That's not possible without what we are doing."

The data show that *JTF* faculty fulfilled Coburn's[8] criteria of *deep change in faculty beliefs* in shifting toward student-centered learning, as well as having progressed to the fifth stage of DOI model of *confirmation* or *adoption* of the *JTF* innovation.

Facilitating Sustainability through Adaptability of Innovation and Depth of Belief Change

As previously mentioned, innovation must be robust and have the flexibility to be sustainable and adaptable in differing or changing contexts. In the *JTF* project this has meant that the web-enabled, engagement and feedback pedagogy has had the flexibility to fit the differing cultures and technical focus of faculty at the four diverse institutions. Additionally, innovation relies upon the depth of belief change of faculty in those programs. Coburn[8] says innovation that is implemented superficially in scaling may fall into disuse. Therefore, determining the degree to which faculty beliefs have changed can be a measure of the extent to which an innovation can potentially be sustained. An important measure is the use of engagement in classroom practice.

Measures of *engagement* in *JTF* are the following. A recent Fall 2014 survey of seven participants showed that, on a scale of 1 to 10, their use of engagement and feedback pedagogy increased from average of 3.9 before *JTF* to 8.3 since joining *JTF*. For a second question of, "How frequently do you contextualize activities and content for class?" the average response, on a scale of 1 to 10, was 9.3. On another question, "What was the effectiveness of your engagement strategies for promoting learning?" the average of responses, on a scale of 1 to 10, was 8.3. This shows that the *JTF* pedagogy has the usefulness and flexibility to be adopted by multiple faculty in diverse settings at four institutions.

Facilitating Spread of Innovation in an Organization with a Community of Practice

Coburn[8] says that the *Spread* factor needs to demonstrate that the educational innovation is spreading with change in underlying beliefs, norms, and principles, for individuals and across the organization of the *JTF* collaborators. In the context of the *JTF* project, this has meant that a sustainable community of practice has been built and developed (CoP) to provide collaborative support for materials science faculty at four diverse institutions who have a common set of professional interests in the materials science discipline.

A Spring 2014 survey showed all faculty were using Blackboard or Concept Warehouse to collect student Muddiest Point feedback and using it to adjust instruction and create learning resources. With respect to measures of forming a Community of Practice, five to eight faculty participated in monthly web meetings over two years; six faculty participated in two *JTF* workshops in Tempe in 2013 and 2014; and six jointly co-hosted a 2014 ASEE workshop to present the web-enabled tools used in their own teaching.[23] Two faculty created two new survey tools now used across the project. These regular and synergistic interactions, as well as the collaborative participation in *JTF* workshops and the ASEE workshop, are indicative of the positive interdependence and mutual benefits derived by the *JTF* faculty from the CoP.

Shifting of Innovation Ownership from External Facilitators to Faculty Practitioners

Coburn[8] states that, in scaling an educational reform innovation, ownership over the innovation must shift so that it is no longer an "external" innovation, controlled by a facilitator, but rather becomes an "internal" reform with the authority for the reform held by, in this case for the *JTF* project, the faculty and the organization of the CoP. Although ownership of an innovation may be internal, it must be expressed explicitly by faculty whose beliefs and strategies are reflected and manifested in student-centered materials, activities, and classroom interactions. As such, there needs to be evidence that faculty assumed ownership of the *JTF* pedagogy, as well as having progressed to Rogers[32] fifth stage of innovation change of *confirmation* or *adoption*.

In the *JTF* project there are various sources of this evidence that demonstrate ownership of the *JTF web-enabled*, *engagement* and *feedback pedagogy* by the participating *JTF* faculty. For *web-enabled tools, and resources*, all participants have stated that they have or are using web-enabled, two-way formative feedback with Concept Warehouse or Blackboard. They have also described other web-enabled approaches to creating inside-and-outside classroom materials, activities, tutorials, and assessments. They include: Blackboard quiz and discussion tools; Google Drive; the Quizlet.com vocabulary site; YouTube videos; and screen cast and pencast tutorials. For *feedback*, all *JTF* faculty are using either Concept Warehouse website or the Blackboard survey tool for acquiring student Muddiest Point data and then giving next-class responses on the student learning issues. The measures of *engagement* for *JTF* include the following. A recent Fall 2014 survey of seven participants showed that, on a scale of 1 to 10, their use of engagement and feedback pedagogy increased from average of 3.9 before *JTF* to 8.3 since joining *JTF*. For a second question of, "How frequently do you contextualize activities and content for class?" the average response, on a scale of 1 to 10, was 9.3.

Impact of *JTF* Pedagogy on Student Performance

The results of the *JTF* project show how some of the *JTF* evidence-based research methods, materials and tools have impacted student performance. The project addressed the three principles of HPL: prior knowledge; conceptual change; and metacognition.

For prior knowledge, early work was done on methods, tools, and processes that were developed for uncovering misconceptions and learning issues. Initially, such data was collected with pencil and paper using: 1) open-ended concept questions in homework, 2) in-class concept quizzes, and 3) end-of-class reflections with students' Muddiest Points.[18] Muddiest Point data collection was automated in the last year using the Concept Warehouse web platform (http://cw.edudiv.org) or the Blackboard survey tool,[5, 24] either of which facilitated "ease-of-implementation." This is now used in the *JTF* project by all eight faculty. This process has catalyzed *JTF* faculty reflection and helped them to shift their practice toward student-centered learning. The results of this process are uncovering a variety of impediments to conceptual change and learning. These results have then been used to: adjust instruction; modify materials; create student activities and learning resources; and provide formative feedback to students.[21]

For conceptual change, three actions were taken by *JTF* faculty from the knowledge that they acquired from the two-way formative feedback process. First, instructional strategies, as informed by knowledge of misconceptions, were used to remodel classroom practice, content, activities, homework, and exams.[21] Second, to improve the personal relevance and future value of technical content and concepts for students, real world contexts were integrated into to the publisher's slide sets and contextualized activities were incorporated into each class.[21] Third, new student web-enabled learning resources were created to address misconceptions and student learning issues.[22] As implemented on open websites, they include: 19 YouTube Muddiest Point tutorial videos (Google: *materialsconcepts*); a vocabulary tool (Google: *matsciasu*) with 500+ terms for 22 topics, and the slide sets used in the YouTube tutorials (Google: *mseasuslides*).

Web-enabled formative feedback assessment is used to acquire, analyze and understand students' misconceptions and learning issues and the strategies they used to address them. Once underlying misconceptions and learning issues were uncovered, teaching strategies and content are adjusted to accommodate and resolve those issues. Also, as previously mentioned, a number of student learning resources are created based on knowledge of the student issues, such as the Muddiest Point YouTube videos and the web vocabulary site. The results, with respect to impact of the *JTF* features of reflective practice, modified materials, and web resources, were assessed for student attitude, achievement and persistence. Persistence for one JTF instructor's class in Fig. 1 (# students present at final exam / # students present third week), shows improvement from average of 85% with lecture pedagogy to 95% with engagement pedagogy. For *JTF* collaborators, persistence across collaborating universities was 97% for 227 students in four classes in Fall 2013 and 95% for 311 students in five classes in Spring 2014.

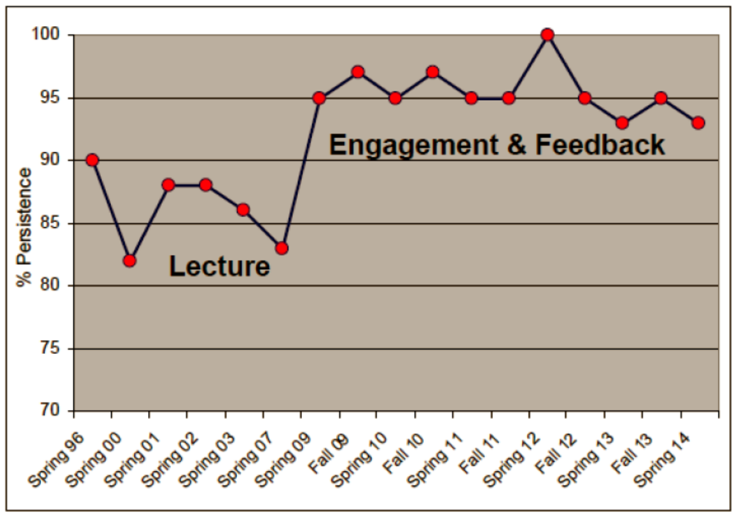

Figure 1. Persistence over time for lecture versus engagement pedagogy in a materials course.

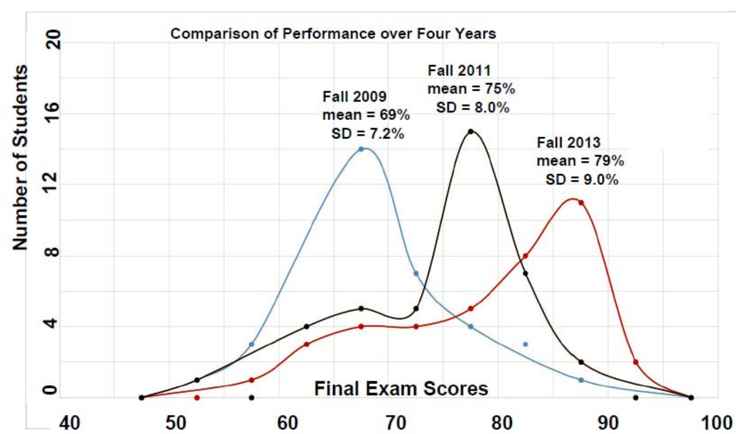

Figure 2. Final exam grade distribution for F09, F11, and F13

Another measure of achievement was the change in final exam mean score for the one Materials class over time, as shown in Figure 2. It shows an upward shift of final exam mean from 69% in Fall 2009 to 75% in Fall 2011 to 79% in Fall of 2013. That represents a shift of a full letter grade over four years, which reflects increasingly effective implementation of the innovative pedagogy, as well as new student learning resources, and experience in teaching with engagement. Similar strategies were used in *JTF* for supporting *JTF* faculty while implementing the strategies in their own classrooms.

For metacognition, in order to assess impact of reflective practice in the web-enabled engagement pedagogy with Muddiest Point two-way formative feedback, a survey based on expectancy / value theory, was created to assess impact of *JTF* pedagogy on student attitude in terms of interest (motivation), utility, and cost. As such, a Student Impact Value Survey, shown in Table 1, was developed and administered to assess the impact of *JTF* web-enabled, engagement and feedback pedagogy on students. Five classes at four institutions all had very positive results discussed here.

STUDENT VALUE OF MUDDIEST POINT REFLECTIONS: RESULTS
n (instructors) = 4 and n (students) =140

INTEREST/ATTAINMENT VALUE	Agree	Disagree
motivated me to do well in the course	59%	41%
was an effective way to increase engagement	79%	20%
helped me better understand my own learning	69%	31%
increased my level of responsibility	59%	41%

UTILITY VALUE	Agree	Disagree
will be of value after graduation	81%	19%
was useful in career and/or graduate school goals	79%	21%
helped me see relevance of eng to the real word	87%	13%
helped me learn importance of mat science to engineering	93%	7%
helped me learn importance of manufacturing to engineering	88%	12%

COST	Agree	Disagree
required too much effort	17%	83%
made me frustrated and anxious	14%	86%
required too much time	15%	85%

Table 1. Student Impact Value Survey results.

The survey was given to five classes at the four institutions with all having similar levels of very positive results discussed here. The results are analyzed with respect to three major factors: interest/attainment value; utility value, and cost. These results are discussed below.

1) Interest/Attainment Value: Interest or intrinsic value is an individual's anticipated enjoyment of engaging in a particular activity. Related to interest value is attainment value or an individual's perception of how the activity contributes to the conception of who he or she is fundamentally. Positive results of 59% to 79% suggested that the majority of students found Muddiest Point reflection to positively impact their experience in the class.

2) Utility Value: Utility value is an individual's perception of the advantages that result from engaging in the task for future goals or rewards. Very positive results from 79% to 93% suggest

that students overwhelming found the material learned in the course to be of value to them in their current and future endeavors as learners and professionals.

3) Cost: Cost represents an individual's perception of sacrifices required, including effort, time, and psychological impact, for successful impact of an activity. Results of 83% to 85% suggest students did not find Muddiest Point reflections to be a frustrating activity that took too much time and effort.

It can be seen from the results above that the use of Muddiest Point reflections is a simple intervention that is capable of having major impact on course outcomes. The benefits of such two-way formative feedback are the associated gains for both instructors and students. From a student perspective, the survey revealed overwhelmingly positive value toward the Muddiest Point reflections. Students saw this opportunity as a way to positively impact interest, attainment, and utility value without too much negatively associated cost. Such results suggest that students found Muddiest Point reflections improved the course in a way that made the course more enjoyable and valuable. This increase in value resulted in high appeal for the course by students. While this final result is likely impacted by the course content and the instructors themselves, the instructors can still appreciate the students' views using such two-way feedback activities as a means of having better insight on student learning issues.

Summary and Conclusions

The JTF project has implemented a student-centered pedagogy with eight instructors at four collaborating institutions. Key features of the pedagogy are web-enabled classroom engagement as well as two-way formative feedback to inform instructors of student learning issues so they can adjust instruction and create adaptive resources to facilitate student learning. In order to use such an innovation at a larger scale, change needs to occur at the individual level, as discussed with Rogers'[32] DOI model, as well as at the community or organizational level, as discussed by Coburns'[8] Characteristics of Effective Innovation model. In this paper it was shown that the JTF faculty collaborators progressed through the fifth stage of the DOI model of *confirmation* or *adoption* as evidenced by their change in their beliefs and in their classroom practice. These types of change also align with two of the characteristics of Coburns' model of change *in beliefs at a deep level* and *ownership of the JTF innovation* shown with classroom practice. These changes were facilitated by the development of a community of practice through supported implementation of the *JTF* pedagogy by experienced practitioners in the *JTF* project. This supports Coburns' characteristic of *Spread*, in which an innovation is spreads across a community or an organization by the change in its individuals' underlying beliefs, norms, and principles. The JTF pedagogy also fulfilled Coburns' characteristic of Sustainability since it has the flexibility and the robustness to be adapted by instructors across four diverse institutions.

With the *JTF* web-enabled engagement and feedback pedagogy, instructors' attitudes and approaches to teaching shift toward student-centered learning with resultant change in classroom practice to make instruction more effective. This was evidenced by improvements in student performance. There has been improved persistence in JTF instructors' classes across the project of 97% for 227 students in four classes in Fall 2013 and 95% for 311 students in five classes in Spring 2014. For achievement, one JTF instructor showed an upward shift of final exam mean from 69% in Fall 2009 to 75% in Fall 2011 to 79% in Fall of 2013, which represents a shift of a full letter grade over four years, Another instructor reported that, over three classes, the percentage of females in a materials class receiving A's or B's increased from 34% to 65% when student reflections on interesting and Muddiest Points were used. For attitude, there were very positive outcomes across institutions for the Student Impact Value Survey. This included the following: 69% who agreed that the Muddiest Points helped them better understand their own learning; 87% who said it helped them better see the relevance of engineering to the real world; and 83% who agreed that Muddiest Points cost little effort on their part.

Overall, the faculty survey results and student performance outcomes demonstrate the effectiveness of *JTF* web-enabled, engagement and feedback pedagogy. Shifting faculty beliefs and classroom practice from instructor-centered teaching toward student-centered learning resulted in positive outcomes of student attitude, achievement and persistence.

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