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The iCollaborate MSE Project: Progress Update 2014

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Abstract

The iCollaborate Materials Science and Engineering (MSE) project is a multiyear, multifaceted research project designed to understand how student learning outcomes, student engagement, and successful course completion rates in introductory MSE courses are affected by a variety of programs and activities that are based upon best practices from STEM education research. A number of interventions and active techniques were used in the classroom, at first, singularly and, as the project progressed, in various combinations. Additionally, a wide variety of faculty and student resources were created as part of this project. For example, test device MSE iPod applications were developed for iCollaborate: Concept Questions, Vocabulary, Basic Knowledge, Tune-Up, Material Properties, Composite Calculator, MSE Convert, and MSE Knowledge Tools and Review. Furthermore, a concept map based web site, which includes web applications of key iPod applications is currently under construction. Initially, the purpose of the website was envisioned as a repository of project resources, but as our research proceeded, it became obvious that the students perceived the concept map and web tools as essential parts of the project and their view of their personal success strategies.

Overall, the basic principles implemented in the project are supported by theory based in cognitive and social constructivism and the substantial body of evidence that favors collaborative learning and the inductive approach over the traditional lecture driven, deductive teaching approach. Collaborative learning, active/inquiry learning, concept learning, peer learning, problem/case-based learning, low stakes quizzing, mini-lectures with just-in-time reading, collaborate research writing, and constructive alignment are all part of the project. The newly developed iCollaborate learning exercises are conceptually targeted, designed to provide scaffolds to prior knowledge, and are active, inquiry based modules. Not surprisingly, we found that students come to the course with different levels of preparation and that scores in prerequisite courses do matter, but these are not always perfect indicators that key information from those courses was retained. Students enter the course with a wide range of learning styles, and some prerequisite information is retained or learned differently based on individual learning styles (as measured by our assessments). Based on our findings, we recommend that every instructor evaluate the prerequisite knowledge of their students and complete targeted interventions aimed at known robust MSE misconceptions and local knowledge gaps. Overall, the students were able to understand the relationships between the collaborative assignments, the low stakes quizzes, and the mini-lectures in helping them learn different types of concepts.

This paper concentrates on previously unreported components of the iCollaborate project that were investigated, evaluated, or developed during the 2012-2013 academic year. The development of the iCollaborate concept map and web applications web site is emphasized in this paper. The paper concludes with a summary of findings thus far from the project and a discussion of future directions and research opportunities. The plans for

the final year of the project will be discussed.

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Introduction

The iCollaborate Materials Science and Engineering (MSE) project is a multiyear, multifaceted research project designed to understand how student learning outcomes, student engagement, and successful course completion rates in introductory MSE courses are affected by a variety of programs and activities that are based upon best practices from STEM education research. A number of interventions and active techniques were used in the classroom, at first, singularly and, as the project progressed, in various combinations. Additionally, a wide variety of faculty and student resources were created as part of this project. For example, test device MSE iPod applications (Apps) were developed for iCollaborate: Concept Questions, Vocabulary, Basic Knowledge, Tune-Up, Material Properties, Composite Calculator, MSE Convert, and MSE Knowledge Tools and Review. Furthermore, a concept map based web site, which includes web applications of key iPod Apps, is currently under construction. Previous papers have reported upon research activities during the previous three academic years[1-5].

The first component of the iCollaborate project was to shift the structure in our fundamental materials science and engineering course from deductive practice to an inductive teaching and learning environment with Information and Communication Technology (ICT) support. The ICT support technology deployed in our research was the iPod Touch, but similar applications (Apps) could be coded for other smart devices with all downloading resources from the same databases. The basic principles implemented in the project are supported by theory based in cognitive and social constructivism[6-9] and the substantial body of evidence that favors collaborative learning and the inductive approach over the traditional lecture driven, deductive teaching approach[10-27]. Collaborative learning, active/inquiry learning, concept learning, peer learning, problem/case-based learning, low stakes quizzing, mini-lectures with just-in-time reading, collaborate research writing, and constructive alignment are all also important components of the project. The developed iCollaborate learning exercises are conceptually targeted, designed to provide scaffolds to prior knowledge, and are active, inquiry based modules.

While much is now known about effective teaching practices in STEM education, barriers to implementing those advances in existing courses remain, and certain elements of those practices and the related course materials development activities consume a great deal of time. A carefully researched project such as iCollaborate, which has been tested in “real” classroom environments, may have a better chance of being adopted elsewhere if the inherent risks with change is better understood and, therefore, better managed in the classrooms of other faculty. We found that students come to our basic MSE course with different levels of preparation and that scores in prerequisite courses do matter, but these are not always perfect indicators that key information from those courses was retained. Students enter the course with a wide range of learning styles, and some prerequisite information is retained or learned differently based on individual learning styles (as measured by our assessments)[1]. Based on our findings, we recommend that every instructor evaluate the prerequisite knowledge of their students and complete targeted interventions aimed at known robust MSE misconceptions and local knowledge gaps. Since our state has a large community college system, local knowledge gaps differed somewhat from section-to-section of the course, but several core key themes emerged. For example, introductory chemistry courses emphasize ionic and covalent bonding, leaving the students with knowledge gaps and robust misperceptions regarding the important MSE topic of metallic bonding.

The students comprehended the relationships between the collaborative assignments, the low stakes quizzes, and the mini-lectures with just-in-time reading in helping them learn different types of concepts and reconstruct their knowledge. If our interventions were grouped into three large categories of active, collaborative learning modules, mini quizzes with just-in-time reading, and ICT activity modules, we found that any two of the three (with a live instructor) produced improvements in student learning outcomes, completion rates, and student engagement. The addition of the third element did not improve overall outcomes and sometimes overloaded the students with too many resources from which to choose.

When we began the iCollaborate research program, we envisioned building a web site that would serve as a repository of project information. But as our research proceeded, it became obvious that the students perceived the web site differently. While the students enjoyed the collaborative work in the classroom and the team assignments with the iPod Apps, many of them wished for more practice time, especially on the conceptual questions and on the materials properties applications. The site also provides struggling students with additional opportunities to engage with the project resources, such as vocabulary terms and tune-up (basic MSE knowledge) questions. The web apps are built from a review/personal resource perspective, while the iPod Apps are built for a collaborative, active learning environment. The concept map on the web site is designed to help students, in either mode, connect key concepts. Students who traditionally struggled with the course have benefited the most overall from the iCollaborate teaching and learning system.

Summary of the STEM Research Base

While the research base for this project has been previously reported in detail,[1-5] a summary of the research justification is presented here so that those not familiar with the iCollaborate project have an overview of its foundation. "The fundamental principles implemented in the project are supported by theory based in cognitive and social constructivism[6-9] and there is a substantial body of evidence that favors the inductive approach over the traditional deductive approach in engineering education[10-27,54-56]. Students build scaffolds from existing cognitive structures to new information when there is connection to existing knowledge. All work developed as part of this project is designed to build scaffolds by connecting new fundamental MSE principles to the existing knowledge base of our students, which was determined by mining several years of data and information from pre-course concept questionnaires, exams, and quizzes. Targeted modules, which connect to the students' existing knowledge base, are very important in an interdisciplinary field such as materials science and engineering. Known MSE misperceptions are targeted in each project component"[1,6-14].

It is also known that cooperative learning is an effective method of enhancing student learning outcomes and persistence[18-27]. "Between 1924 and 1997, more than 168 studies were conducted comparing the relative efficacy of cooperative learning. These studies indicate that cooperative learning promotes higher individual achievement than do competitive approaches …"[18]. "The meta-analysis (of cooperative learning) demonstrates that various forms of small-group learning are effective in promoting greater academic achievement, more favorable attitudes toward learning, and increased persistence through STEM courses and programs"[23]. We modeled our collaborative work after the work of Johnson and Johnson[18-27] (and others) to include the elements needed for cooperative efforts to be more productive than individual efforts: "clearly perceived positive interdependence; considerable face-to-face interaction; clearly perceived individual accountability and personal responsibility to achieve the groups' goals; frequent use of relevant interpersonal and small-group skills; and frequent and regular group processing of current functioning to improve the groups' future effectiveness[18]". All classroom active experiences, open-ended design problems, research writing, ICT modules, and just-in-time exercises were all completed collaboratively.

Most collaborative teams worked well together, but occasionally a group needed some intervention from the instructor. And in only one instance (over 3 years of the project) did a team remove a member with the agreement of the instructor. Team members reviewed each other (and themselves) at the end of the term and had the opportunity to provide comments for the instructor. Most often students underrated their own contributions and were forgiving of other team members. Teams were not forgiving when it came to not contributing a fair share to collaborative exercises or for falling behind in their team commitments.

"Another important component of the iCollaborate project is conceptually based peer learning. Mazur[28] and others have[29-31] shown that conceptually based peer instruction is an effective way to improve student outcomes in physics. Peer teaching and concept learning has also been researched in materials engineering[29-31]. We have observed that a group, which is composed of only weak or only strong students, seems to impede the learning process and leads to difficult group dynamics. Obviously, if no one in the group understands the question conceptually, little peer learning can take place.[1]"

"There is also a research base to support ICT in distributed cognition and collaboration. "Distributed cognition is a way to understand how people interact with their environment and how they can be enabled by the environment to undertake highly complex tasks that would usually be beyond the abilities of the unassisted individuals"[32]. Vygotsky first examined activity theory in the 1930's. Later, Hutchins and many others have contributed to research in distributed cognition[32-38]. Additionally, there have been studies investigating why computers enhance student learning and results indicated that task engagement increases at conceptual levels, student self-regulation increases, and exploration is encouraged[35]. There is also research to support that peers and social interactions are important components of distributed cognition[1,38]".

Research also supports the use of self-quizzing and knowledge cards to improve student outcomes[36-47]. McDaniel's work shows that "in the context of an actual course that quizzing benefits learning and that it does so much more than focused reading of targeted facts"[45]. "Quizzing with feedback (either going over the quiz in class, or allowing the students time to consider their answers and subsequently reviewing the graded quiz) provides a more positive learning outcome than multiple readings without quizzes"[47]. A study by Karpicke and Roediger found that "repeated retrieval practice enhanced long-term retention, whereas repeated studying produced essentially no benefit"[44]. Recite-Recall-Review has been reported by McDaniel to "improve student learning, and another advantage of this method is that it is under the learner's control"[45].

A more robust description of the research base that supports connections between ICT enhanced collaborative learning based upon active, conceptually contained explorations, cognitive and social constructivism, distributed cognition, peer instruction, and STEM enhanced student outcomes is reported in more detail elsewhere[1-5].

Analysis of Pre-Course Instruments and Prerequisites, a Review

As part of this research project, students completed a pre-course evaluation instrument consisting of 26 questions in three broad conceptual areas (chemistry, basic physics/science knowledge, and hands-on/project learning). Students were placed into four categories for this analysis: engineering technology (ET) majors, industrial technology (IT) majors, science (SCI) majors, and non-science or technology majors (NSCIT). For the pre-course evaluation materials, we examined overall GPA, GPA in Chemistry, GPA in Mathematics, and the Index of Learning Styles (Felder's ILS[50]) data for each student for each question. A one-way ANOVA test with $p<0.05$ was used to evaluate statistically significant differences, except where IT and ET students only were compared. In those cases, a T-test with $p<0.05$ was used. An outside evaluator completed the assessment activities with the students.

When we aggregated the pre-course assessment into broad categories (chemistry, physics/general science and hands-on), we found that the students answered only about half (54%) of basic prerequisite questions correctly. This result was very surprising in that we believed a high proportion of the students would know most of the answers before we began this project component as the questions seemed very basic and were covered in prerequisite courses. The performance results challenged many of our basic assumptions about prerequisite knowledge. The students performed the worst on the basic chemistry questions (only 44% correct answers), while they only did only somewhat better on the questions based upon on hands-on learning (55% correct answers). While it would be tempting to complain about the lack of prerequisite knowledge and conceptual understanding and move on, it is more important to know about what hinders student learning and knowledge building and make sure that those key concepts are addressed and any robust misperceptions resulting from those missing concepts are targeted with effective interventions. The same is true of local knowledge gaps.

"For example, we continue to find that students who had only one quarter of prerequisite chemistry have very little understanding of important MSE prerequisite concepts. ET students scored the lowest (34.5% correct answers) and SCI students scored the highest (60.5% correct answers). It is interesting to note that on the question where the students are asked about metallic bonding, 12% of the IT students answer correctly, while only 9% of the ET students answer correctly. The low level of student knowledge regarding metallic bonding must be addressed in any fundamental MSE course. For the metallic bond question, GPA in the introductory chemistry class resulted in different outcomes as well, with 2.0 GPA students scoring the lowest (34% correct answers), as compared to 3.0 and 4.0 GPA students (48% 44%, correct answers, respectively). Chemistry GPA also influenced the ability of the students to name a ceramic material. Seventy-four percent of Chemistry GPA 4.0 students were able to name one ceramic material, while only 51% of the GPA 2.0 students answered correctly. Math GPA was significant in the chemistry assessment, hands-on assessment, and overall. Overall GPA and Chemistry GPA were significant in the general science/physics knowledge assessment as well[1]".

Other papers present more detailed analysis of our pre-course assessments and corrective actions and interventions that subsequently were developed[1-5], so they will not be presented in this paper.

iPod Applications and Web Applications

The following Apps have been developed for the iPod Touch test platform: iCollaborate Vocabulary (Vocab), iCollaborate Basic Knowledge Building (BasicK), iCollaborate Concept Questions (ConQuest), skill tune-up (Tune-Up), a graphical Materials Properties application with list features (MSEMatProps), a unit conversion tool specific to units encountered in a basic MSE course (MSEConvert), a tool to calculate the Elastic Constant of Unidirectional composites (MSEComposites), and a study guide (MSEKnowledge Tools). Three web app tools have been developed so far: MSE Materials Properties, MSE Vocabulary, and MSE Tune-Up. A 'concept or mind map', which assists in connecting key terms and concepts, is being constructed on our project web site. The concept map may be used in either active group learning or review mode.

Our research web site has become an integral component of the iCollaborate project. The database content from all the iPod Apps will be incorporated into the web site and concept map. The change in our thinking about the web site came about because of formative feedback from our students. While we thought of the web site as a repository of information (mainly for other faculty), the students viewed the web site as a resource they could use to develop their conceptual understanding and check their knowledge base at any time that was convenient for them. And they view this resource as a very different tool than their collaborative classroom work and iPod App work because they see the web site as a personal (and review) tool, rather than a collaborative tool. The top students and the struggling students requested the web site tools, while the mid-range students seemed satisfied with the iPod Apps and the collaborative work or the mini-quizzes with just-in-time lectures.

Figure 1 shows the user interface and the topics for the iCollaborate iPod Vocabulary App arranged by the order of topics covered in our class. Figure 1 also shows the conceptual topic titles that are common to many of the applications. Figure 2 shows web app topic lists, which in this case are listed in alphabetical order. The difference in the two approaches is that the iPod Apps are used in collaborative work in class, while individuals use the web apps for review sessions. While we wanted all the applications to work in a similar fashion and have a common interface, we found that it was not possible to have identical interfaces between the web based apps and the iPod Apps. However, they function in a similar way and have a similar set-up.

As shown in Figures 3, 5, and 7, the iPod Apps are "smart" in that they record the number of correct answers and incorrect answers (visual display in red or green boxes) and they provide additional resources for students who have answered the question incorrectly. Since the iPod Apps are used in "real time" collaborative learning in the class and outside team exercises, they must provide resources for the students to construct or reconstruct their knowledge. Figures 2, 4, and 6 show that the web apps are not "smart" and function much like flash cards. Again, the web apps are designed for personal review purposes and not for collaborative knowledge building. iPod Apps operate in practice modes and test modes so that during the collaborative experiences students have the opportunities to practice, before they submit their answers to the test database (required submission before the next class period).

The conceptual iPod Apps work a bit differently, but their user interfaces are similar. In these applications, the students are given multiple answers to choose from in their work session. The incorrect answers are composed of known misperceptions and known logic errors (see Figure 8). The Tune-Up questions in the web apps operate like flash cards since the students are reviewing knowledge only (Figure 9).

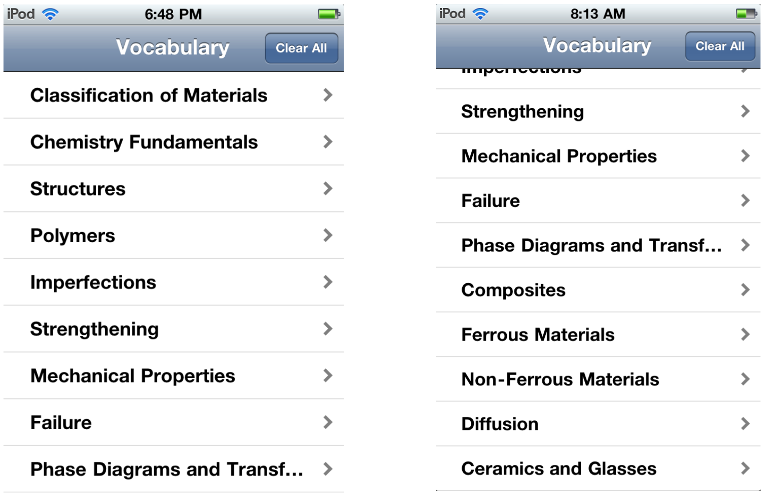
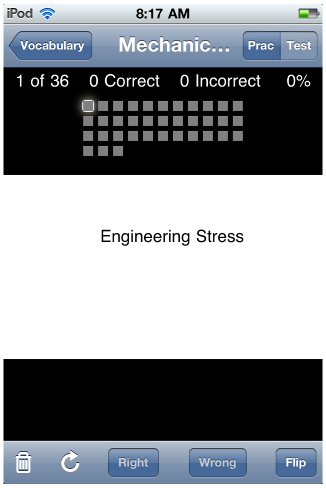


Figure 1. Apps Arranged by Ordered Conceptual Topics

Ceramics and Glasses
Chemistry Fundamentals
Classification of Materials
Composites
Diffusion
Failure
Ferrous Materials
Imperfections
Mechanical Properties
Non-Ferrous Materials
Phase Diagrams and Transformations
Polymers
Strengthening
Structures

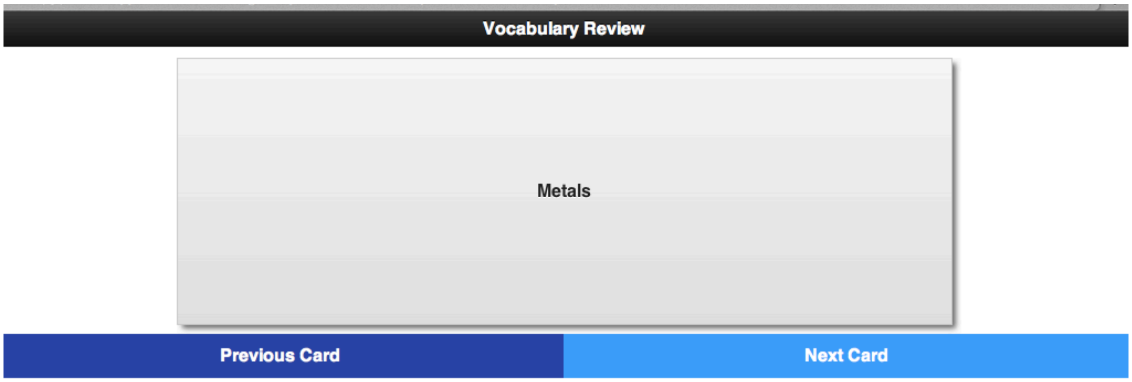
Figure 2. Website Arranged by Alpha Conceptual Topics



1 of 36 0 Correct 0 Incorrect 0%

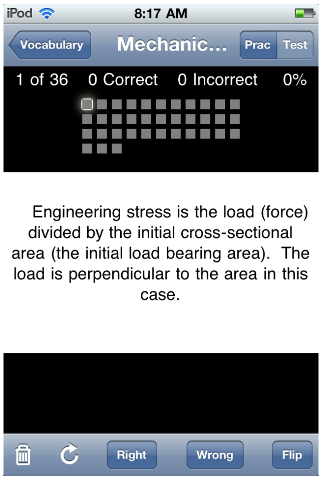
Engineering Stress

Figure 3. Smart App Card Vocabulary Card



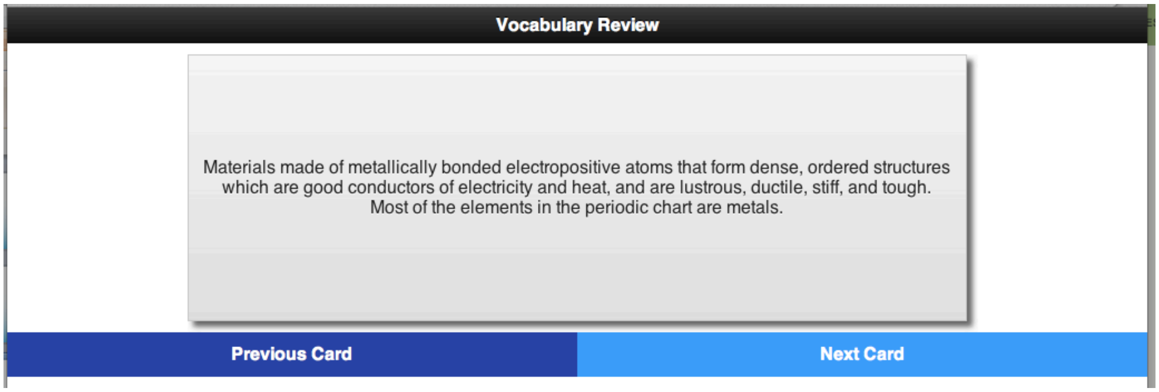
Metals

Figure 4. Web App Vocabulary Card



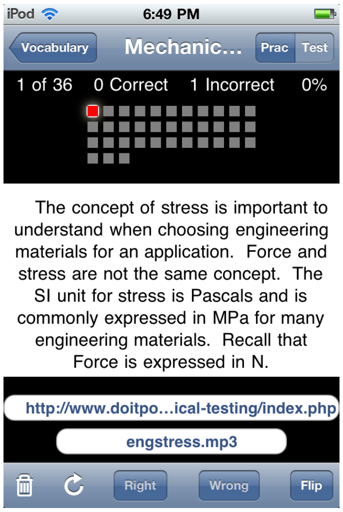
Engineering stress is the load (force) divided by the initial cross-sectional area (the initial load bearing area). The load is perpendicular to the area in this case.

Figure 5. App Correct Answer, User Interface



Materials made of metallically bonded electropositive atoms that form dense, ordered structures which are good conductors of electricity and heat, and are lustrous, ductile, stiff, and tough. Most of the elements in the periodic chart are metals.

Figure 6. Correct Answers Only in Web App

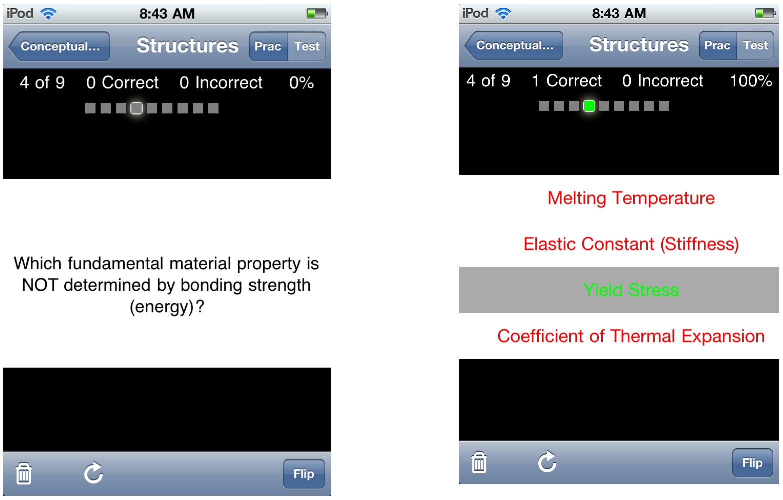


The concept of stress is important to understand when choosing engineering materials for an application. Force and stress are not the same concept. The SI unit for stress is Pascals and is commonly expressed in MPa for many engineering materials. Recall that Force is expressed in N.

http://www.doitpo…ical-testing/index.php

engstress.mp3

Figure 7. iPod App Only - Additional Help for Incorrect Answers



Which fundamental material property is NOT determined by bonding strength (energy)?

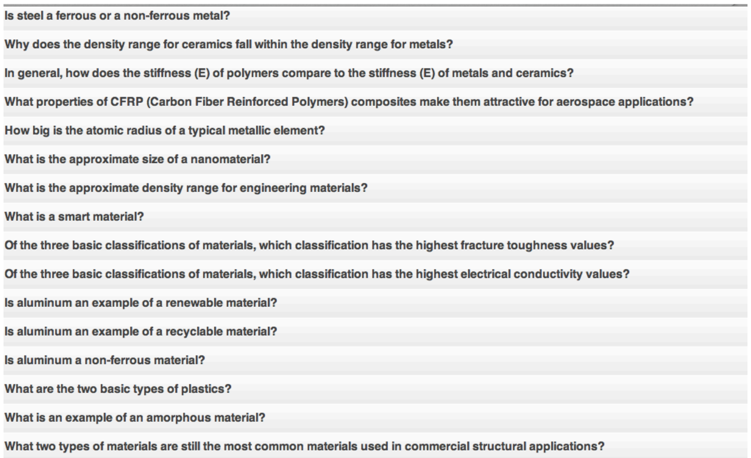
Melting Temperature

Elastic Constant (Stiffness)

Yield Stress

Coefficient of Thermal Expansion

Figure 8. Conceptual Type Questions Work Differently



Is steel a ferrous or a non-ferrous metal?

Why does the density range for ceramics fall within the density range for metals?

In general, how does the stiffness (E) of polymers compare to the stiffness (E) of metals and ceramics?

What properties of CFRP (Carbon Fiber Reinforced Polymers) composites make them attractive for aerospace applications?

How big is the atomic radius of a typical metallic element?

What is the approximate size of a nanomaterial?

What is the approximate density range for engineering materials?

What is a smart material?

Of the three basic classifications of materials, which classification has the highest fracture toughness values?

Of the three basic classifications of materials, which classification has the highest electrical conductivity values?

Is aluminum an example of a renewable material?

Is aluminum an example of a recyclable material?

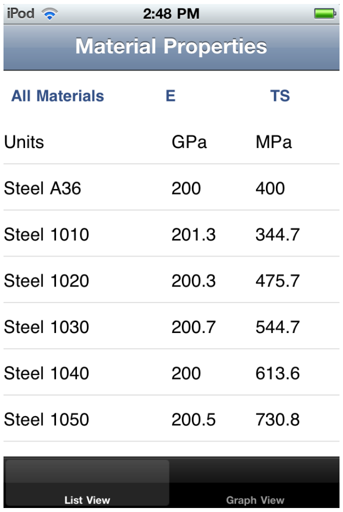
Is aluminum a non-ferrous material?

What are the two basic types of plastics?

What is an example of an amorphous material?

What two types of materials are still the most common materials used in commercial structural applications?

Figure 9. Tune Up Questions in Web Site



All Materials	E	TS
Units	GPa	MPa
Steel A36	200	400
Steel 1010	201.3	344.7
Steel 1020	200.3	475.7
Steel 1030	200.7	544.7
Steel 1040	200	613.6
Steel 1050	200.5	730.8

Figure 10. The List View of the MatProp App

The MatProp iPod App is especially useful to help the students gain conceptual understanding of material properties for different material classifications and also as the students begin working on design problems during the later part of the quarter.

Figures 10 and 11 show the basic features of the MatProp application. MatProp shows conceptually contained lists of material properties (Figure 10), as well as the ability to compare a material property of 6 different materials (Figure 11) or scatter plots of two different material properties for six different materials. The bar graph view (Figure 11) is more useful at the beginning of the term, but the scatter plot is more useful as the students begin their design work. Figures 12 and 13 show how the web app version of the MatProp program. While the user interface is different, conceptually the two operate similarly. This application is very popular with the students. During the first part of the term, the students use it to understand the conceptual differences between material categories.

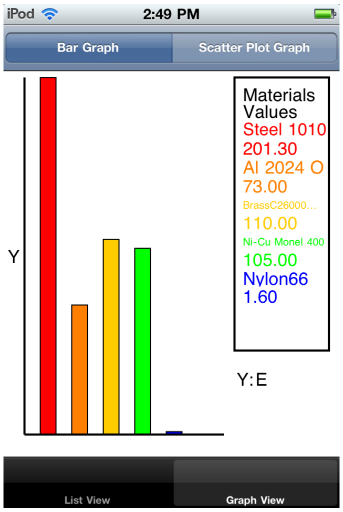


Figure 11. The Bar Graph View of the MatProp App

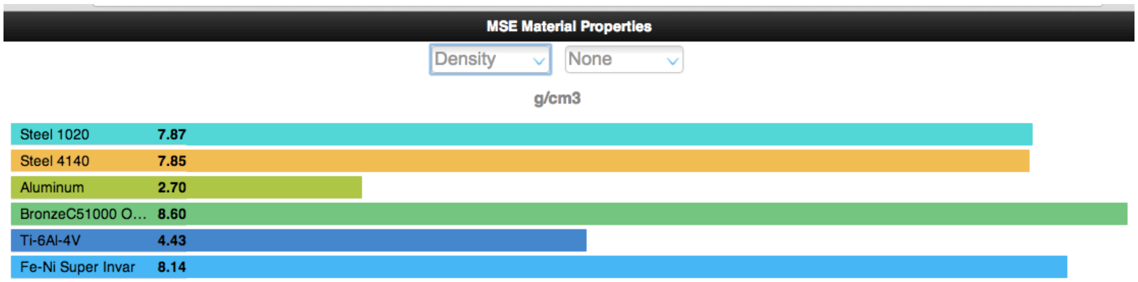


Figure 12. Web App Bar Graph Comparing One Group of Materials (Metals)

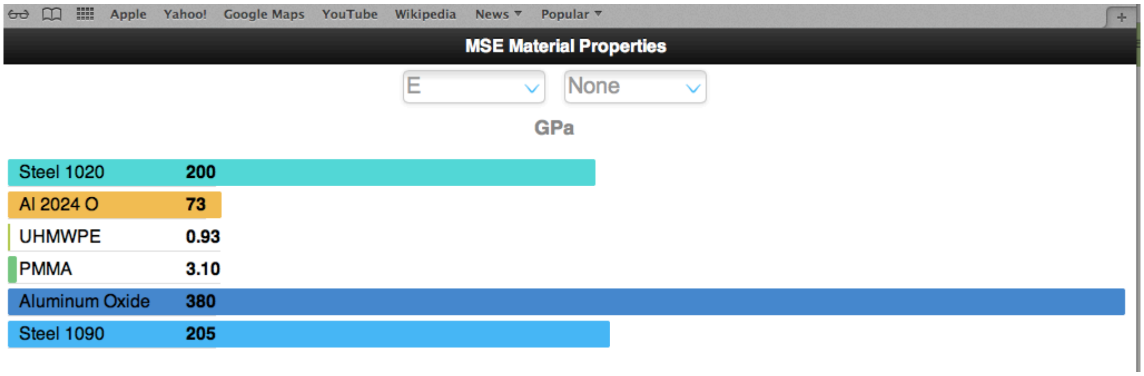


Figure 13. Web App Graph Comparing Different Groups of Materials

The MatProp iPod application also displays scatter plots of one material property on the x axis and another material property on the y axis (see Figure 14). On the other hand, the web app version will display a bar graph of one material property divided by another (see Figure 15).

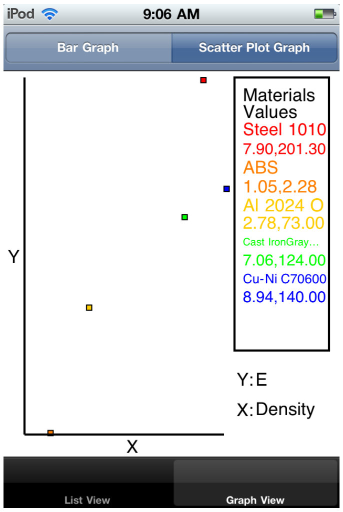


Figure 14. Scatter Plot Graph in MatProp App

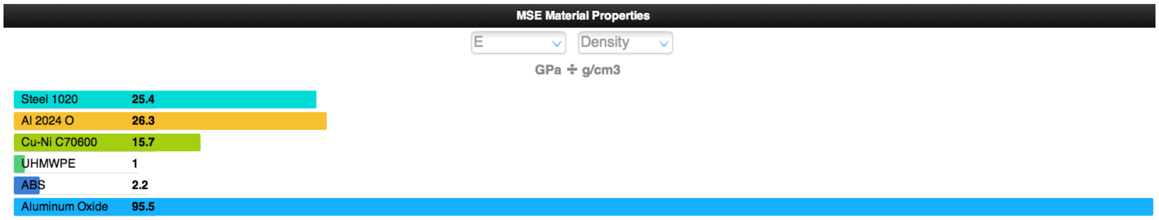
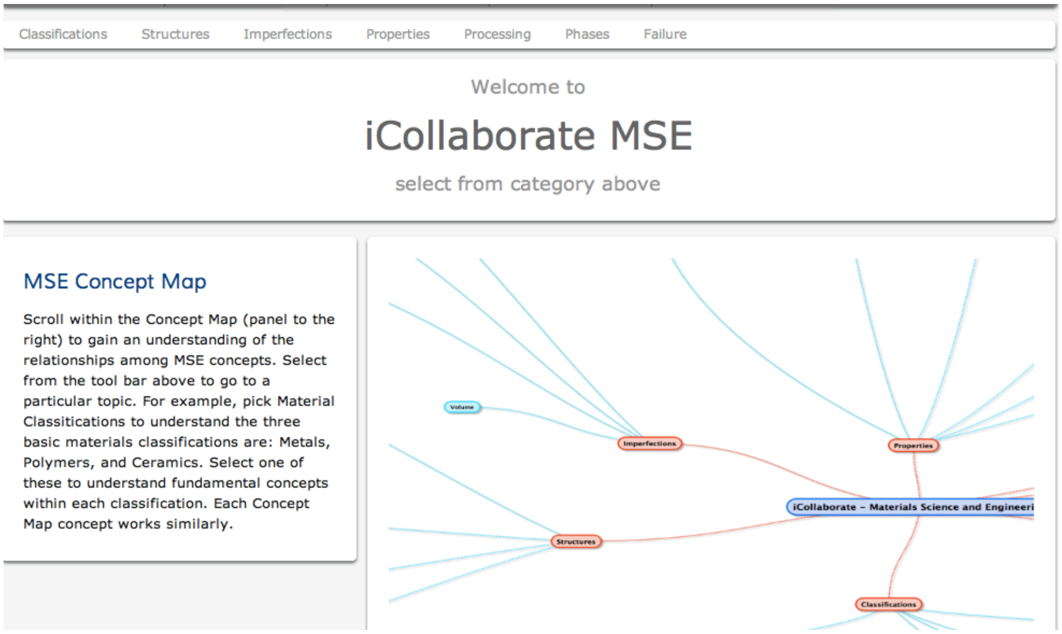


Figure 15. Bar Chart of One Material Property Divided by Another

A new feature of the iCollaborate web site is that vocabulary terms and the knowledge database are displayed conceptually using a “concept or a mind map”. The idea of using a concept map to understand the key connections between topics in a basic MSE course was based on formative feedback from the in-class students, and, more frequently, from the students actually working on the project. Figure 16 shows the basic concept outline of how the web site is designed to work. The features thus far are divided into several broad categories: Classifications, Structure, Imperfections, Properties, Processing, Phases, and Failure (see the top bar in Figure 16). There is additional room on the categories bar for three more sections, if they are needed.



Welcome to

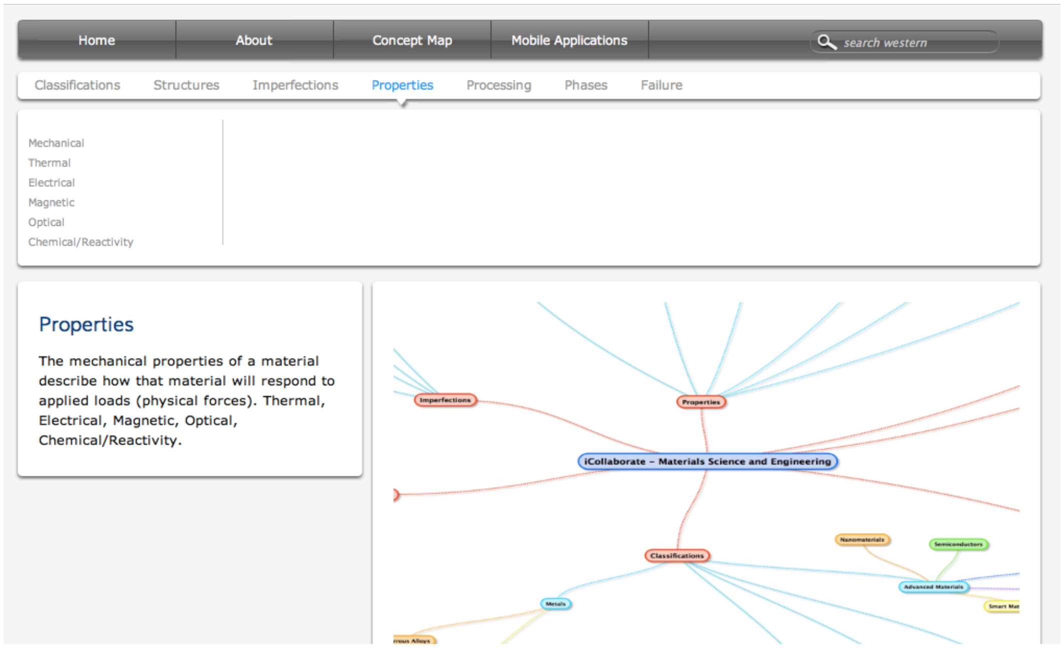
iCollaborate MSE

select from category above

MSE Concept Map

Scroll within the Concept Map (panel to the right) to gain an understanding of the relationships among MSE concepts. Select from the tool bar above to go to a particular topic. For example, pick Material Classitications to understand the three basic materials classifications are: Metals, Polymers, and Ceramics. Select one of these to understand fundamental concepts within each classification. Each Concept Map concept works similarly.

Figure 16. Basic Concept Map of iCollaborate Web Site

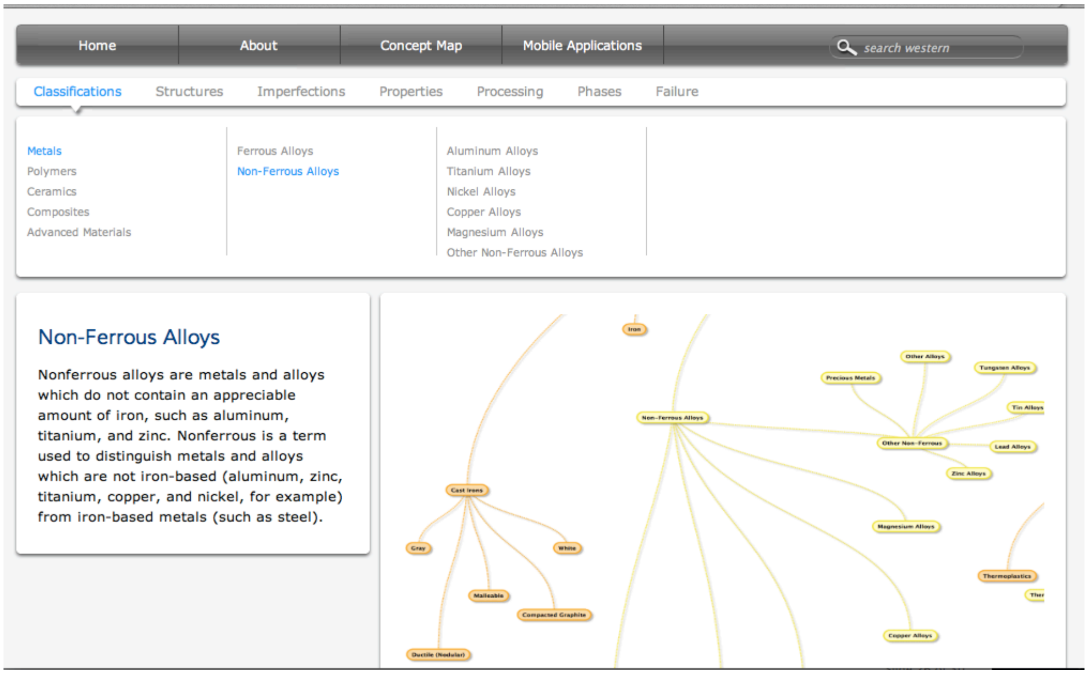


Properties

The mechanical properties of a material describe how that material will respond to applied loads (physical forces). Thermal, Electrical, Magnetic, Optical, Chemical/Reactivity.

Figure 17. Selection from Top Bar Displays Sub-Topics

Once the category is selected, the map moves to that part of the screen and an explanation of that category appears in the left hand box and the concept moves to the middle of the screen (see Figure 17). The sub-categories of available topics are then shown in the left hand box. The relationship to the other categories is shown in the top bar and the map is shown in the middle of the page (also see Figure 17). Figure 18 shows the progression of sub-topics across the top and sidebars as well as the concept map position movement. Figure 19 illustrates a complete conceptual build out sequence (plain carbon steel).



Non-Ferrous Alloys

Nonferrous alloys are metals and alloys which do not contain an appreciable amount of iron, such as aluminum, titanium, and zinc. Nonferrous is a term used to distinguish metals and alloys which are not iron-based (aluminum, zinc, titanium, copper, and nickel, for example) from iron-based metals (such as steel).

Figure 18. Sub Topics Highlighted by Broad Category (Top of Screen)

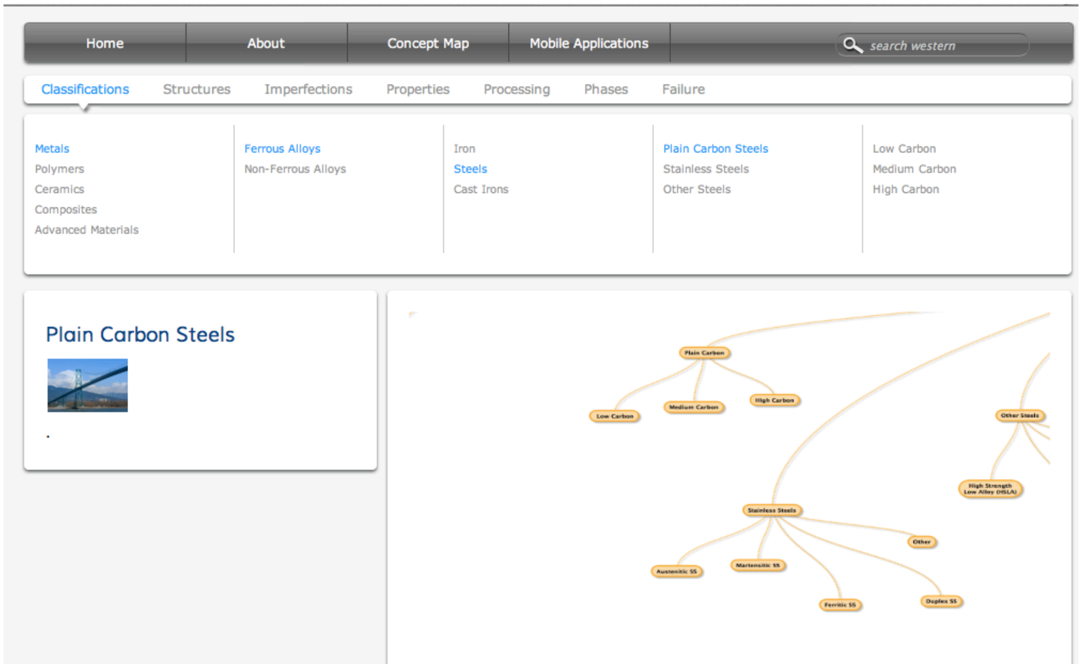


Figure 19. Example of Sub-topics Build Out Across All Categories

Overview of Feedback from Students

A detailed analysis of student feedback has been previously reported[1-5] and only an overview is given here. "Students were able to understand the relationships between the collaborative assignments, the low stakes quizzes, and the mini-lectures with just-in-time reading. Since these items have all been designed to compliment and reinforce each other, it was very positive that most students readily found the connections. And they did, more often than not, believe that their peers and the collaborative learning helped them. Not surprisingly, the students perceived that the mini-quizzes were directly related to their own personal outcomes. The feedback from the students regarding the low stakes quizzing was extremely positive with more than 90% of the students finding them of value[1]". The students are likely overvaluing the low stakes quizzes because it is so easy for them to perceive a tie between the quiz and an exam score. The students feel the quizzes encourage them to complete the collaborative work and keep up in class. And their team members insist they do as well. The students are right in that completing the collaborative work is necessary to do well on the quizzes, but the quiz is designed to provide the individual accountability and mastery. However, our work showed that having any two of the three main interventions available (mini-quizzing, collaborative learning, and the iPod Apps) improved student outcomes and course completion rates.

One consistent complaint from the students was about the course structure in that it is only loosely correlated with the assigned textbook. Students are assigned chapters for just-in-time reading in the text, but the problem sets, Apps, and modules deliberately take a much different approach to learning than the text does (by design). Our active, collaborative modules and Apps took years to develop from what we (and others) uncovered about robust MSE misconceptions and local knowledge gaps. And those modules were designed around concepts very different than traditional homework problems. Since the collection of our modules, iPod Apps, web applications, and web site does not yet contain information comparable to a textbook, we felt the text was an essential tool for the course. At some point in the future, perhaps enough open access material will be available to make this issue non-existent.

When compared to a totally deductive approach, successful course completion rates have improved by approximately 10-12% (depending on the term), but students enter and exit the course at about the same rates during the first week of the quarter using either the deductive or inductive approach. We speculate this is because some students prefer traditional instruction course methods, while others are excited by the prospect of more active learning and participating in instructional explorations. The overall top and next tier scores in the class remained flat. The top students very much engaged in the collaborative learning experiences and iPod App modules, and their check out rates of individual devices was very high. Their mastery scores did not change significantly in the course material, but their engagement was very different. Top students participated in most every class and every module. Results were flat for the next tier students and their participation rate was unchanged. These students had enough resources to do relatively well in the class (B range) and did not seek out additional time on the devices. However, the student engagement was much different for the students who had traditionally struggled with the class or dropped out near the end of the term. The struggling students checked out individual iPods at a rate as high as the top students and actively participated in the collaborative experiences. In other words, this group of students became engaged in their own learning and their success rates improved. These students did not give up on difficult design problems; instead, they persisted until their group had reasonable solutions. Successful completion rates rose and drop-rates near the end of the term declined.

No teaching and learning system is perfect. When all three interventions in the course are present, formative feedback from the students told us that there were too many resources and too many different activities the students could complete. The top students were frustrated because, being top students, they wanted to complete every single activity more than once for mastery. The struggling students sometimes do not understand how to choose modules and review sessions to optimize their learning. The mid-tier students merely complain. Based on our research results on student learning outcomes and course completion rates, we conclude that providing any two of the three interventions plus a live instructor produces approximately equally good results.

With regard to particular student learning outcomes, some individual questions on the two traditional mid-term exams and the final exam showed remarkable improvements. Of course, these problematic areas were also targeted for attention, so improvements should be expected. The collaborative work combined with the MatProp App improved the ability of the students to rank order material properties by classification, especially density, elastic constant, tensile strength, and coefficient of thermal expansion. Improvements were also made in the conceptual understanding of specific tensile strength and specific elastic constant. Results also showed it was possible to successfully reconstruct most of the students misconceptions regarding metallic bonding, although in no instance did 90-100% of the students answer the question correctly on the final exam. While this is a substantial improvement over previous results, it is disappointing that a topic covered so many times, in so many different ways, with so many exercises, was not enough to overpower the pre-course misperceptions about ionic and covalent bonds for these few students. This was especially true for ET and IT students. Disappointingly, scores on the open-ended design problem remained relatively flat on the first mid-term. Scores did improve on the final design problem. And collaboratively completed term research papers showed considerable conceptual improvement.

Conclusions and Future Work

The iCollaborate MSE project has been a remarkable project of building MSE resources and diving deeply into how to assist student learning of MSE concepts. All of the iPod Apps that we have promised to build have been built and demonstrated on test devices. The web site to accompany the project is being built and its primary purpose changed as a result of formative student feedback. While no other smart device platforms are being developed, the web app platform on key iPod Apps will enhance our dissemination efforts. And the concept map on the web site should help students construct connections between important terms and concepts. An extension of the iCollaborate project would be to revise the iPod Apps to understand how the students use the iPods in their own learning. Google Analytics has been built into the web site for this purpose. Another additional project would be to use the iCollaborate methodology in totally on-line versions of the course, but considerable development work would be necessary.

It is clear that student engagement is certainly enhanced in our course, as are successful course completion rates, and that the students are interested in providing good formative feedback for the project. Overall, the students find the low stakes quizzes, with just-in-time reading, and the collaborative modules most valuable in enhancing their understanding of course concepts. If our interventions were grouped into three large categories of active, collaborative learning modules, mini quizzes with just-in-time reading, and ICT activity modules, we found that any two of the three (with a live instructor) produced improvements in student learning outcomes, completion rates, and student engagement. The addition of the third element did not greatly improve overall outcomes and, at times, overloaded the students with too many resources from which to choose. Students who traditionally struggled with the course have benefited the most overall from the iCollaborate teaching and learning system. Many, but not all, targeted student learning outcomes have been improved. Overall, our novel multi-faceted approach to inductive teaching and learning appears promising and our research is working toward understanding how best to improve student learning outcomes, engagement, and successful course completion rates in introductory MSE courses. Development work on the concept mapped based web site will continue during this academic year.

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