AC 2007-787: PAUL REVERE IN THE SCIENCE LAB: INTEGRATING HUMANITIES AND ENGINEERING PEDAGOGIES TO DEVELOP SKILLS IN CONTEXTUAL UNDERSTANDING AND SELF-DIRECTED LEARNING

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Paul Revere in the Science Lab: Integrating Humanities and Engineering Pedagogies to Develop Skills in Contextual Understanding and Self-Directed Learning

Abstract

ABET, ASEE, and the wider engineering community have long acknowledged the potential benefits of interdisciplinary education, including the opportunity to develop non-technical skills such as communication and teamwork while cultivating a broader awareness of the ethical, societal, historical, and environmental impacts of engineering work. Instructors have encountered many challenges in planning and implementing integrated courses, such as the difficulty of coordinating the teaching methods, content, and learning objectives of different academic disciplines in a finite and already overcrowded curriculum. This paper presents the goals, design approach, implementation, and selected outcomes of one integrated project-based course (using Paul Revere and other case studies to integrate materials science with the history of technology) and uses it to discuss the advantages of disciplinary integration, particularly with respect to improved student self-direction and contextual understanding. Assessments administered during and after class suggest that this integrated course successfully engendered high student motivation along with an increase in student aptitudes over the course of the semester without a corresponding loss of discipline-specific knowledge. The implementation of this integrated course and the evaluation of its outcomes are works in progress, and future assessments are being designed to shed additional light upon these issues.

Introduction

In recent years, the broader engineering community as well as individuals and departments around the country have affirmed the importance of modernizing and updating engineering pedagogy in many ways, including the application of self- (or student-) directed learning approaches (i.e., activities that help students to gather and evaluate information, set educational goals, and plan and execute activities that help them achieve these goals) as well as the integration of broader social, historical, ethical, environmental, or other context into technical projects and topics. Authors Martello and Stolk initiated this study as a first step towards understanding these educational approaches and implementing them in a customized interdisciplinary activity. Beginning in 2003, the authors initiated a double-sized integrated course block titled Paul Revere: Tough as Nails that combines an introductory materials science course with a history of technology course, allowing students to work on engineering projects with broader implications than the purely technical. This course takes place at the Franklin W. Olin College of Engineering, a relatively new undergraduate college located in Needham, Massachusetts, whose small student body consists solely of engineers. To date the instructors have taught this course twice, with a third offering in progress in spring of 2007. The authors have begun some assessments of this integrated course, but as this project is still ongoing these assessments are not comprehensive. This paper represents a first step in understanding these issues in this particular science and humanities setting, and investigates the connections between self-directed context-rich learning experiences, student attitudes, and broad competency development.

Self-directed learning and integration of context

Technical savvy alone will not enable individuals to identify opportunities and solve complex problems in the global society of the 21st century. The National Science Foundation and other groups within the technical community have called for systemic changes in engineering education that include a shift to integrated and multidisciplinary approaches; an emphasis on understanding of societal impacts of engineering; increased teaming skills, including collaborative, active learning; and an improved capacity for life-long, self-directed learning.[1,2,3] This study focuses upon two of the critical skills listed above: self-directed learning and contextual understanding.

Calls for educational reform emphasize the need for new student-centered learning approaches that aid development of broader skills and attitudes to complement traditional knowledge acquisition.[1,2] A capacity for self-direction and life-long learning is often identified as a critical outcome for educational systems, and many assert that a self-directed learning approach best facilitates understanding.[4] ABET and other organizations ask educators to promote the development of students' life-long learning skills through their curricula.[3,5]

Most experts define self-directed learners as motivated, independent, and responsible students who are able to gather, organize, and critically evaluate information.[6] Most engineering educators agree that these skills are important – even essential – for success in today's technology-centered environments with their ever expanding information bases. To effectively promote self-directed learning, faculty need to develop skill in implementing and facilitating pedagogies that effectively engage students in self-direction; a sensitivity to and understanding of student behaviors in self-directed settings; and knowledge of the roles projects and integration can play in student self-direction.

One solution to the issue of student engagement in learning may lie in the design of active, student-centered learning environments such as problem- and project-based learning that emphasize inquiry, problem-solving, broader context, and student control of the learning process. Student self-direction is generally considered an essential component of the problem- and project-based learning approaches that are increasingly implemented in undergraduate technical curricula. Recent analyses comparing students in problem-based and traditional lecture courses indicate that students in self-directed environments generally perform at an equal or higher level on content acquisition examinations, and that their broader skills improve as a result of problem-based approaches.[7],[8] Although there is general agreement that self-directed learning can provide benefits in broader skill development, many engineering faculty identify losses in content acquisition as a possible downfall of student-directed approaches.[9,10,11,12] Perrenet et al. state that problem-based learning "may not always lead to constructing the 'right' knowledge," and some suggest that direction of content through lectures is required to ensure complete subject coverage, good student decision-making, and proper development of students' metacognitive skills.[13,14]

Student attitudes toward the self-directed learning environment are critically important. Many students in self-directed settings cite high frustration levels, a lower perception of acquired knowledge, and concerns that they are not learning the "right stuff."[10,15,16] This student discomfort is understandable. In transitioning from a traditional to a self-directed learning mode, students need to embrace unfamiliar roles, responsibilities, and behaviors. Although frustration and dissatisfaction tend to decrease with time,[10] these responses are not always easy to overcome and may have significant effects on the classroom social environment and on student learning. Faculty development of an understanding of the causes of student attitudes and skills in appropriately responding to students are vital to the fostering of self-directed learners.

A second vital set of skills, repeatedly flagged by both ABET and the larger engineering community, relates to a student's ability to identify and relate to the many contextual factors that shape both the creative process and the societal reception of completed technologies.[1,5] A technical education can emphasize contextual understanding in many ways, including the integration of arts, humanities, and social science perspectives as well as the specific study of ethical, societal, historical, or environmental impacts of engineering work within technical courses.

Many schools have developed integrated course approaches in an attempt to address calls for reform in engineering education.[17] In principle, integrated curricular components should result in many advantages, including improved learning due to the increased stimulation of cognitive structures, avoidance of unproductive repetition, synchronization and linkage of related subjects, improved interdisciplinary thinking, and greater opportunities for teaming skill development. Assessment data suggest that integrated technical curricula result in improved student learning, deeper understandings, better student performance throughout the curriculum, higher retention, and greater appeal to underrepresented groups.[18,19,20,21,22,23,24] While integration appears to benefit student learning and retention, some students complain that integrated schemes driven by the grouping of related technical content do not always place disciplinary knowledge in context.[25,26]

One possible solution to the lack of context in integrated technical curricula is the explicit integration of humanities and social science topics. Calls for engineering education reform clearly identify the need for increased consideration of social, economic, political, and environmental factors.[1,2,27] Atman and Nair report that first-year engineering students have weak conceptual frameworks on science, technology, and society issues;[28] and Vanderburg and Kahn express deep concern over the lack of context in engineering curricula.[29] Several schools have implemented integrative courses or course blocks that build important connections among technical and non-technical topics and that develop an understanding of the significance of context on technology,[30,31,32,33] but the effects of the content integration are not entirely clear. Some literature reports that students in integrated courses often fail to make connections between technical and liberal arts topics,[34] while other reports cite an increased student interest in broader contexts, an enhanced awareness of humanistic considerations in engineering, and improved skill development in writing and critical thinking.[35,36,37] Despite promising reports from those involved in delivering and assessing integrated technical curricula, careful measures of the effects of technical-humanities integration on student learning and attitudes are lacking, and important questions remain.

Integrated course block: Paul Revere enters the science lab

Paul Revere is a project-based course that employs new pedagogies and laboratory facilities to test the effectiveness of different educational approaches and assessment mechanisms. The current incarnation of the course is completely integrated, i.e., students only encounter a single set of assignments and learning objectives that apply to both the history of technology and the materials science halves of the course, and students may not take one component without the other. Team-based projects encourage students to develop experiential understanding of both technical and humanities/social science content and methods, control their learning in a self-directed manner, and develop life-long learning skills in the process. The open-ended projects let students directly apply fundamental materials science theory, use historical context to plan and shape project goals, apply analytical processes in self-designed experiments, learn through practical experiences, discover the similarities in the goals and standards of history and materials science research, and develop strong written, oral, and graphical communication skills. A high level of self-direction of content acquisition enables students to master the course objectives while making them more aware of their own learning styles.

The title and central project component of this course block relate to Paul Revere, the well-known patriot and subject of Martello's ongoing research. Revere's greatest contribution to American history may have been his silver working, iron casting, bronze bell and cannon casting, malleable copper working, and copper sheet rolling endeavors. Revere's records detail these metalworking activities and their connections to historical context while leaving many questions unanswered. This offers a valuable backdrop for interdisciplinary projects, because materials science students can use their growing knowledge of material properties, microstructures, fabrication methods, and analytical techniques to reproduce some of Revere's work, examine the efficiency of his processes, and answer questions he was unable to frame.

The course focus is broadened through additional course phases with distinct emphases. The course begins by connecting the material culture of ancient societies in the copper, bronze, and iron ages to materials science techniques pertaining to material structure and properties. After the Paul Revere module in the middle of the course, students conclude with a study of modern materials techniques and their social and environmental contexts. Identification of linkages between the historical and materials science concepts in each phase is paramount to successful implementation of the *Paul Revere* course.[16,38] All aspects of the *Paul Revere* integrated course block have been designed to provide students with self-directed interdisciplinary project experiences (Figure 1). Historical and materials science content is tightly synchronized, and students are given primary responsibility for the planning and management of projects and the guiding of classroom discussions. Projects culminate in physical deliverables and written reports or posters that are co-evaluated by the faculty team.

Project Theme and Allotted Time	Materials Science Goals and Objectives	History of Technology Goals and Objectives
1. Analysis of a Common Object 4 weeks	• Develop basic laboratory and experimental design skills • Collect and analyze data on composition, structure, properties • Explain connections among material properties, composition, structure and bonding • Identify characteristics of materials that make them suitable for use in products • Develop graphical and visual communication skills	***+ Contextual Analysis of the Common Object*** • Research and analyze the social context of a modern material artifact, emphasizing ethical, environmental, political, and cultural influences and impacts • Research a historical counterpart to a modern item and explore its context as well • Connect historical and technical analysis and evidence • Develop written communication skills

2. Microstructure-Processing-Property Connections 5 weeks	• Design and implement experiments to investigate a question related to microstructure-processing-property relationships in a material system • Collect and evaluate experimental data on microstructure, properties, and processing, and compare to theory • Examine applications of an alloy system, and research modern alloys and processing techniques • Develop oral, written, and graphical communication skills	***+ Paul Revere Theme for Materials & Processes*** • Identify a problem or question relevant to the metalworking career of Paul Revere • Research the larger historical context of this question • Propose a thesis statement and support it with logical argument and relevant technical and historical evidence • Develop oral, written, and graphical communication skills
3. Modern Materials and Methods 3 weeks	• Design and implement an experimental procedure for analysis of a modern material, component, or process • Identify information resources for the project investigation • Articulate structure-processing-service environment-property relationships in modern materials systems • Evaluate materials in technical applications; identify relationships between materials selection and design • Develop communication skills	***+ Contextual Analysis of Modern Material or Process*** • Study and summarize the relevant history of a modern materials technology • Propose a thesis statement relating to cultural, political, environmental, or societal context and support it with logical argument and relevant technical and historical evidence • Develop oral and written communication skills

Figure 1. Materials science and history of technology goals and objectives.

Olin College also offers a "stand-alone" materials science course that is often taught by Stolk, one of the co-instructors of *Paul Revere.* The following analysis uses this stand-alone course as a point of comparison for the *Paul Revere* integrated course, to help understand the potential impacts of an integrated approach. Both the stand-alone and the integrated courses intentionally incorporate features known to promote creative thinking and engage students in the learning process, and the fact that the same instructor is involved in both courses helps ensure a consistent set of learning objectives and pedagogical style between the two.

Based on the educational literature, we hypothesized that the design of the *Paul Revere* integrated course block would offer several benefits over the non-integrated materials science course, and the First, we believed that the integration of broader contexts would markedly improve student attitudes (e.g., motivation, interest, engagement) toward the learning environment and their learning experience. Second, we believed that the strong contextual framework and the coupling of history and materials science goals in *Paul Revere* would improve students' development of their technical knowledge and skills. Third, we believed that the integrated course block would help students better develop broad and transferable skills such as communication, teamwork, and capacity for life-long learning. The information gathered through our previous course implementations, combined with literature research and data collected in ongoing efforts to examine student responses to self-directed learning environments, has enabled us to identify interesting student behaviors related to attitudes and learning outcomes, and to highlight important issues warranting further investigation. Lessons learned and ongoing efforts in the areas of student attitudes, student competency development, and student self-perceptions of learning are described below.

Preliminary assessment

The results presented in this paper represent data from the fall 2004 *Paul Revere* course block (N=18) and the fall 2004 stand-alone materials science course (N=14). Students in both the *Paul Revere* course block and the stand-alone materials science course are introductory-level courses that Olin College engineering students typically complete during their sophomore year. Enrollment in each course generally includes students from all three Olin College degree programs: Engineering, Mechanical Engineering, and Electrical and Computer Engineering.

The *Paul Revere* course block offerings were not initially designed as formal educational experiments, but rather as prototypes of an interdisciplinary, tightly integrated, undergraduate course block in a new engineering college setting. As such, our preliminary assessment data are limited to (i) student attitudinal responses to the Olin College course evaluation survey items, (ii) student self-perceptions of learning objectives attainment, (iii) student self-assessment of teaming competency, and (iv) instructor assessment of student competency development as demonstrated in the major course assignments. Although these preliminary data are limited, they do highlight several trends and issues that warrant further investigation and more in-depth analyses.

Student attitudes: motivation and interest

Maintaining student engagement is critical for achievement of learning outcomes, particularly in environments that place responsibility for learning on the students. Only through effective intellectual stimulation and strong engagement throughout the course will students actively pursue deep learning in an unfamiliar and nontraditional educational structure. Problem- and project-based learning environments that emphasize self-direction have traditionally shown benefits in student motivation levels. Interest levels tend to be high when students feel control over their learning,[39,40] when students consider the problems they study authentic and relevant to their personal needs, and when students are engaged in the hands-on use of tools and artifacts. The creation of a "classroom community" in collaborative, team-based settings is also believed to contribute to student motivation.

Written reactions to the integrated course block indicated student recognition of the high levels of freedom and control, an appreciation for the hands-on projects, and a sparking of student creativity and interest. The following student quotations from the *Paul Revere* course evaluations provide a sense of these positive responses.

> I really enjoyed this class. The projects gave me a lot of room to explore and try out things which were interesting to me - and those are the things I learned the most about. I think the Part I project was a great way to get a running start and learn the machines in the lab. There was certainly a lot of freedom in choosing project topics.
>
> …projects offered enough flexibility for the students to learn about subjects they wished but well enough constrained to keep them on topic.
>
> We were able to go off in our groups and explore an aspect of what we were learning in depth, focusing on what was interesting to us.
>
> I am still in shock when I think about how much I've learned this semester. You've opened the floodgates of my imagination and curiosity for materials, something I never thought would happen.
>
> The nicest thing about the projects was their variety: I wrote an integrated history paper, made a poster and wrote an illustrated children's book all to explain the materials science I was learning. This was one of the most do-learn classes I've had at [the

institution], and consequently, one of the best.

[the instructor] is understanding and flexible when it comes to assignments, allowing for creative options.

Course survey data collected by the authors indicate that both the stand-alone materials science course and the integrated *Paul Revere* course effectively stimulate student interest and help students think creatively about the subject (Figure 2). Although student responses to the motivation-related survey items are high for both courses, data collected to date indicate that students in *Paul Revere* show stronger positive responses. The next questions involve a determination of the statistical significance of these responses (i.e., how relevant is the integrated course's increase in self-assessed student motivation) and a determination of the factors responsible for the high level of motivation. This will require experimentation, data collection, and additional analysis in future offerings of the courses beginning in spring 2007.

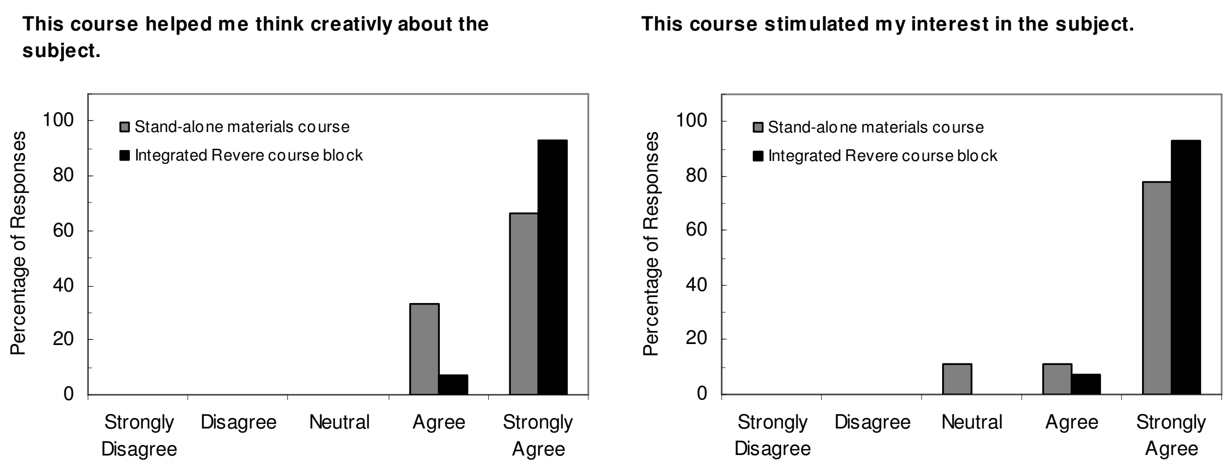

Figure 2. Student survey responses regarding interest stimulation and creative thinking

Student competency development and technical capabilities

Project-based, integrated, self-directed learning experiences have the potential to aid students' development of broad and transferable skills. We use Olin College's competency assessment system to address assessment needs of new learning approaches and deal with the shortcomings of traditional assessment methods.[41,42,43] The competency grading system centers on nine learning outcomes directly tied to the institutional mission and program goals: qualitative analysis, quantitative analysis, diagnosis, design, teamwork, communication, contextual understanding, opportunity assessment, and lifelong learning. These competencies are shared among all courses and other student activities (e.g., summer internships, research). Assessment of the competencies allows for tracking of student progress and needs in many areas of their educational development.

All learning outcome assessments in the *Paul Revere* course and the stand-alone materials science course are based on the competency assessment system and designed with project open-endedness in mind. For each major assignment, we provide students with detailed feedback and a grade assessing their progress in the communication (oral, written, graphical, and visual), contextual understanding, quantitative analysis, qualitative analysis, and diagnosis competencies. Teaming skills are assessed through peer- and self-evaluation, and students assess their development of life-long learning skills through reflective essays. Course letter grades are computed as a weighted average of the individual competency grades. The thread of competency assessments provides students with valuable information concerning their development of nontraditional skills that they could use to further their learning by identifying and reacting to their specific strengths and shortcomings. The emphasis on the formative feedback provided through the instructors' competency assessments is illustrated in the following student quotations.

> One particular thing that sticks out for me is your grading. Rather than saying, "You're a smart guy, this is a pretty good paper, I'll write the letter A on it and hand it back," you take the time to go through students' deliverables line by line, all the way down to syntax. While some may receive that as overly critical, it was the most helpful feedback I have gotten from a teacher in a long time.

> [the instructor] gives a lot of feedback on assignments, allowing for students to greatly improve from one piece of work to the next.

We believe interdisciplinary integration offers benefits in student learning of nontraditional competencies such as communication and teamwork without sacrificing the more traditional learning objectives found in technical courses (e.g., quantitative analysis and diagnosis). Although the *Paul Revere* course block design was based on certain hypotheses about student learning and attitudes, the first two offerings of the integrated experience were more exploratory prototypes than formal educational experiments. As a result, the competency development evidence and observations presented here are somewhat retrospective, and further assessment based on these preliminary findings are required to verify or refute our hypotheses. Nonetheless, the preliminary data are sufficiently promising to warrant further investigation and deeper probing of pertinent issues.

Scores for the instructor-assessed student development in the qualitative analysis, quantitative analysis, diagnosis, and technical communication competencies were calculated at the end of the semester. Independent groups t-tests were performed to compare the mean scores between the integrated course block ($N = 18$) and the non-integrated materials science course ($N = 14$). Mean grades in the quantitative analysis, qualitative analysis, diagnosis, and communication competency areas were consistently higher in the *Paul Revere* integrated course block than in the non-integrated materials course, but the higher means were not statistically significant with an alpha of 0.05. It is possible that the statistical insignificance in many competency areas may be attributable to the small class size. Additional assessments in future courses may reveal that the interdisciplinary integration does offer significant benefits in the development of these key competencies, but strong conclusions regarding positive benefits of integration on our students' technical skill development cannot be made at this time.

The interdisciplinary integration did benefit students' development of the teaming competency.

Teamwork skills were self-assessed and peer-assessed through teaming evaluation surveys administered at the end of each project. In the teaming evaluations, students provided a numerical rating for themselves and their teammates, and they wrote self-reflective comments on teaming-related lessons learned during their project experience. The instructor collected the teaming evaluations and provided summary comments to individual students. The end-of-semester teaming competency grades for the integrated course block ($M = 92.9$, $SD = 4.2$) were statistically significantly higher than those in the non-integrated course ($M = 87.4$, $SD = 6.7$), $t(30) = 2.86$, $p = 0.004$.

This positive outcome in teaming may reflect the integrated course's pedagogy and logistics. It has long been known that social environment – and more specifically, social context, social process, and social interactions, can play a vital role in learning. Peer discourse and feedback, activities that are dictated at least to some extent by the pedagogical approaches and classroom environment, are essential for effective construction of knowledge and individual understanding.[44] The effectiveness of collaborative learning seems inextricably linked to each team member's ability to communicate and conduct himself or herself effectively within the group. Faculty-student interaction and student-student interaction have been identified as the two most influential factors leading to a general positive educational outcome.[45] Students in the integrated course block spend approximately twice the amount of time on team-related tasks as those in the non-integrated course. In addition, the emphasis on broader context in the *Paul Revere* course provided both an added challenge and an added motivation to the project teams. *Paul Revere* student teams were required to work collaboratively to initiate, design, and manage project plans that were far more complex than those in the non-integrated course. Successful deployment of these project plans required a sharing of ideas, interests, and motivations that spanned multiple disciplines, and the development of a contextual framework for their project that reflected a team understanding of purpose and goals. This collaborative learning approach most certainly caused individual anxiety, discomfort, and conflict; but the additional time allocated to teaming activities may have helped teams attain better communication and more practicable management approaches by end of the semester. Teams of people who get along well and respect each other are naturally more conducive to high quality work, and small group learning advances students' ability to manage or overcome the inherent awkwardness associated with team formation.[46] Students who learn in a collaborative team environment also show an increase in perceived social support from teachers and other students. This improved social comfort aids group effectiveness, but also increases student integration, provides social incentives for attendance, improves self-esteem, and adds to students' sense of belonging.[46]

We have not yet explored the competency area of contextual understanding. We hypothesize that students develop greater contextual awareness and systems thinking, and measurably improved skills in interdisciplinary knowledge synthesis and capacity to identify and evaluate the broader impact of technology as a result of context integration in the course block. Instructor observations of students' written analyses and class discussion comments throughout the *Paul Revere* course reveal a marked improvement in students' ability to identify and connect the ethical and societal issues related to readings and their own research. For example, one student commented that, "The integrated class with MatSci was also really interesting. I learned so much about relating cultural aspects of technology to systems and to my specific research topics." A similar assessment of contextual understanding did not take place in the stand-alone course. Careful assessment of students' awareness of context and broad technological impact is critical to our understanding of the potential benefits of interdisciplinary integration on student knowledge, skill, and attitudinal development.

One issue related to students' mastery of different competencies is the overall student performance on technical examinations. As mentioned above, some educators fear that increased development of student competencies will come at the price of decreased technical capabilities. The instructors administer written exams at the end of Projects One and Two to test materials science technical knowledge and skills, and these exams merge content acquisition objectives with higher-level skills in qualitative analysis, quantitative analysis, and diagnosis. To attain success on the individual examinations, students must demonstrate that they can synthesize fundamental content knowledge and critical thinking skills, and apply these to unfamiliar situations based on real-world problems. Achievement on an identical Project One technical examination administered to students in the integrated course block (M = 78.8, SD = 7.9)and the non-integrated materials course (M = 77.4, SD = 12.4) showed insignificant differences in a t-test analysis with an alpha of 0.05. This preliminary analysis of technical performance indicates that the coupling of broader context and emphasis on historical themes does not deleteriously affect engineering student development of technical competencies and acquisition of disciplinary knowledge.

Student self-perceptions of learning

Student perception of learning outcomes is an important component of self-directed learning. Simply put, if students perceive advancements in their learning, they are much more likely to maintain high levels of motivation, build confidence in problem-solving, and continue to engage in the learning process.

Figure 3 shows the student responses to some end-of-semester survey items related to achievement of the course learning objectives. As shown in the data, most students in both the integrated course block and non-integrated course have relatively high perceptions of their learning. Students perceive their abilities in content-specific objectives (I and II) to be slightly lower than their learning in the broader areas of laboratory skills (III) and communication (IV). This result is not unexpected, as students in learning environments that emphasize self-direction tend to establish inaccurately low perceptions of their knowledge acquisition.[47]

The data indicate that students in the integrated course block have developed a higher perception of their self-efficacy. Of particular interest are the differences in the perceptions of technical communication abilities between students in the integrated and non-integrated courses. As noted earlier, many aspects of communication – analytical writing, reflective writing, technical writing, discussion, oral presentation, and graphical presentation – are emphasized in the integrated course block. Compared to the non-integrated course block, students in *Paul Revere* are provided with more opportunities to develop communication skills and more feedback from the instructors regarding their communication abilities.

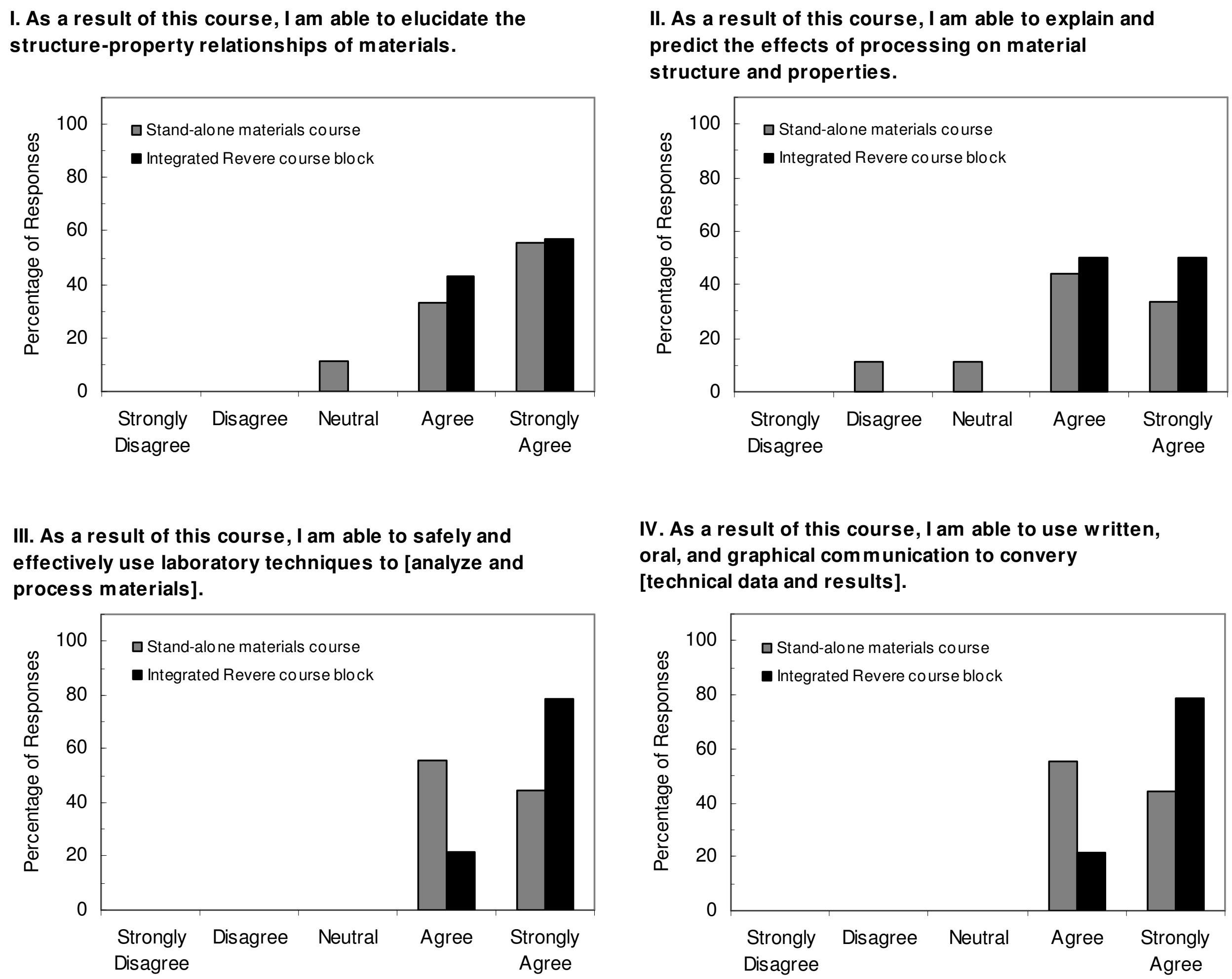

Figure 3. Student self-perceptions of learning outcomes achievement as reported on end-of-semester surveys.

Further exploration of students' development of self-efficacy in the broad and transferable skill areas such as communication is critical to our understanding of the potential benefits of interdisciplinary integration. Self-perception of ability is related to student confidence and ultimately to success in self-directed environments. As such, the factors responsible for any change in perceptions as a result of course structure should be examined and understood by learning facilitators.

Responses to self-directed learning

Self-directed learning ideally enables students to master course objectives while making them more aware of and in control of their own learning styles. In the *Paul Revere* course, students praise the student-directed, open-ended projects, but we have not closely examined the contributions of the self-directed learning approach to learning and attitudes. Self-directed knowledge acquisition remains a controversial approach that deserves close examination, as some students cite self-direction as a positive aspect of the courses while others report concerns with learning due to student control. This is discussed in more detail below.

Both the stand-alone materials course and the *Paul Revere* course place heavy emphasis on student self-direction. Students are given great freedom in selecting project topics of personal interest, setting project goals designing analytical approaches, and managing time and resources. Teams share project experiences through peer instruction sessions and informal class discussions. Compared to the stand-alone materials course, students in the *Paul Revere* course are provided with additional opportunities for student-guided learning: student teams run portions of the history discussions by planning debates, presentations, and discussion subjects; and students develop historical research skills through the contextual analysis component of the projects.

In an attempt to better understand student responses in self-directed settings, we recently initiated a study of Olin College student attitudes and perceptions of their self-directed experiences. The survey's quantitative and qualitative portions were designed to identify and evaluate sources of student challenge, discomfort, and frustration, and to characterize the positive and negative aspects of their self-directed learning experiences. The survey was administered to the entire student body, and the response was outstanding – over two-thirds of the student body voluntarily provided numerical and written feedback.

Several themes and trends in the data have been identified. The clearest result from the written portion of the survey involved the "need to care." Over 50 percent of the respondents observed that a self-directed learning experience would almost certainly succeed if students felt an engagement with the topic (students used terms such as motivation, interest, passion, and excitement to clarify this concept), and the learning experience would probably fail if students failed to find this connection. Women generally expressed a stronger "need to care" in self-directed environments than men.

Survey respondents volunteered several potential weaknesses in self-directed settings. Approximately 50 percent of students cited problems associated with self-regulation, typically a struggle with time management, as a negative aspect of self-directed learning. Similarly, over 40 percent of respondents identified the lack of structure and goal-setting as an issue that can negatively affect self-directed learning. In the positive direction, nearly 40 percent of students cited synthesis ability and deep understanding as a positive aspect of self-direction; and 30 percent of students reported the development of broader skills and attitudes as a positive outcome. Self-perceptions of learning and abilities – feelings that they have learned the "right stuff," developed skills, and gained understandings – were important to many students. Over 30 percent of students reported that self-direction positively affected their deep understandings, and about 15 percent of students cited concerns with content or knowledge acquisition in self-directed settings.[48]

We believe that the *Paul Revere* course provides an effective learning environment by addressing many of the themes that were identified in the self-directed learning survey. The high levels of student control and freedom of choice in projects enables students to pursue topics of personal interest. Hands-on project experiences foster students' deep understandings and development of broad skills. An emphasis on the study of technologies within a broader context highlights societal connectedness, drives student motivation, and enables multidisciplinary synthesis and application. The course structure gradually increases learner responsibility and control throughout the semester, enabling students to more comfortably transition to a self-directed learning mode.

Feedback regarding the student self-directed learning aspects of the *Paul Revere* course was generally positive. Students frequently cited their appreciation for the open-endedness of the projects and the ability to select project topics of personal interest. Students felt that the course block helped prepare them for self-directed learning and embracing of new challenges and uncertainties. Examples of positive student feedback regarding self-directed learning in the integrated course block are provided below.

> This course consisted of three large, self-directed projects that were intended to guide our learning. It worked. Really well. I honestly feel that I can do everything described in the course objectives, and much more, and I will still be able to do so many years from now.
>
> The self-guided approach worked really well… when other resources failed, [the instructor] gave us lectures on the tricky bits. Because *everything* was applied, we could make connections with other areas and really understand the subject. If I saw something like this implemented in every other course, I would be very happy…

Students in the integrated course block also recognized the challenges associated with freedom and control. Although the positive responses far outweighed the negative, some students in the course expressed specific concerns about their learning. Nearly all of the cited concerns were linked directly to their traditional thinking about knowledge and course content. Students wanted assurance that they learned the "right stuff," and they requested that more lectures be introduced into the materials science course plan. The high level of student responsibility was disconcerting to some individuals, as indicated in the following student quotations.

> Project based learning - lots of effective application, but a bit of a lack of knowledge that didn't specifically apply to your project. A little more lecture time would have helped with this.
>
> If anything, I feel that the class may have been too unstructured at times. If you can define a sort of MatSci core, certain things that you want everyone to come away with, then periodic lectures on that material would be helpful. Especially at times like the Part II and III projects, where people are working on specialized subjects, it would be good to lay down a fundamental knowledge base.
>
> This class was very project-based. I feel that there could have been more time for lectures to make sure that we were learning the right things and drawing the right conclusions from our projects, but overall this method was VERY effective.

Future studies and work in progress

It is obvious that there is still much work to be done in advancing our understanding of the roles of integration of context and self-direction on student learning and attitudes. It is clear that the development of technical competencies such as quantitative analysis and diagnosis is not reduced as a result of the emphasis on historical context in the integrated course block, and positive effects in these areas may be revealed with additional data collection and analyses. Teaming skills are notably improved in the larger course block. Anecdotal evidence and indirect student assessments indicate that student development of certain transferable skills such as communication and contextual understanding may be improved as a result of integration. Student motivation, interest, creativity, and self-efficacy levels are higher in the integrated course block. Although we are unable to draw many strong conclusions at this time regarding benefits in student learning due to interdisciplinary integration, there are sufficient positive results and indicators to warrant further investigation.

Beginning in spring 2007, we will rigorously test the validity of these observations in both the *Paul Revere* integrated course and the stand-alone materials science course. We propose a study that focuses on the interrelationships between integration of disciplinary methods and content, and the development of self-directed learning ability and contextual understanding in engineering undergraduates. We plan to use three assessment strategies to explore these issues: anonymous surveys that provide qualitative and quantitative data on student attitudes, reactions, and self-perceptions; classroom feedback and individual student interviews directed at issues highlighted by the survey data; and instructor evaluation of competency development. These assessment tools will be divided into three sections: Course Effectiveness (focusing on student interest, engagement, satisfaction, and motivation levels), Learning Approaches (survey items related to student self-perceptions of the learning environment and learning effectiveness, and student comfort levels with the learning environment), and Learning Objectives (investigating student perceptions of learning and understanding in areas defined by the course learning objectives). Our study will emphasize three questions: first, does integration of context improve student attitudes toward technical learning? Second, does integration of context aid broad competency development, including a broader awareness in considering and evaluating technologies? And third, does integration of context improve students' attitudes toward or capacity for self-directed learning? All survey data will be statistically analyzed to determine the differences from the start to the end of the semester in both courses, and to identify whether context integration in the course block significantly affects student attitudes toward or capacity for self-directed learning.

The very nature of disciplinary integration lends itself to many of the positive outcomes desired by the engineering community. For example, teamwork demonstrated by faculty members in different disciplines, the interchange of faculty viewpoints, and the ability to observe faculty collaboration on complex real-world problems offers a model that helps students develop their own teamwork and interdisciplinary problem-solving skills. Student motivation is also fostered by the visible connection of problem solving methods to authentic and relevant issues that clearly exist in a larger societal context. While interdisciplinary education raises certain challenges, such as the difficulty in identifying complementary disciplines (and faculty) and the logistical complexity of interdisciplinary courses, the solution to these problems serves as an important end in itself, offering the possibility of dissolving disciplinary barriers, allowing instructors to learn from each other by sharing methods, and forging stronger connections between educators who often discover they were working towards the same goals all along.

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