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Pedagogical Fusion: Integration, Student Direction, and Project-Based Learning in a Materials Science–History of Technology Course Block*

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Imagine a course block in which students discuss the cultural implications of 17th century iron working in North America in one hour, and design experiments to examine connections between composition and strength in modern steel padlocks immediately afterwards. In the Paul Revere: Tough as Nails *course block, students don't just study materials science and history of technology topics, they experience them. Through a series of readings, discussions, and self-designed projects, students explore materials science concepts alongside the social, cultural and environmental factors that shaped technological and scientific history. Although the course includes many formal in-class activities, approximately half of all class sessions are flexible, allowing students to engage in individualized learning approaches. The projects are loosely framed, enabling students to develop key competencies while investigating topics of personal interest and controlling project focus and direction. In this paper, we discuss the processes and motivating factors that led to the initial design and continued development of the* Paul Revere: Tough as Nails *course block. We describe the pedagogical and practical benefits of the course, and we elucidate the important role the course plays in Olin's engineering curriculum.*

Keywords: materials; technology history; project-based learning; assessment.

BACKGROUND ON OLIN COLLEGE

THE FRANKLIN W. Olin College of Engineering (Olin College) is a small and brand new engineering college in Needham, Massachusetts, currently home to about 300 students. Because of a generous grant from the F. W. Olin Foundation, Olin offers full tuition scholarships to all its students. This scholarship is one of the factors drawing gifted students to Olin.

Students come to Olin College anticipating something different. The College was inaugurated with the goal of changing the way students learn about engineering and best serving the engineers of the new millennium. Olin College aspires to be bold, flexible, and creative. The Olin curriculum, with its emphasis on interdisciplinary approaches, teamwork, hands-on design, business, communication and creativity, is designed to address the National Science Foundation and engineering community's calls for reform in engineering education [1–3]. Olin College touts its cutting-edge campus and engineering programs, and attracts students who desire an 'education like no other' [4].

The Olin College mission is to prepare future leaders through an innovative engineering education that bridges science and technology, enterprise, and society. Olin graduates are expected to be skilled in independent learning and the art of design, and have the capacity to seek opportunities and take initiative to make a positive difference in the world. These broad goals of the College are clearly defined, but realization of the high-level aspirations in individual courses or course blocks is not a simple task.

COURSE BLOCK HISTORY AND DESIGN

Introduction

In the fall of 2003, two faculty members at the Franklin W. Olin College of Engineering began teaching a new course offering, titled *Paul Revere: Tough as Nails*. Referred to as a 'course block' because it was two to three times the size of a typical undergraduate course, *Paul Revere: Tough as Nails* attempted to accomplish three key learning objectives:

1. to teach students to pose questions and solve materials science and historical problems in an *interdisciplinary manner*, using the content, methods, and perspectives of both fields to achieve a greater contextual and qualitative understanding of common topics;
2. to encourage students to control their own learning process in a *self-directed manner* and develop 'lifelong learning' skills in the process;

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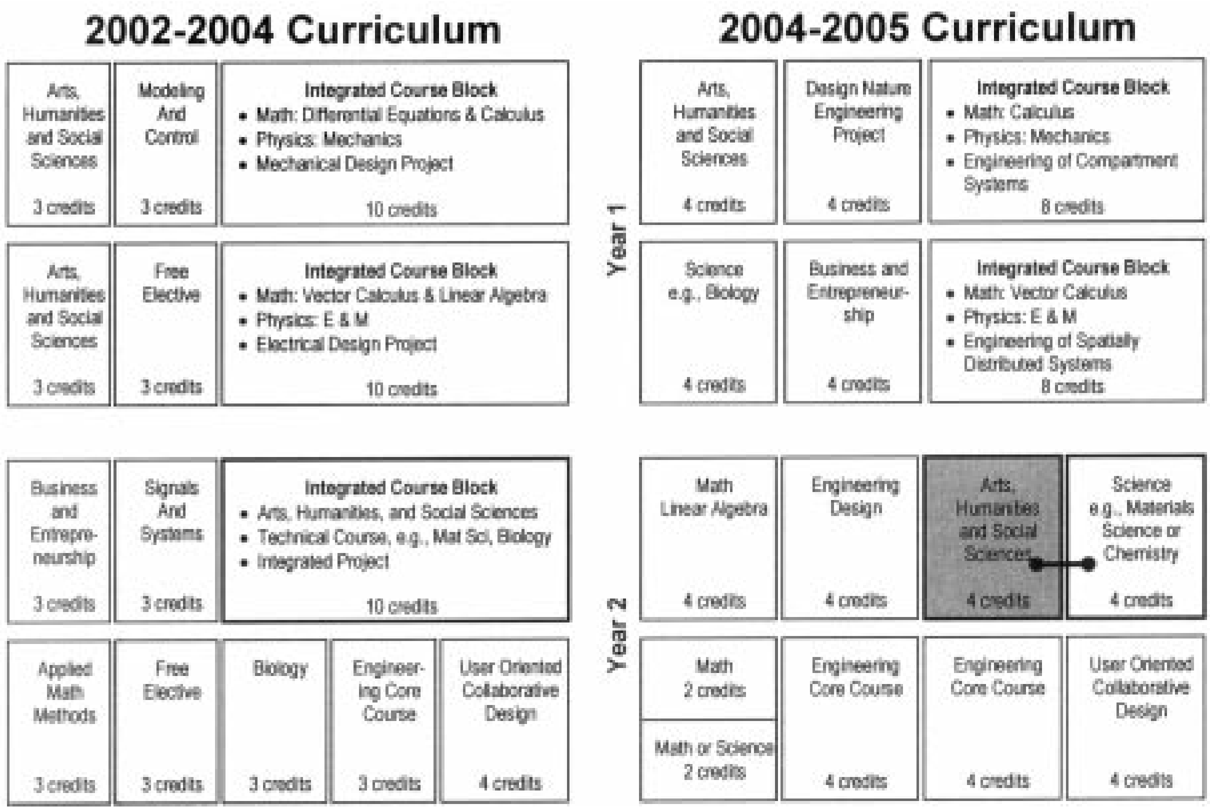

Fig. 1. Two implementations of the first and second years of Olin's engineering curriculum. The shaded blocks indicate the size and timing of the history–materials science course block under each curriculum model.

3. to use projects as a primary pedagogical mechanism, encouraging a *hands-on experiential understanding* of content and methods as well as expertise in the conceptualization, design, and implementation of a project.

This paper describes the execution of different incarnations of this course in more detail, with particular emphasis upon project implementation and pedagogical goals. The effectiveness of this activity is assessed via a study of student and faculty feedback.

Olin Integrated Course Blocks

The Olin College curriculum provides a strong foundation in engineering, mathematics and applied science subjects and promotes development of engineering analysis, diagnosis, modeling, and problem-solving skills. In addition to student attainment of technical expertise, the curriculum emphasizes student growth in the key areas of design, communication, contextual understanding, entrepreneurship, opportunity assessment, and arts, humanities, and social sciences. The first two years of a typical course of study are shown in Fig. 1.

Many of the distinctive features and goals of the Olin curriculum are incorporated in Integrated Course Blocks (ICBs) offered early in the curriculum. In ICBs, multiple faculty members collectively develop synchronized courses in conjunction with a hands-on project. These blocks enable tight coordination between the understanding of underlying disciplines, application of disciplinary knowledge to open-ended problems, and development of important skills. The design of Olin's ICBs was guided by the pedagogical benefits and implementation challenges reported by other institutions with integrated or design-centered approaches [5–13]. Olin's original ICBs incorporated lessons learned in areas of content integration, early hands-on experiences, and open-ended problem solving, and they included a large-scale project equivalent to a full-sized course.

Figure 1 shows the major differences between Olin's former and current curriculum models. Under the 2002–2004 curriculum, Olin students participated in ICBs in the first three semesters. The first year ICBs were designed to take advantage of the synergies that exist among mathematics, science and engineering topics. First year ICBs included coordinated projects that provided opportunities for students to apply fundamental math and science to real engineering problems and that further clarify important linkages among disciplinary topics. In 2002–2004, the first year ICBs merged math, physics and mechanical and electrical design content, and students completed a separate course in modeling and control. In the current (2004–2005) curriculum model, first-year students complete math–physics–engineering ICBs that include modeling and control projects, and the design project is offered as a separate course.

In 2002–2004, all Olin College sophomores participated in ICBs that merged technical content with business, arts, humanities and social sciences, allowing students to work on engineering projects with broader implications than the purely technical. In addition to the *Paul Revere* course block, Olin College offered combinations of Biology–Business, and Electrical Engineering–Music. A primary consideration in the development of this type of integrated course block was to elucidate the inherent connections among technical and non-technical topics and to develop understanding of the significance of the broader context on technology. Such integration of engineering and technology topics in the broader contexts of arts, humanities and social sciences has benefits that are described in the literature [14–23].

Paul Revere ICB, Version 1

The original concept for the *Paul Revere: Tough as Nails* course was sparked when the authors first met, and development of the integrated course block was a natural extension of the authors' knowledge and experience. The *Paul Revere* course was designed in the summer 2003 through a series of lunch meetings, and the first version of *Paul Revere* was offered in the fall 2003 semester. The first course block implementation encompassed content from three courses: (1) *Principles of Materials Science*, an introductory level materials course with lab (2) *The Stuff of History—Ancient, Revolutionary, and Contemporary Materials Technologies*, an intermediate level arts, humanities and social sciences elective course, and (3) *Foundation Project III*, a hands-on project course intended to integrate technical and non-technical content. Although the materials science professor nominally taught the first and third portions of the course and the history professor officially ran the second part, in reality both professors sat in on each others' courses and collaborated on the writing and assessment of all assignments. Twenty-two enrolled students earned 10 credits in the course block (120 credits required for graduation; most 'normal' courses at this time were three credits in size) and they were expected to spend approximately 30 hours per week on course-related activities, including in-class time. This course block occupied three fifths of most students' course load for that semester.

The title and central project component of this course relates to Paul Revere, the subject of the history of technology professor's ongoing research. Although Revere is primarily known for his patriotic activities during the Revolutionary War, his greatest contribution to American history may have been his many metallurgical endeavors: beginning his career as a silversmith apprentice and eventually the owner of a successful silver shop, Revere sought additional prestige and income after the American revolution and initiated iron casting, bronze bell and cannon casting, malleable copper working, and copper sheet rolling enterprises until his retirement in 1811. Revere's voluminous records (primarily ledgers and correspondence) detail some of his metalworking activities and their connections to historical context, while leaving many other questions unanswered. This proved an almost ideal backdrop for an interdisciplinary project.

Although Paul Revere's metallurgical work served as a valuable central theme of the course, the authors recognized early in the design process that focusing solely on Paul Revere would make the course seem too narrow. To increase the breadth and complexity of the course block, and to boost connection building between the history and introductory materials science course content, additional course phases with distinct emphases were introduced. Identification of strong linkages between the historical and materials science concepts in each phase was paramount to successful implementation of the *Paul Revere* ICB.

As this was the first offering of a unique course at a new institution, a statistical comparison of learning effectiveness and student satisfaction in this course versus traditional courses is impossible, but available evidence indicates that the fall 2003 *Paul Revere* course block was a success. As shown in the Assessment section at the end of this paper, the end-of-semester course evaluation results indicated that students responded quite positively to the course. Motivation and satisfaction levels remained exceptionally high throughout the course, as did student self-assessment of learning objectives achievement. Students continually expressed an appreciation for the collaborative faculty effort and praised the integration of topics, application of theory in hands-on work, experimental design experience, and discussion-based class sessions.

Paul Revere ICB, Version 2

The relatively successful first implementation of the *Paul Revere* course block died a quiet (and presumably happy) death. Olin's small size posed several implementation challenges to the original curricular plan to offer integrated technical–humanities course blocks to all second year students. Among these challenges were limited faculty resources in the arts, humanities and social sciences, and the desire to provide sufficient registration choices for all students. As a result, a curriculum revision in 2003 eliminated the mandatory nature of second year ICBs and sparked a major re-design of the Paul Revere course block. Under the new curriculum specifications, the Foundation Project III course disappeared, and the previously integrated science and humanities courses became individual courses. Students were no longer required to register for an ICB in the second year, but provisions were made to accommodate faculty who wished to offer integrated two-course blocks. Thus, in the current curriculum, Olin faculty may still build multidisciplinary connections through tightly-coupled, team-taught course blocks, but only a fraction of Olin students are able to participate in such courses.

The *Paul Revere* faculty decided to continue offering the *Paul Revere* course block in the fall 2004 semester. They required cross-registration of the history and materials science courses, but they were left with an issue: instead of the previously allocated ten credits, the total credits for the course block was now eight. The course needed to be streamlined, and portions of the course had to be removed. Rather than viewing this issue as a major problem, the course instructors viewed it as an opportunity for improvement.

The change in total course time prompted reconsideration of the educational purpose of the integrated course block. In keeping with Olin's mission and use of best pedagogical practices, several primary goals for *Paul Revere* were identified during the early stages of the course revision. First, the course block must integrate technical and non-technical content in an effective, creative manner. Second, project experiences should provide motivation and context for the course content, and be the foremost mechanism for attainment of the learning objectives. Third, the course plan should be flexible enough to allow individualized learning approaches and a high level of student control and self-direction.

To realize these educational goals in the smaller sized course block, scheduled lectures were eliminated, historical and materials science content was more tightly synchronized, students were given more responsibility for the planning and management of classroom discussions, and several major projects and writing assignments were combined into three large integrated activities. These modifications, particularly the elimination of formal lectures for content delivery, pushed the course block further toward student-directed, non-traditional learning.

PEDAGOGICAL APPROACHES

The uniqueness of the *Paul Revere* course block is manifested in its effective fusion of several pedagogical approaches that have garnered much interest in recent years: multidisciplinary integration, project-based learning, and self-directed learning.

Integration

Student learning in the *Paul Revere* course block necessarily occurred across disciplinary boundaries. The instructors defined course goals and organized topics to emphasize linkages between history of technology and materials science. These linkages accomplished two broad objectives: enrich the delivery of both subjects by illustrating how they connect to each other and to larger issues; and teach students to identify and evaluate interdisciplinary and contextual connections throughout their educational careers. All major assignments were designed with the linkages in mind, and all project reports and presentations were completely integrated to help students synthesize ideas and demonstrate understanding of interdisciplinary connections. The instructors attempted to model good teamwork throughout the semester by maintaining close communication, planning the weekly schedule and assignments together, and attending each other's class sessions. The integrated assignments were assessed by both instructors in accordance with the defined learning outcomes, and detailed feedback was provided in areas of qualitative analysis, quantitative analysis, contextual understanding, communication and diagnosis.

Project-based learning

A number of large, open-ended projects allowed students to apply fundamental materials science theory and methods directly, use historical context to plan and shape technical goals, apply analytical and quantitative processes to a social science discipline, test modern claims, and learn through experience. The course projects also provided a motivating framework upon which students could base their learning of materials science and historical content.

The project-based learning approach in the *Paul Revere* course block is not entirely new. Rather, it combines aspects of existing project-based learning and problem-based learning methods. Although these two forms of active learning are quite similar, distinct definitions that outline the similarities and differences of the two approaches have been suggested in recent literature [24–29]. Based on these suggested definitions, it is clear that the *Paul Revere* course experience lies somewhere between the project-based and problem-based approaches, as described below.

As in most of the reported problem-based learning approaches, students in *Paul Revere* had great control over the learning of new content and defining of learning requirements, and they focused on problem management and problem-solving processes. Unlike most of the reported problem-based learning methods, however, the instructors in *Paul Revere* did not carefully determine the specific problem to be solved; rather, they emphasized student identification of problems. As is typical of most project-based learning techniques, the *Paul Revere* projects provided a loosely-defined problem and served as the dominant learning activity throughout the semester. Since the students were not expected to have prerequisite fundamental knowledge, some of the early content acquisition was supported through faculty-prepared assignments, but students gained increasing control of the specific content learning throughout the semester. A key aspect of the project-based learning in the Paul Revere course block was the gradual relaxing of problem constraints as the semester progressed. Students started the semester with a relatively small set of applicable content and available laboratory resources, and ended the semester with completely self-defined problems, project goals, and project learning experiences. This loosening of constraints provided opportunities for students to identify, access, and apply the pertinent content as required by the project. Students also gained skill in management of time and resources, and identification and assignment of team member roles. Another similarity to reported project-based learning approaches was the focus on a written outcome and the emphasis on analysis, manipulation, or creation of physical artifacts. In all the *Paul Revere* projects, students apply hands-on, practical skills and practice or develop laboratory testing and characterization techniques, and many projects culminate in the creation of both physical deliverables and written reports or posters.

Project-based learning approaches and the closely-related problem-based learning approaches have been used for many years in diverse ways and across many disciplines. Many benefits of problem-based learning and project-based learning—increases in problem-solving ability, occupational preparedness, capacity for self-directed learning and self-assessment—and some challenges of these pedagogical approaches—holes in content, student frustration, faculty resistance, cost effectiveness—have been described in the educational literature [26, 30–35].

Self-directed learning

Although student self-direction is generally included as a component of problem- and project-based learning approaches, the authors feel that this important aspect of the course warrants explicit discussion. In *Paul Revere,* students learned through cooperative team projects, student-directed classroom and laboratory experiences, and student-guided active discussion. This approach would ideally enable them to master the course objectives more effectively while also making students more aware of and in control of their own learning styles. In each project, students held the responsibility of identifying the knowledge and skills required for success. Learning of fundamental materials science content was accomplished through readings and completion of homework assignments that were not collected or formally assessed. Student teams ran portions of the history discussions by planning debates, presentations and other activities. Laboratory and historical research skills were developed on an as-needed basis through the project work. Class times remained flexible throughout the semester, allowing individualized or team approaches to time management. Teams shared their knowledge and project experiences through peer instruction sessions and informal class discussions. Throughout the semester, the faculty positioned themselves as learning facilitators, not as project supervisors or knowledge masters.

These three pedagogical approaches serve as common themes throughout the semester-long *Paul Revere* experience. The application of integration, project-based learning, and student-directed learning techniques is made clear through the following description of the student experience in the course block.

THE STUDENT EXPERIENCE

On the first day of the materials science class, students in the *Paul Revere: Tough as Nails* course block were given a challenge. They were asked to form three-person teams; select a common consumer product; design laboratory experiments to analyze technical aspects of materials used in the product; explore the cultural, environmental and political values embedded in the product; identify an approximate 'ancient' (Roman Empire or earlier) counterpart to the modern product; and compare and contrast the societal impacts of the modern and ancient products. The students were provided with a general framework for the five-week project, but not much more.

Student reactions were priceless: jaws dropped and blank stares abounded. This was not a typical manner in which to start a first-semester sophomore course, and this assignment was not a typical first-day task. There was no build-up of content and foundational information, no textbook homework sets to prepare them for more complex synthesis of concepts, no well-defined, highly-constrained problem that they could easily grasp. This was day one, and students were asked to plan and execute an interdisciplinary project that combined materials and cultural/historical analyses. They were granted a high level of freedom, and an accompanying high level of responsibility. Students were given control of their learning.

Week One: Early student response

After the initial shock of the first-day assignment began to wear off, the students busied themselves with forming teams, selecting common objects (tennis rackets, cutlery, padlocks, bicycles), and struggling to determine what, exactly, they were supposed to do with this first assignment.

Some students immediately embraced the open-endedness of the project, and delved into materials testing of their products with high energy and utter abandon of their textbook and homework problem sets. Other students approached the project with measured caution, attempting to develop a deliberate plan for their materials testing and historical research. Some students immediately identified an obvious ancient counterpart to their modern object (for example, a Roman chariot as a counterpart to the bicycle), and others struggled before settling upon a more challenging connection (such as associating an automobile protection device with Chinese terra cotta guardian statues). A good number of students expressed concern about the proper balance between materials science and historical analysis, and struggled to integrate the different components of the assignment into a coherent paper. At some point in the early stages of project one, most students expressed at least some discomfort with the project expectations and some frustration with the open-ended, student-directed nature of the learning. The instructors expected the initial student anxiety [35], and they hoped that students would adjust to the non-traditional style.

Guidance and support system

As students developed plans for their first project, they soon realized they had not been carelessly flung into the deep end of the pool. Early in the semester, the instructors revealed a thoughtfully designed support system to aid learning. Such support systems are essential for successful implementation of flexible, student-directed learning experiences that occur early in the curriculum.

The support system in the *Paul Revere* course block had two essential characteristics. First, the system included a set of course-related information, assignments, and materials that were designed to smooth the transition to self-directed learning and gently nudge students in the direction of the learning objectives. In the history component of the course block, students read and discussed a series of texts, including portions of *Science and Technology in World History*, *Napoleon's Buttons: 17 Molecules that Changed History,* the journal article 'Indigenous African Metallurgy: Nature and Culture,' and the code of Hammurabi [36–38], that took a historical approach to the role of science and technology in various ancient societies. Students also wrote open-ended journals that reflected on the ways technologies affected cultures and were shaped by cultural values in turn. The material in the first section of the history course exposed students to both historical content and contextual analysis techniques that connected history and technology, and therefore began preparing them for the first project. On the materials science side, students were assigned regular reading assignments and homework problem sets, which included both simple textbook problems and open-ended challenges that required higher-level thinking and synthesis of multiple concepts. The open-ended homework problems were intentionally designed to help prepare students for the integrated projects. In the spirit of self-directed learning, due dates for all materials science readings and homework were specified, but none of the completed homework was collected. Instead, homework solutions were posted at the due date, and students were strongly encouraged to assess their own work.

The second essential characteristic of the support system was acceptance of a non-traditional role by the faculty. To help move the students toward active, self-directed learning, the instructors attempted to avoid the 'content expert' position and instead embraced guiding, facilitating and enabling roles. Rather than delivering fundamental content through 'efficient' lectures, the materials science instructor asked guiding questions and encouraged collaborative team efforts to help students find essential information in the library, the web, or their textbook. Instead of controlling classroom discussions and identifying pertinent historical archives, the history instructor occasionally inserted a few thought-provoking questions for discussion, allowed students to manage much of the class time, and required students to research and analyze information to support their project theses. Instructor assistance was always available, but the 'answers' were not provided up front in a nice, neat package.

In completing their first project, students gained foundational knowledge in materials structure and properties; developed skills in historical and laboratory analysis; polished their writing skills; and articulated important linkages between historical themes and technological developments. By the end of the first project, students exhibited an increased confidence with open-ended problem solving and an expanded appreciation for the broader contexts of science and engineering. They were ready for the next challenge.

Projects Two and Three: Further development

By the end of their first major project, students were more confident, highly motivated, and willing to try just about anything. They had started to accept the role of self-directed learner, they were somewhat used to finding pertinent information to support their projects, and they had embraced the instructors as useful guides in their learning adventures. Not surprisingly, at this point in the semester, some students expressed a personal need for more guidance, a desire for clearer direction for their learning, and some uncertainty that they were really learning the 'right stuff.'

The challenges that followed project one included increased demands on synthesis and design skills, and a broader technical scope. As students' skills and knowledge developed throughout the semester, the project constraints were relaxed, and boundaries of exploration were expanded. Although learning objectives and primary goals were identified at the start of each project phase, the successive projects were intentionally designed with a gradual shift from loosely structured to unstructured problems. Table 1 summarizes the basic project goals and constraints.

The second project, entitled The Last Ride of Paul Revere, represents the inspiration for and central theme of the course block. In the Paul Revere project, students explore connections between historical and technological materials

Table 1. Overview of the *Paul Revere* course block project themes, goals, and constraints.

Project theme	Project time	Goals and objectives	Constraints
1. Conceptual Analysis of a Project Experiment	5 weeks	Materials Science: • Develop basic laboratory and experimental design skills. • Learn to use testing equipment and analytical instrumentation. • Collect and analyze data on material composition, structure and properties. • Explain connections among material properties, chemical composition, and atomic structure and bonding. • Identify basic characteristics of materials that make them suitable for use in common products.	Materials Science: Laboratory experiments limited to property testing (mechanical, thermal, physical) and structural and compositional analyses (XRD, FT-IR, and EDS). No materials processing, very limited microstructural examination.
		History: • Research and analyze the social context of a modern material artifact, emphasizing ethical, environmental, political or 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.	History: Students must choose an ancient counterpart to their object dating no later than 500 AD.
2. The last ride of Paul Revere	4 weeks	Materials Science: • Continue to develop laboratory skills. • Design and implement an experimental procedure for investigation of a material system. • Collect and evaluate experimental data on material microstructure, properties, and processing. • Explain and predict the microstructural and property changes that occur as a result of compositional modification, mechanical processing and thermal processing. • Research modern alloy processing techniques, and use similar methods to process laboratory specimens.	Materials Science: Materials and processing limited to metals and alloys used by Revere. Laboratory experiments must include some processing and some microstructural analyses.
		History: • Identify a problem or question relevant to the career of Paul Revere. • Research the historical context of this question. • Prove a thesis statement and support it with relevant technical and historical evidence. • Develop oral, written, and graphical communication skills in presenting results.	History: Students restricted to primary source documents from Paul Revere records, online sources, and a small collection of relevant secondary texts.
3. Modern materials and methods	4 weeks	Materials Science: • Design and implement an experimental procedure for characterization or testing of a modern material, component or process. • Identify appropriate materials science information resources for investigation of your project topic. • Articulate structure–processing–service environment–property relationships in modern materials systems. • Evaluate materials selected for particular technical applications, and recognize relationships between materials selection and design.	Materials Science: Projects limited only by time, course budget and laboratory resources.
		History: • 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 relevant technical and historical evidence. • Develop oral and written communication skills in presenting results.	History: Limited project time tests students' ability to find relevant sources.

science developments through an examination of Paul Revere's metallurgical work. Student teams selected one of 'Revere's' alloy systems (silver, iron, copper or silver) and a process applicable to the alloy (casting, drawing, rolling or forging). Students learned new laboratory techniques and designed experiments that used state of the art technology and laboratory methods to understand Revere's work, life and world better. The goal of the project was to answer a historical question of importance to Revere and to shed light on materials processing–microstructure–property relationships that were unclear in Revere's day. Emphases were placed upon collection, analysis and use of evidence to investigate a thesis relevant to the project.

For example, one student group chose to use modern materials science equipment and methods to evaluate Paul Revere's decision to switch from a bronze composition alloy to pure copper, and from casting to forging at the start of his spike forging career. The group began with a contextual study of Revere's work, emphasizing the entrepreneurial decisions he made, the production processes at his disposal, and the typical ways his spikes would be used in ship hulls. They designed and conducted a series of experiments (shear testing, impact testing, microstructural analysis) on spikes that they forged in a 'Revere-like' manner from different materials. The students used materials science theory (such as the role of dislocations, annealing temperature, and composition in determining phase transformations, grain size and morphology and properties) to compare these results with Revere's desired outcomes, confirming that the switch to pure copper led to the best combination of properties for spikes used in ship hulls.

In the final phase of the course, projects were largely unconstrained, and students were charged with directing their own learning experience. Teams selected a modern materials science topic of technological and societal (historical) significance and explored issues through a self-designed program of research and laboratory experimentation. For example, one group chose to investigate the material properties of different fiber optic technologies used throughout history, and relate these properties and technologies to the increasing interconnectivity and globalization of human societies. Both the historical and materials science components of the project were open-ended, and projects were constrained only by the students' imaginations and the resources available for the course. Students selected a thesis based on one of the course themes, and they applied this thesis to their technical research project. The final paper and presentation included a discussion of technical results and an analysis of the relevant social, environmental, political and economic aspects of the technical topic. Students backed up their study with persuasive evidence and definitive source materials, and they used this information in a well-organized manner that addressed the thesis and selected themes. Successful completion of Part III required synthesis of numerous course concepts and thoughtful consideration of interdisciplinary connections. Student selection of topics provided a strong sense of ownership and responsibility, and students shared their special topics with the class through a presentation geared toward peer instruction.

ASSESSMENT

Student competency assessment

The non-traditional approach used in the *Paul Revere* course block provided assessment challenges. In completing self-directed projects, the student teams covered different content, focused on different aspects of the project-based learning process, and acquired depth of knowledge in different areas. To address the differences in specific content learning, the instructors emphasized fundamental concepts, goals and broad learning objectives throughout the semester.

Olin recently instituted a new competency assessment system to accompany the traditional course grading system already in place at the College. The competency grading system is based on nine learning outcomes or 'competencies' that are directly tied to the institutional mission and program goals. The nine competencies are shared among all courses and across other student activities (e.g., summer internships, extracurricular endeavors, research, passionate pursuits), and assessment of the competencies allows for tracking of student progress and needs in many areas of their educational development. Olin's competencies are qualitative analysis, quantitative analysis, diagnosis, design, teamwork, communication, contextual understanding, opportunity assessment and lifelong learning.

Course assessment mechanisms in the *Paul Revere* course block were based on the competency assessment system and designed with project open-endedness in mind. The instructors decided to evaluate students in seven of the nine Olin competency areas. Major assignments were assessed according to students' abilities and skills in communication (oral, written, graphical and visual), understanding of context, quantitative analysis, qualitative analysis and diagnosis. For each major assignment, instructors provided students with detailed feedback and a grade in each competency area. Teaming skills were assessed through peer- and self-evaluation. A self-assessment of life-long learning skill development was included as the final piece in the course assessment picture. For this end-of-semester assignment, students were asked to write a one-page maximum statement that described how (or if) the integrated course block contributed to development of their life-long learning skills. Overall course letter grades comprised the individual competency grades. The

Table 2 Summary of student responses to survey questions related to learning objectives attainment. Survey question form was, 'As a result of this course, I could *learning objective text*.' Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Stronly Agree. The learning objectives are listed in Fig. 2.

Course year	Total students	Survey respondents	Average response for learning objectives I–IV			
			I	II	III	IV
2003	28	23	4.61	4.65	4.74	4.52
2004	18	14	4.57	4.50	4.79	4.43

thread of competency assessments provided grading coherency for both faculty and students, and it provided students with valuable information that they could use to identify shortcomings and further their learning.

Student self-assessment of learning

Student perception of learning in the course block was high. Figure 2 shows the student responses to the end-of-semester survey questions related to attainment of learning objectives. Results of the survey are summarized in Table 2. Interestingly, the student responses in the two course block versions were not significantly different, even though there were substantial differences between the 2003 and 2004 course designs. Compared with 2003, students in the 2004 course block spent less total time, had less formal course

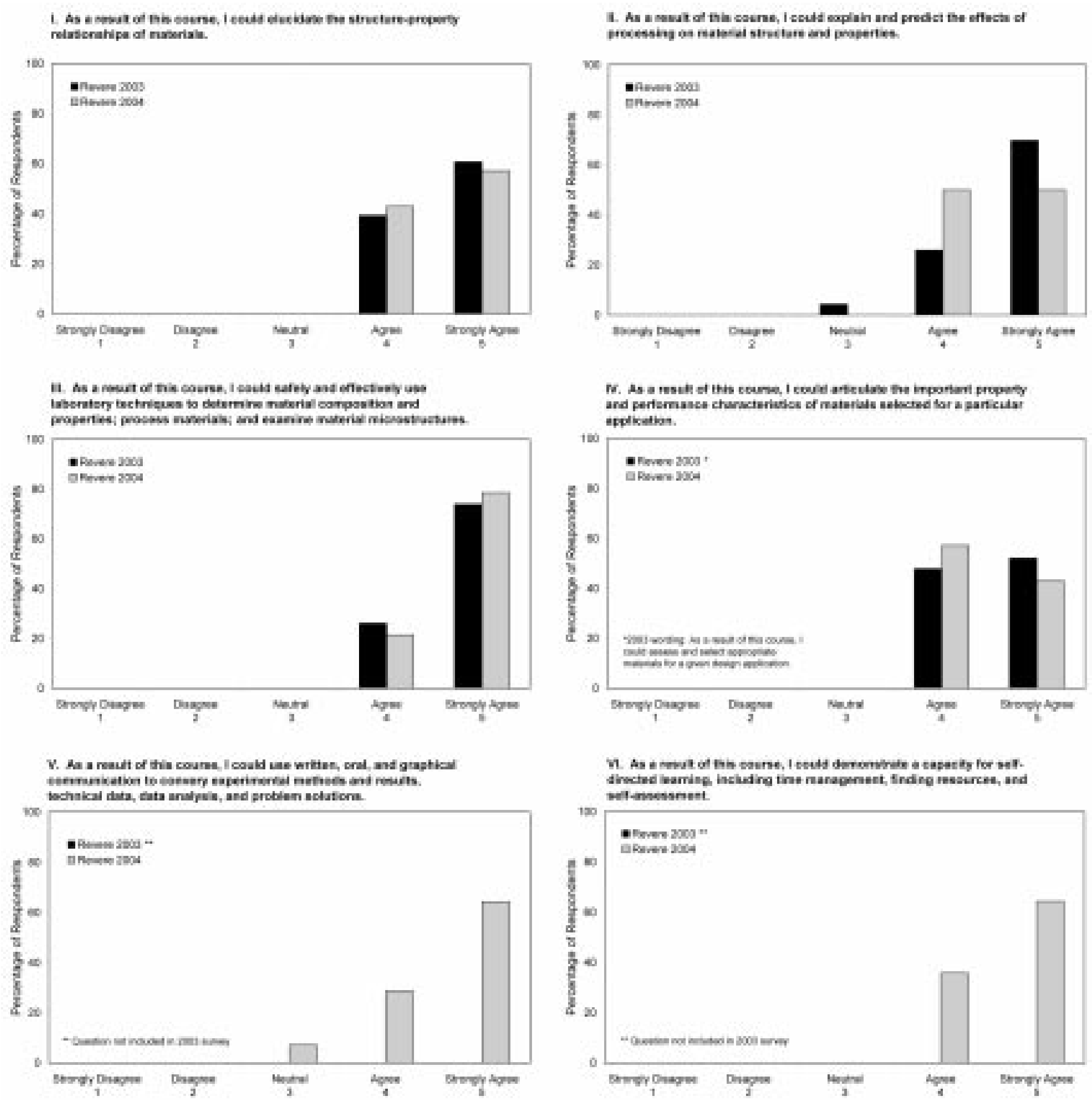

Fig. 2. Student responses to survey questions related to the materials science course learning objectives.

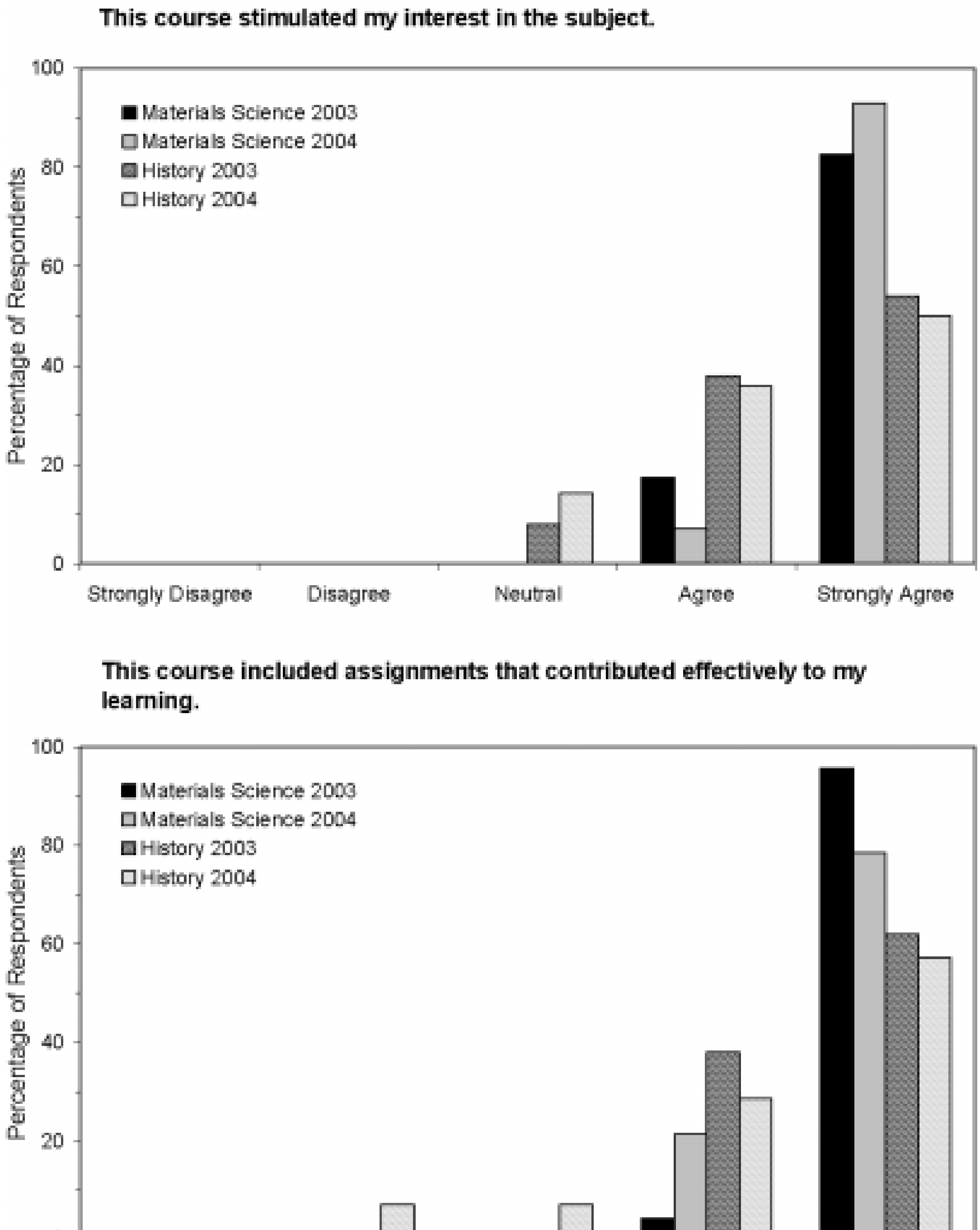

Fig. 3. Course evaluation survey responses for 2003 and 2004 versions of the *Paul Revere* course block.

structure, and were granted fewer credits; yet their perceived levels of learning were about equal to the 2003 levels.

Student course evaluation

Upon completion of the final project, students in both 2003 and 2004 expressed a high level of satisfaction and an overwhelmingly positive attitude toward the *Paul Revere* course block. As shown in Fig. 3, the end-of-year course evaluations showed that the materials science and history portions of the course block stimulated student interest and contributed effectively to student learning.

In the 2004 course evaluations, students frequently cited their appreciation for the open-endedness of the projects, the ability to select project topics of personal interest, the detailed assessment and feedback on assignments, and the high level of course integration. Students felt that the course block helped prepare them for self-directed learning and embracing of new challenges and uncertainties. Specific examples of positive student feedback on the 2004 project-based learning course format are as follows:

What specific pedagogical or educational approaches were used in this course? Which were most effective or least effective?

> 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 discussion base for this class was really effective. Not only do I feel more comfortable speaking up in classes as a result, I was also able to learn a lot more by participating so much. The integrated class with Mat Sci was also really interesting. I learned so much about relating cultural aspects of technology to systems and to my specific research topics.

> The self-guided approach worked really well . . .and when other resources failed, [the professor] 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 . . .

> This class had three distinct projects, many discussions, a few lectures, and a lot of readings. Every single one of them contributed to a nice balance within the course and they were all very effective.

> This teaching style was one of the most effective I have found at Olin. We were just given access to all of the equipment and set loose to do our projects.

> The main assignments were three big projects. They were very fun to do and taught the material very well. These projects offered enough flexibility for the students to learn about subjects they wished but well enough constrained to keep them on topic.

> Projects offered enough flexibility for the students to learn about subjects they wished, but were well enough constrained to keep [students] on topic. Most of the course involved open-ended lab work, which was great. Students simply had to know the material in order to construct and evaluate effective experiments.

What were the best features of this course?

> Integration of two subjects and the project based approach.

> The projects in this class are fun, and probably the most effective tool for learning the material.

> It was fun having discussions with both [professors] in the class. I also loved how integrated history and materials science were.

> I loved the projects. 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.

> A huge variety of readings that spanned from the beginning of human history to technology that is on the verge of just being invented now. Stuff of History was always interesting and helped develop my skills as an analyst.

Confidential comments for your faculty member:

> I learned so much from this class. I feel prepared to take on more challenging tasks now than when I started this semester as a result of having to design and implement the three experiments. Researching the material helped me learn more about the subject in general.

> I loved your class. It was awesome! I loved how open-ended it was, in the discussions and journals and topics of the papers. I had a good time writing papers for you.

> I can sincerely say that this was one of the best classes I've EVER taken in my life . . .

Although the positive responses far outweighed the negative, some students in the 2004 course block 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. These rather strong feelings for additional lectures and the uncertainties of their learning are evident in the following statements from student participants:

What specific pedagogical or educational approaches were used in this course? Which were most effective or least effective?

> 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.

> 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.

Confidential comments for your faculty member:

> If anything, I feel that the class may have been too unstructured at times. If you can define a sort of materials science 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 course was great, but I wish some more time was spent on in-class teaching, i.e. lecture . . .

It is obvious from the student response that they see the benefits from the pedagogical approach used in the course block, but that they are still somewhat hesitant to fully endorse an absence of the traditional instructor delivery of content via lectures. Many students indicated that lectures provide reassurance that they are learning the right content and finding the right answers.

Faculty reflection: Evaluation of pedagogical approaches and transferability

The authors believe that the *Paul Revere* course block embodied the Olin College mission, directed students toward many of the institution's educational goals, and was an important part of the engineering curriculum. Students experienced a rare opportunity to participate in a course block that merged foundational science content with motivating historical context, and they acquired knowledge and developed skills in an environment that focused on student control of the learning process.

The *Paul Revere* instructors considered the first incarnation of this course a success, and the second even more so. Both the quality of student work and the degree of student confidence improved during the course of the semester. The faculty members found their interactions with students (project facilitation, classroom discussions, extra help visits) increasingly directed and efficient as time passed because the students learned to take ownership of their learning objectives and saw the instructors as resources or allies to help them.

As mentioned above, the newness of Olin College makes it difficult to compare the 'traditional' learning outcomes of this course with those of other courses. Students were expected to master foundation-level materials science processes and concepts, learn ancient and Revolutionary-era historical context, and develop writing and presentation skills. Student work certainly exhibits an impressive command of these areas, and the instructors are extremely pleased with the student achievements, considering them equal to or better than any prior group of students they have ever taught.

The clearest benefits occurred in non-traditional learning objectives involving self-directed learning, the ability to integrate technical and contextual analysis, and the ability to plan and complete individual or group projects. Specific conclusions on these issues follow.

- **Integration** of technical and non-technical knowledge, skills, and perspectives represented a tremendous benefit of this course, visible to both students and faculty. Successful integration depended on the presence of two faculty members who had some appreciation for each other's disciplinary approach, and this appreciation soon transformed into familiarity. The faculty instructors had to spend time attending each other's classes, and occasionally gave feedback on portions of assignments nominally in a different discipline. But for the most part the common learning objectives (exemplified in the competencies shared by both courses; i.e., communication, qualitative analysis, lifelong learning, and teamwork) represented a natural combination of the two disciplines, and common activities and deliverables satisfied both. Each instructor believes that the educational experience for his course was significantly enhanced by the connection with the other. In the future, the faculty hope to investigate the synergistic effects of the multidisciplinary *Paul Revere* approach on students' learning of materials science and history of technology.
- **Project-based learning** also required substantial effort on the part of the instructors and led to some of the greatest outcomes of the activity. The project-centered approach to the entire course quickly caused students to adopt a 'hands-on' mentality to both materials science and history: they looked at all educational activities as potential tools that would help them explore advanced issues on their own, and they used their project goals to guide their knowledge acquisition. Project research and assessment naturally connected the other two pedagogical objectives, requiring students to integrate materials from the two courses while shaping their own methods and goals.
- **Self-directed learning** was the most controversial of the three pedagogical approaches, as it made some students feel uncomfortable, especially at the beginning of the course. Fortunately, the instructors believe that the benefits outweighed the costs, and that the insights students gained into their own learning approaches more than compensated for the initial discomfort. Students developed skills in project planning and time management, as illustrated by the increased quality of deliverables and reduced student stress by the end of the semester. Students learned to take a leadership role in class discussions, and their contributions took the course in creative new directions. This approach succeeded in part because of the support structures ('scaffolding') that prevented the students from drifting too far off course. These structures include required proposals for all major deliverables, extensive faculty feedback on proposals and deliverables, availability of instructors during and outside of class sessions, and a frequently-updated Web page that guided students to resources. These mechanisms should be particularly useful to other institutions attempting to duplicate the student self-direction aspects of this activity.

The major drawback to this course, and a potential barrier to its transfer to other institutions, is the high workload on the faculty side. The two instructors did not have to prepare many traditional lectures, but did have to communicate with each other before and throughout the course, attend many of each other's classes, work informally with students throughout the course, and assess a number of large integrated projects at different stages of completion. This workload was not sufficiently burdensome to rule out future incarnations of the course, but the instructors are considering ways to improve the teaching efficiency. For example, students might be asked to assess each others' work at an early stage, mini-lectures might be designed to address common questions that many students raised in individual counseling sessions, and the deliverables might be shortened a bit. Design and implementation of an integrated, project-based course block that emphasizes student-directed learning is certainly not without challenges, but the instructors believe that the challenges are manageable, and that the benefits to student learning more than compensate for the added faculty effort.

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