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Interdisciplinary Learning through a Connected Classroom*

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An interdisciplinary course is described whose learning objectives were to build foundational knowledge, collaborative skills, and functional knowledge in an advanced technical area. The 'connected-classroom' instructional design stressed active, collaborative learning through a structured combination of World-Wide-Web-based tutorials, lecture supplemented with Socratic dialogue, role-based group assignments, and applied laboratories. A characteristic that makes interdisciplinary courses difficult, namely the mixed student backgrounds, was used to guide collaborative activities and to promote an interconnected view of concepts. Over three semesters, the course format and components were implemented, assessed, and revised based on the assessments. Learning effectiveness was strongly influenced by the course components that addressed disparities in student background and that linked foundational concepts to applications. Senior undergraduates and graduate students from electrical engineering, computer engineering, mechanical engineering, aerospace engineering, and civil engineering participated. The topical area was composite materials and sensor systems for smart structures.

INTRODUCTION

MANY VITAL technologies encompass multiple engineering disciplines. Engineers must interact with technical peers in other disciplines at all stages of design, development and application. In particular, the transfer of new multidisciplinary technologies to application can be limited by the interdisciplinary knowledge and abilities of engineers. Consequently, the needs for engineering education to cross traditional boundaries and to develop soft skills are widely recognized [1]. Current accreditation criteria address this need directly by requiring that engineering graduates demonstrate an ability to function on multidisciplinary teams [2]. Nontraditional educational models can help achieve this outcome.

A fundamental approach to education innovation is to make the learning process more focused on student needs [3]. Courses can be designed to integrate cognitive sciences understanding, e.g. cognitive flexibility theory, cooperative learning theory, and situated action theory, and to benefit from advance information technologies and capabilities. A 'connected-classroom' design stresses active, collaborative interaction which:

- promotes active, student-centered learning with less emphasis on lecture [4];
- emphasizes communication and collaborative skills especially in interdisciplinary settings [5];
- incorporates hands-on activities to link foundational knowledge to a 'real-life' context [6, 7].

Also, World-Wide-Web (WWW) resources can actively engage students through interactivity and multimedia and can provide great flexibility through asynchronous access and hyperlinked content [8]. The effectiveness of various educational techniques are shown in isolation typically; the integration or comprehensive application of multiple approaches are less common.

This work describes a curriculum model for training engineers with interdisciplinary skills and experiences. We are part of the Smart Engineering Group, an interdisciplinary faculty team in the smart structures area, at the University of Missouri-Rolla (UMR). The course concept grew out of our group experiences as researchers and student advisors. This research examines the resulting course for the senior-elective/introductory-graduate level. Students from electrical engineering, computer engineering, mechanical engineering, aerospace engineering, and civil engineering participated. Instructional delivery components were selected using a cognitive sciences approach and were modified based on various student measures and an external evaluation committee. An associated WWW site is the focal environment for student learning and its hyperlinked structure mirrored the interconnectedness of the activities and the content area. The instructional approach was successfully applied in three iterations and received favorable student ratings.

PROJECT OVERVIEW

Interdisciplinary learning environment

The learning objectives of the interdisciplinary course are:

1. To integrate cross-disciplinary knowledge.
2. To build interdisciplinary collaborative skills.
3. To gain related applied experience.

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Table 1. Characteristics of student participants

	Background & major	Average UMR G.P.A.	Learning styles
Fall 1999	9 U.S. & 5 International	3.7/4.0	7 C, 3 D, 3 AS, & 1 AC
Undergraduates	3 EE, 2 ME, 1 CE	3.7/4.0	
Grad. students	2 EE, 6 ME	3.6/4.0	
Fall 2000	7 U.S. & 8 International	3.3/4.0	9 C, 0 D, 6 AS, & 1 AC
Undergraduates	2 EE, 1 AE, 2 ME	2.9/4.0	
Grad. students	3 EE, 4 ME, 1 AE, 2 CE	3.5/4.0	
Fall 2001	10 U.S. & 7 International	3.3/4.0	9 C, 1 D, 4 AS, & 3 AC
Undergraduates	6 EE, 2 CpE, 1 CE	3.0/4.0	
Grad. students	3 EE, 1 CpE, 4 CE	3.7/4.0	
Learning styles Ratings	C—Converger (abstract conceptualization and active experimentation) D—Diverger (concrete experience and reflective observation) AS—Assimilator (abstract conceptualization and reflective observation) AC—Accommodator (concrete experience and active experimentation)		

The technical interest area is smart structures which involves the intelligent monitoring and control of structures using permanent sensors, actuators, and processors. It crosses traditional boundaries by combining materials, manufacturing, sensing, signal processing, structural analysis, etc. [9]. For instance, a load test on a new bridge element could involve civil, electrical, manufacturing, and mechanical engineers who all need to be aware of discipline-specific terminology and connecting concepts. The civil engineer needs an appreciation for sensor noise and processing accuracy; the electrical engineer needs to be aware of strain directions and bonding issues; etc.

The target learners are majoring in electrical engineering, computer engineering, mechanical engineering, aerospace engineering, and civil engineering. The listed course prerequisites are senior or graduate standing and four semesters of undergraduate differential equations and calculus. The backgrounds, characteristics, and interests of the participating students were diverse and are summarized in Table 1.

While all students were traditional, the group had a mix of USA and international backgrounds and had little experience with significant team interaction and interdisciplinary work. Their academic background shows a range of GPAs. Surveys using the Kolb model of learning styles show a wide range of preferences [10]. Topical interest varied from those who enrolled mainly due to course convenience and instructor familiarity to those who were actively engaged in smart structures projects. However, most students had considerable interest in at least one of the component topics. Fourteen students were enrolled in

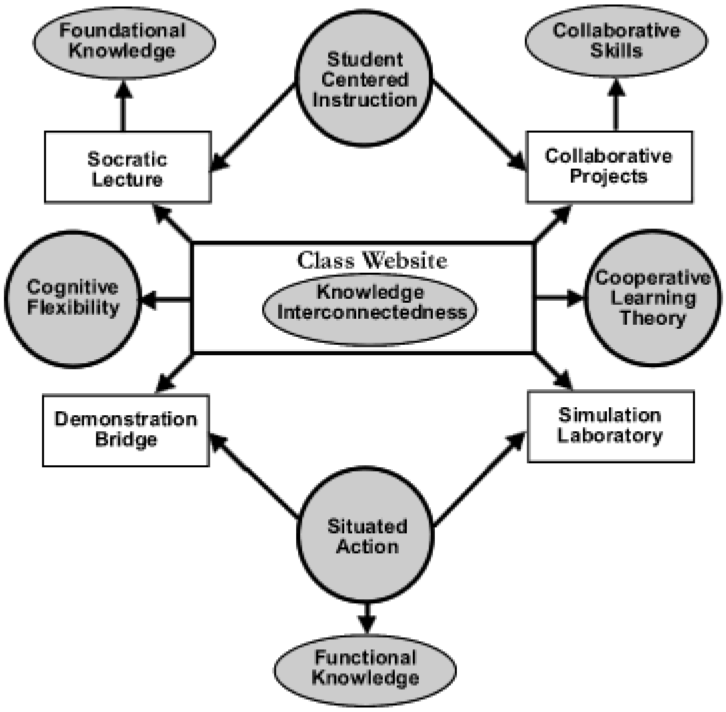

Fig. 1. Connected-classroom model in which the oval, round, and rectangular nodes represent learning objectives, educational theory, and instructional components, respectively.

the fall semester 1999, fifteen were enrolled in the fall semester 2000, and seventeen were enrolled for 2001. Of the undergraduates in 1999, two took the course for graduate credit. The instructors were graduate research supervisors for eight students in 1999 and two students in both 2000 and 2001.

Connected-classroom methodology

Instructional delivery was tailored to the desired learning objectives of the course and the student diversity through a structured combination of preliminary tutorials, Socratic lectures, group collaboration on progressively more involved projects, and active laboratory experiences including a large-scale smart bridge. The course WWW site was the main out-of-class administrative and content resource. This connected-classroom approach is illustrated in Fig. 1.

The cross-disciplinary foundational knowledge was delivered using WWW tutorials followed by a Socratic lecture. Individual and group problem sets gave reinforcement. The WWW tutorials provided flexibility in that students working in their major could quickly survey familiar content while those outside of their major could study the content in depth. Afterwards, the students could all focus on integrating knowledge during the in-class lectures. The lecture emphasis was on answering students' questions and proposing questions in a Socratic dialogue. This student-centered structure was more tailored to student differences and activity than traditional instructor-centered lectures [11, 12].

Interdisciplinary collaborative skills were practiced through group problem sets, laboratory activities and reports, and capstone design or analysis projects with both written and oral documentation. Team membership of typically three students was multidisciplinary and was maintained throughout the semester in order to allow inter-member dynamics to mature. The group activities were structured with each student having a distinct content specialty or interest and having specific assigned roles in accordance with cooperative learning theory [13]. In addition, individual grades to promote accountability and group grades to promote interdependence were combined as per components-of-cooperative learning theory [14]. Several exercises and discussions were included on the nature and group dynamics of engineering teams.

Functional knowledge was developed through problem-based assignments and laboratory activities. Situated action theory [15–17] states that all knowledge is acquired within a given context, and that this context is inextricably tied to the knowledge. Consequently, assignments were focused on applications. For instance, the laboratory reports had a technical memoranda format to emphasize applied interpretation rather than procedure or abstract theory. The final laboratory activity was performing a load test on a demonstration smart bridge.

The technical content was presented as forming a three-dimensional knowledge space linking materials, metrology, and structures. The WWW site served to graphically and relationally interconnect all of the course components and the technical topics through the use of multiple displays, hyperlinking, and hypermap knowledge spaces [8]. The multiple representations of knowledge and the complex interconnecting links are consistent with cognitive flexibility theory [18–20].

The interdisciplinary, diverse mix of students was a defining aspect of the course. Our rationale was to place the students in uncontrived situations in which they must learn from and depend on each other. The assignment of teams and projects reflected student interests and often were directly related to outside research projects. Also, the learning outcomes were different for each student. The course content and assignments were geared toward developing specialists with interaction ability rather than generalists. For instance, an electrical engineering major is not expected to become qualified to do civil engineering work, but to be able to interact with civil engineers with knowledge of terminology and concepts.

COURSE IMPLEMENTATION

Course description and modification

The course is entitled 'Smart Materials and Sensors' and was team-taught by the authors Watkins and Chandrashekhara. The topical content in the first half semester was strain sensing (including sensing theory, electrical resistance gages, linear variable differential transformers, and fiber optic sensors) and materials (including material properties, anisotropic behavior, and fiber-reinforced polymer composites). The second half semester covered application technologies including sensor networking, composite fabrication, and the demonstration bridge. We emphasized new developments and how they relate to established technologies.

All assignments built on the content of the tutorials and lectures and they grew more dependent on collaborative effort as the semester progressed. Grading was based on a midterm examination (individual = 20%), attendance and participation (individual = 20%), problem sets (individual = 10% and team = 10%), laboratory memorandums (individual = 10% and team = 10%), and the team projects (individual = 5% and team = 15%). All assignments (homework, laboratories, and projects) were iterative in that students had to simultaneously apply more concepts and interdisciplinary content as the assignments became more involved. For instance, the first homework assignment was for individuals and required a direct application of lecture and tutorial material. The next homework assignment was for teams and required some knowledge of topical terminology and concepts. The midterm examination was the same for all majors and had a structures and a

Table 2. Schedule and pedagogical structure of the course

	Lecture content	Group collaboration	Laboratory
Beginning of term (1 week)	Explanation of Course Objectives and Pre-tests	Team Assignments and Teamwork Training	Laboratory Safety and Reporting Expectations
First half semester	Presentation of Component Technologies	Team Assignments of Problem Sets with In-Class Work	Demonstrations of Lecture Material (Components Emphasis)
Midterm (1 week)	Midterm Examination (Individual)	Project Paper and Presentation Guidelines	Discussion with Industrial Panel
Second half semester	Presentation of Application Technologies	Team Projects on Assigned Topics with Assigned Team Roles	Applications Experience (Systems Emphasis)
End of term (1 week)	Smart Composite Bridge Overview	Smart Composite Bridge Overview	Smart Composite Bridge Load Test
Finals week		Student Evaluation and Final Assessment	

sensors section. Hence, students had to rely on the other majors in their groups for assistance with team homework assignments and for explaining concepts related to the midterm examination. The initial homework and laboratory team assignments and the out-of-major midterm examination content was intended to create opportunities for internal communication and self-teaching within the groups. Almost all teams reached some degree of effective collaborative practice before the project assignments in the second half-semester.

We assigned the projects based on the collective team interests and had one distinct component of literature review, analysis, or design for each team member. One member was assigned as the leader for each component so that all team members were the lead for one component. A team grade was given for each component and the leader's grade was doubled to promote accountability. Each project component had a series of assignments including a presentation outline, weekly collaboration reports, and a final paper or an in-class presentation. The small teams (groups of three) and the lead assignments promoted full participation by all members of the team and resulted in obvious disadvantages for those teams that did not effectively interact and collaborate. Since the instructors made the team assignments and lead assignments, problems associated with teams defining their own management structure and roles were avoided. The focus of this course was the development of interdisciplinary communication and collaborative skills. (A premise of the course was that practice with team formation occurs more frequently in other in-major courses and that communication and collaborative skills could best be developed with a direct situational approach.)

The course activities were organized as shown in Table 2. The typical schedule was a tutorial review, the Monday lecture and an individual problem set, a Wednesday team problem assignment with in-class work, and a Friday laboratory. After midterm, the midweek activity was in-class work on the assigned projects and the project presentations.

The course was modified after the fall semester 1999 based on student input, instructor observations, and an external review. The full-day external review was performed by a committee consisting of five industry and academic professionals with a variety of educational and technical specialties (see acknowledgements section for list). The review included student interviews. The principal changes were the removal of a midterm assessment session; the revision of the WWW password procedure, the content of the tutorials, and laboratory focus to more applied experiences; and the addition of collaborative learning and teamwork instruction, team laboratory reports (verses only individual reports), weekly collaboration reports, and the smart bridge load test (the bridge was not installed until 2000). The course was further modified after the 2000 semester based on student input and instructor observations. The principal changes were additional content in the WWW tutorials, additional laboratory experiments, and revised teamwork instruction. The tutorials were a combination of WWW-based and paper-based resources during the first semester, but they were primarily WWW-based the second semester and third semester.

Supporting WWW site

The course WWW site [21] was a primary resource for student learning and helped provide a context for the content. It is part of an umbrella Smart Engineering site that also includes documentation for the related demonstration smart bridge project [22]. The main components of the course site are administration, content resources, glossary, and index. The first component contains a syllabus, schedule, policies, collaborative learning instruction, team guidelines, laboratory safety tutorial, and assignment guidelines.

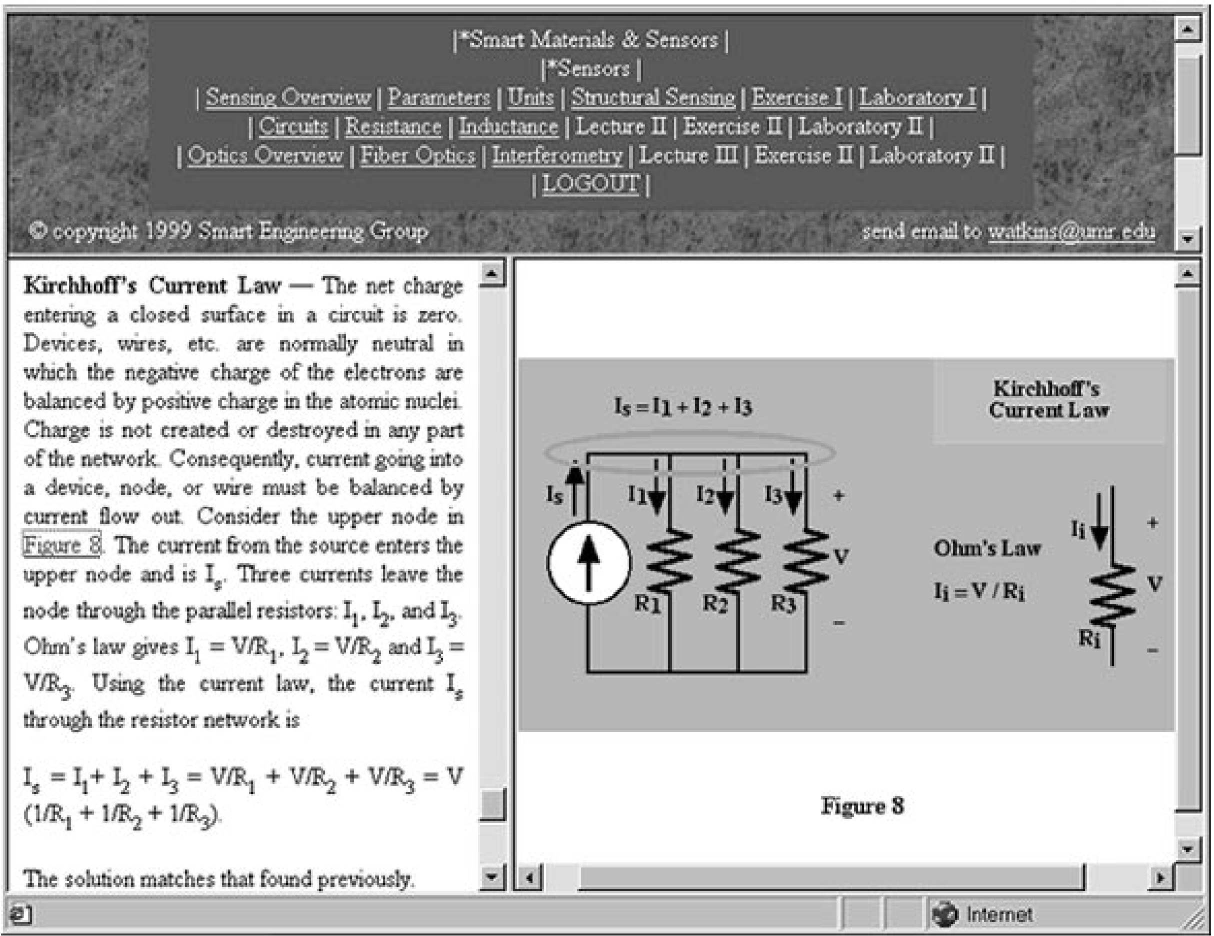

Fig. 2. An example page from the WWW sensing tutorial.

The content resources support the connected-classroom approach. Detailed tutorials of foundational knowledge for each topical area and of a case study of the demonstration bridge are included. Students were required to visit the assigned tutorials before the relevant lecture and were monitored via a tracking feature. An example page for the Smart Sensors topical area is shown in Fig. 2. The design features a clear hierarchical menu, tutorial text, and supporting graphics. Students could access text and graphics independently to accommodate learning preferences.

Fig. 3. Load test of the UMR smart composite bridge.

Table 3. Questions about knowledge, interest, and application concerning target concepts from pre/post questionnaires

	Categories		
	Knowledge	Interest	Application
Statements to be rated	'I know a great deal about (target concept).'	'I am very interested in (target concept).'	'I believe that a knowledge of (target concept) will allow me to better perform my work as an engineer once I finish my degree.'
Rating scale	1..2..3..4..5..6..7..8..9..10 Disagree to Agree	1..2..3..4..5..6..7..8..9..10 Disagree to Agree	1..2..3..4..5..6..7..8..9..10 Disagree to Agree
Target concepts	Fiber Reinforced Polymer (FRP) Composites, Active Vibration Control, Fiber Optics, Composite (FRP) Manufacturing, Strain Measurement, Composite (FRP) Materials, Bridge Design, Damage Monitoring, Smart Structures, Electrical Resistance Gages, Piezoelectric Sensors & Actuators, Optical Interferometric Sensors		

The site follows a distinct design philosophy that emphasizes the close interaction of content providers with media programmers and the careful consideration of learner characteristics. WWW users have conflicting needs for consistent and succinct content that is easy to navigate and download and for interactive and adaptable features that promote learning. Consequently, this learning environment takes advantage of the unique strengths of the media and reflects a balance of simplicity and complexity elements [23, 24].

Demonstration smart bridge

An instrumented all-composite bridge was a field laboratory for the course and provided a strong link between foundational knowledge and applications, cf. Fig. 1. This bridge was designed, analyzed, and manufactured as a companion project to the course and installed on the UMR campus. The development was a cooperative effort which was led by UMR with industry and government partners and which included substantial student involvement [21, 22, 25]. The prototype

Table 4. Example questions concerning the sensors topical area for course components by outcome category from post-questionnaire

	Course components		
	Lecture	Group activities	Laboratories
Learning	'I learned a great deal of information from the Sensors lecture.'	'I learned a great deal of information from the Sensors team activities.'	'I learned a great deal of information from the Sensors laboratories.'
Motivation	'I found the Sensors lectures to be very motivational.'	'I found the Sensors team activities to be very motivational.'	'I found the Sensors laboratories to be very motivational.'
Application	'I learned a great deal of information from the Sensors lectures that will be very useful in my work as an engineer once I finish my degree.'	'I learned a great deal of information from the Sensors team activities that will be very useful in my work as an engineer once I finish my degree.'	'I learned a great deal of information from the Sensors laboratories that will be very useful in my work as an engineer once I finish my degree.'
Metacognition	'The Sensors lectures were effective in aiding me in recognizing how much I know and don't know about smart materials and sensors.'	'The Sensors team activities were effective in aiding me in recognizing how much I know and don't know about smart materials and sensors.'	'The Sensors labora-tories were effective in aiding me in recognizing how much I know and don't know about smart materials and sensors.'
Collaboration	'The Sensors lectures encouraged me to collaborate with my classmates.'	'The Sensors team activities encouraged me to collaborate with my classmates.'	'The Sensors laboratories encouraged me to collaborate with my classmates.'
Knowledge Integration	'The Sensors lectures encouraged me to integrate information from diverse engineering disciplines.'	'The Sensors team activities encouraged me to integrate information from diverse engineering disciplines.'	'The Sensors laboratories encouraged me to integrate information from diverse engineering disciplines.'
Rating Scale	1..2..3..4..5..6..7..8..9..10 Disagree to Agree	1..2..3..4..5..6..7..8..9..10 Disagree to Agree	1..2..3..4..5..6..7..8..9..10 Disagree to Agree

Please use the following scale to respond to each of the statements in Part A:

Strongly Disagree 1 ... 2 ... 3 ... 4 ... 5 ... 6 ... 7 ... 8 ... 9 ... 10 **Strongly Agree**

The following statements refer to the class WWW site.

_____ 1. I learned a great deal of information from the **class WWW site**.
_____ 2. I found the **class WWW site** to be very motivational.
_____ 3. I learned a great deal of information from the **class WWW site** that will be useful in my work as an engineer once I finish my degree.
_____ 4. The **class WWW site** was effective in aiding me in recognizing how much I know and don't know about smart materials and sensors.
_____ 5. The **class WWW site** encouraged me to collaborate with my classmates.
_____ 6. The **class WWW site** encouraged me to integrate information from diverse engineering disciplines.
_____ 7. I visited the portion of the **class WWW site** associated with the Sensors section frequently.
_____ 8. I visited the portion of the **class WWW site** associate with the Materials section frequently.

Fig. 4. Example format for post-questionnaire for the WWW site by outcome category

structure, the first all-composite bridge in Missouri, is designed for an AASHTO H20 highway load rating [26] and features a novel composite-tube approach to short-span bridges and an embedded fiber-optic-sensor network for measurement of temperature, flexure strain, and shear strain. The rating was confirmed with a destructive laboratory test of a full-scale test article and a near-rating load test of the installed bridge.

The bridge development and testing was fully documented with technical specifications, finite element simulations, laboratory testing, manufacturing and installation procedures, cost analysis [27], and load test history. The students in the course devoted one week to the bridge project as a case study which was supplemented by video documentary of the bridge manufacture, installation, and load testing and by a laboratory exercise of the sensing network monitoring a live load test as shown in Fig. 3.

COURSE ASSESSMENT

Instruments and procedure

Pre-class and post-class questionnaires were administered during the first and last weeks for each of the three years (1999, 2000, and 2001). The students were given an entire period to complete their ratings and comments. The questions were based on target concepts identified by the content experts, i.e. the course instructors. This development of evaluation instruments used an assessment model applied by the UMR Media Research Laboratory in a number of evaluation projects [8, 23, 28]. Both questionnaires contained statements about knowledge, interest, and application for each of twelve target concepts (see Table 3). In addition, the post-class questionnaire addressed components and topics of the course, i.e. the lecture, group work, and laboratories for the sensing and materials topical areas, and the course WWW site, in conjunction with various outcomes. The outcomes were learning, motivation, application, metacognition, collaboration, knowledge integration, and frequency of WWW visits. The range of questions for the sensing topical area can be seen in Table 4 and the questionnaire format for the WWW activities is shown in Fig. 4. In all cases, the students rated their response to the statements on a scale of one (strongly disagree) to ten (strongly agree).

Pre/post item ratings as a function of experimental group

Pre/post changes in student attitudes regarding the twelve target concepts (cf. Table 3) were

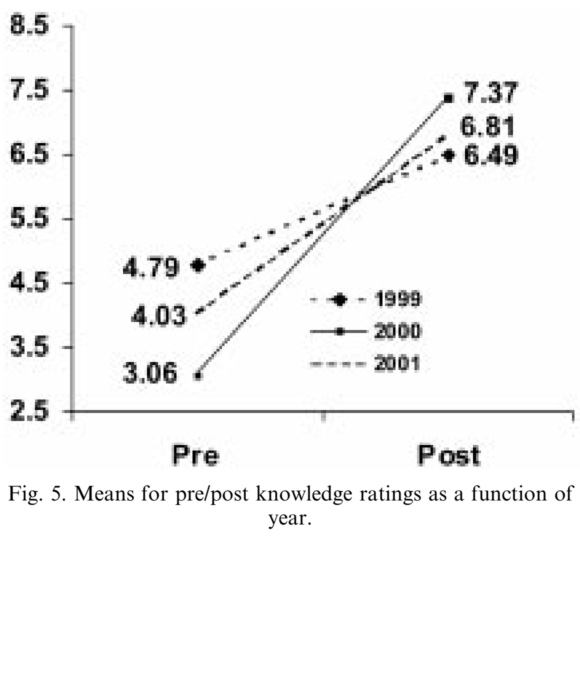

Fig. 5. Means for pre/post knowledge ratings as a function of year.

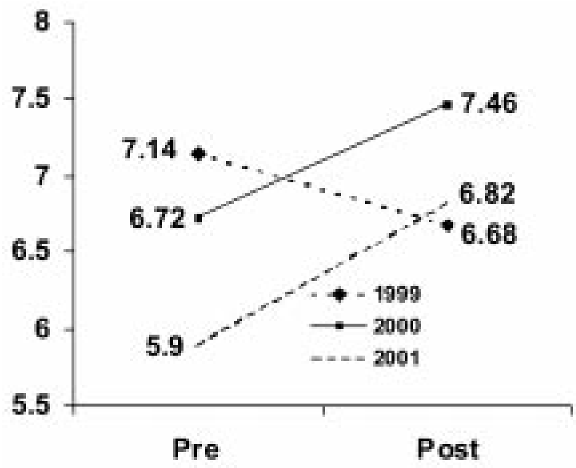

Fig. 6. Means for pre/post application ratings as a function of year.

assessed as a function of year using a series of three analyses of variance (ANOVAs). A composite score was created for each of the knowledge, interest, and application categories, which consisted of the average pre- and post-rating for the concepts. Each of the three ANOVAs was mixed with year (1999 versus 2000 verses 2001) serving as a between-subjects factor and questionnaire (pre verses post) serving as a within-subjects factor. The composite ratings served as the dependent measures in each ANOVA.

In the Knowledge ANOVA, a significant main effect was found for questionnaire $F(1,40) = 130.64$, $p < 0.001$, with students scoring significantly lower on the pre-questionnaire ($M = 3.92$, $SD = 1.56$) than on the post questionnaire ($M = 6.78$, $SD = 1.22$). In addition, an interaction was also found $F(1,40) = 8.28$, $p < 0.01$. (The means associated with this interaction are displayed in Fig. 5).

In the Application ANOVA, no significant main effects were found, but the interaction was marginally significant $F(1,38)$, $p < 0.076$. (The means associated with this interaction are displayed in Fig. 6).

In the Interest ANOVA, no significant effects were found.

Post ratings of course components as a function of experimental group

The student ratings of the course components were compared across the years through a series of twenty-five one-way between-subject analyses of variance (ANOVA). The course year (1999 verse 2000 verses 2001) served as the independent variable and the outcome rating served as the dependent measure. The results of these analyses are displayed in Table 5 for the major course components of lecture, group activities, laboratories, and WWW site. The student means are given for each year on each rating, followed by the statistical significance associated with overall F Test and explanation of Tukey's Post Hoc Tests.

Interpretation

The connected-classroom approach was favorably received by the student participants as indicated by the generally positive ratings. Also, the external evaluation committee supported the

Table 5. Post ratings of class components as a function of year

	Rating Results					
Component	Outcome	1999	2000	2001	Sig.	Post Hoc
Lecture	Learning	6.07	7.93	7.82	**	1999 < 2000 & 2001
	Motivation	5.86	6.73	6.47	ns	
	Application	6.18	7.20	6.71	ns	
	Metacognition	7.07	8.93	8.23	**	1999 < 2000
	Collaboration	6.82	7.93	7.47	ns	
	Knowledge integration	6.61	8.13	8.06	ns	
Group	Learning	6.39	7.13	7.53	ns	
	Motivation	5.93	6.27	6.29	ns	
	Application	6.07	7.12	6.88	ns	
	Metacognition	6.54	8.27	7.82	(*)	
	Collaboration	6.75	8.40	8.41	*	1999 < 2001
	Knowledge integration	6.07	7.80	8.35	*	1999 < 2001
Laboratory	Learning	5.18	7.80	7.82	**	1999 < 2000 & 2001
	Motivation	4.96	7.33	6.41	*	1999 < 2000
	Application	5.39	7.67	6.35	*	1999 < 2000
	Metacognition	5.79	8.07	6.82	*	1999 < 2000
	Collaboration	5.43	8.60	7.71	***	1999 < 2000 & 2001
	Knowledge integration	5.21	8.20	7.35	**	1999 < 2000 & 2001
WWW Site	Learning	5.07	7.53	7.00	*	1999 < 2000
	Motivation	4.50	6.07	5.35	ns	
	Application	4.79	6.13	5.41	ns	
	Metacognition	5.14	8.07	5.71	**	1999 & 2001 < 2000
	Collaboration	3.36	4.53	3.41	ns	
	Knowledge integration	3.86	6.00	6.06	(*)	
	Visited frequently	5.21	7.33	6.82	(*)	
Significance Code (Sig.)	ns not significant; (*) $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$					

objectives and methodology. In particular, they noted the synergy among the different engineering faculty and the educational specialists. Moreover, the redesign of the course between 1999 and 2000, based on evaluation feedback from the first semester and the external evaluation, appear to have resulted in substantial improvement of course effectiveness as reflected in the consistently higher ratings from students in the 2000 and 2001 classes. However, other factors, such as course composition (i.e., students), may have contributed to these improvements.

The significant main effect for the Knowledge ANOVA supports the overall effectiveness of all three years of the class. The subjective-ratings of both groups show an increase in content knowledge. Also, the significant interaction between the pre/post test knowledge and the years (1999 versus 2000 verses 2001) are indicative of improvement from the first to second year. The changes from pre-test to post-test were more dramatic for the 2000 and 2001 courses than that for the 1999 course. The main contributing factor may have been the WWW site whose primary role was to address disparities in pre-knowledge. By increasing its breadth and importance in the course activities for the 2000 and 2001 courses, the students may have been more easily brought into the interdisciplinary setting. A second factor that may have accounted for differences, which is not related to design changes, is confidence level. The 1999 class may have been more confidence in their own abilities, which may have accounted for their high pre-test rating (and may have consequently effected their expectations and their post-test rating). The 1999 class was atypical in that it had an unusually strong academic record (see Table 1) and contained a higher percentage of students from our personal graduate research groups (eight students out 14 for 1999 versus 2 out of 15 for 2000 and 2 out of 17 for 2001).

The marginally significant interaction of Application ANOVA ratings with year also indicates a more effective second and third iteration. Prior to beginning coursework, the 1999 participants rated the material to be learned as being potentially more applicable to their future careers in engineering than the 2000 or 2001 students, but in the post-test ratings, the order of the means changed (see Fig. 6). Even more dramatic is the drop in the perceived applicability of the concepts from pre-test to post-test for the 1999 class, while the 2000 and 2001 students found the class material and activities more applicable than they initially thought (as would be expected). A major conclusion drawn from the initial assessment of the first-year class was that application of concepts needed to be further emphasized and the class design was changed accordingly. Therefore, as with the knowledge-by-year interaction, these differences across years may be largely accounted for by instructional design changes, and/or may have been affected by initial preconceptions of the students.

A post-rating comparison of the three years for the class components helps interpret these effects (see Table 5). With respect to the lecture component, the 2000 and 2001 groups rated themselves as having learned more than the 1999 group. Furthermore, the 2000 group also rated themselves significantly higher on learning what they knew and did not know about the material (metacognition) than the 1999 group and the 2001 mean was substantially higher as well. With respect to the group component, individuals in the 2001 semester rated the group activities significantly higher than the 1999 students in improving their skills in collaboration and knowledge integration, and the 2000 group was substantially higher as well. Also, the 2000 and 2001 participants found the laboratories much more worthwhile than did the 1999 participants with both years significantly higher on three ratings and the 2000 group significantly higher on all six outcome ratings. These changes were very likely due to changes in course design, since one of the major redesigns, based on assessment of the initial class, was to emphasize application in the laboratory activities. Also, the field laboratory concerning the smart bridge was available for the second and third course iterations.

For the WWW site ratings, again, the 2000 class rated it as being more effective than in 1999 for several outcomes. The site was rated significantly valuable for learning and metacognition. Interestingly, the 2000 group rated metacognition more valuable than both the 1999 and 2001 groups. The 2000 and 2001 participants also rated the site substantially higher with respect to aiding in knowledge integration, and both groups gave higher ratings for the amount of visits to the site, as indicated by the means and marginally significant F scores for these ratings. The increase in usage is a result of more assignments requiring visits (which were monitored) and of added site content in the second and third years. The added visits possibly relate to the effectiveness ratings, though the direction of cause and effect is difficult to determine. On one hand, students may have found the site more effective because they visited it more frequently, but conversely, they might also have visited it more frequently based on its usefulness in completing course assignments.

SUMMARY

This curriculum model is an example of interdisciplinary experience for students, shows effective transfer of current research to the classroom, and is supported by an instructional structure that incorporates a cognitive sciences methodology and by a WWW-based resource with clear educational goals. The course has been implemented, assessed, and revised over three semesters and has been given a permanent number at UMR. The student participants were from five engineering disciplines and rated the learning experience favorable in most respects. Student comments were mostly positive and their criticisms tended to relate to emphasis and detail rather than approach. As per the course design, the most satisfied and successful teams were those that took time to teach each other concepts and vocabulary. Teams that initially tended to work independently of one another and that tried to assemble assignments with little true collaboration were frustrated until they began interacting. Also, students that we supervised on research projects following the course displayed markedly improved independence and group skills [29].

We believe that the connected-classroom design can assist in the development of difficult interdisciplinary skills and can aid in bringing new multidisciplinary technology to application. Students need to experience situations that require collaborative effort and that connect knowledge to applications. The structured environment promoted active learning and student interaction through a series of progressively more involved assignments. A major difference from traditional courses is that the learning outcomes are intended to be different for the various disciplines and, to some extent, for the students within a discipline. In particular, each student was faced with rather straightforward in-major content and fairly challenging out-of-major content, and had a non-contrived team environment requiring extensive interdisciplinary collaboration.

The course has been taught a limited number of semesters and is still a work in progress. However, several general conclusions can be drawn from the research. The learning effectiveness seems to be very dependent on two factors. First, the interdisciplinary mix of students brings wide disparities in pre-knowledge to the course activities. In our model, the WWW tutorials and the group assignments must effectively address these disparities. Second, the foundational knowledge and the group activities must directly relate to applications. The instrumented bridge, as a working demonstration, was a particularly effective resource. Our plans for the course are to further develop the WWW resources and to add application elements, e.g. videos of research tests, as well as to give more guidance and structure to the group activities. The experience gained in designing tutorials and instruction for students with diverse backgrounds is also being applied to a similar short course for working engineers.

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