The Iron Range Engineering (IRE) Model for Project Based Learning in Engineering

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Abstract
In the heart Minnesota's Mesabi iron range, a new model for engineering education has been funded and began delivery in January 2010. The IRE (Iron Range Engineering) model is a project-based-learning (PjBL) model in which students work with industry or entrepreneurs on design projects with a focus on producing graduates with integrated technical/professional knowledge and competencies. Students at IRE are upper-division mechanical engineering students, enrolled at Minnesota State University Mankato, who are mostly graduates of Minnesota's community colleges. IRE students do not take classes;100% of their learning is done in the context of the industry/entrepreneurial projects. The PjBL model readily lends itself to regional economic development making the IRE program an education/economic hybrid system.

Overview
Since the publication of *Engineer 2020* [1] (and before) there have been numerous calls for a new-look graduating engineer. With guidance from some of the most respected leaders in engineering education, the IRE model has been developed to utilize industry-based project-based-learning (PjBL), outcome-based assessment, just-in-time interventions, self-directed learning, and emphasis on reflection to graduate engineering practitioners with integrated technical/professional competency.

Educating Engineers: Designing for the Future of the Field [2] together with other recent research and reports on engineering education, make a compelling case for envisioning engineering education in a new way. The new Iron Range Engineering program explores a completely different way of approaching engineering education. Some of the characteristics of this new approach are:

> * Primary emphasis is on development of learning outcomes that have been spelled out in national reports, including *The Engineer of 2020*. This emphasis is contrasted with primary emphasis on coverage of topical material that characterizes many of the engineering programs throughout the world.
>
> * Faculty members in the program invest heavily in developing abilities of students in the program to assess their development with respect to these outcomes. To support self assessment, faculty members articulate criteria with which development with respect to these outcomes can be evaluated.

* Learning activities are organized around externally-sponsored projects. Each semester, students manage projects in which they perform engineering functions such as design, development, research, testing, etc. for local and regional industries and entrepreneurs. Faculty members use the projects as contexts for developing competencies and learning subject matter.

* This contextual problem based learning model provides an exciting environment for synergism between education and economic development. Learning by working on externally sponsored projects from industry and inventors, the innovation process is moved into the undergraduate education process and allows for more globally competitive regional industries and the promise of new hi-tech start-up companies.

* Students complete course and graduation requirements by exceeding or meeting levels of competencies with respect to clearly articulated outcomes using a modified Bloom's Taxonomy.

Rationale Supporting Need of "New Look" Engineer

The evidence for needing and the calls for a new model of engineering education are extensive. These calls have come from a wide variety of sources, such as:

- The National Academies of Engineering (NAE) in *The Engineer 2020* and *Educating the Engineer of 2020* publications:

  "If the United States is to maintain its economic leadership and be able to sustain its share of high-technology jobs, it must prepare for this wave of change. Although there is no consensus at this stage, it is agreed that innovation is the key and engineering is essential to this task; but engineering will only contribute to success if it is able to continue to adapt to new trends and provide education to the next generation of students so as to arm them with the tools needed for the world as it will be, not as it is today." [3]

- The National Science Board (NSB) in *Moving Forward to Improve Engineering Education*:

  "The Board feels that a continuation of the status quo in engineering education in the U.S. is not sufficient in light of the pressing demands for change". [4]

- The leaders in engineering education through several American Society for Engineering Education (ASEE) Journal of Engineering Education (JEE) Articles:

  "Converging on a view of engineering education that not only requires students to grasp traditional engineering fundamentals, such as mechanics, dynamics, mathematics, and technology, but to also develop the skills associated with learning to imbed this knowledge in real-world situations. This not only demands skills of creativity, teamwork, and design, but in global collaboration, communication, management, economics, and ethics." [5]

> "In view of the broadening and rapidly shifting scope of the engineering profession, it is imperative to shift the focus of engineering curricula from transmission of content to development of skills that support engineering thinking and professional judgment. Future engineers will need to adapt to rapidly changing work environments and technology, direct their own learning, broaden an understanding of impact, work across different perspectives, and continually revisit what it means to be an engineer. Traditional approaches to engineering education (chalk-and-talk lectures, individual homework, three years of "fundamentals" before an introduction to engineering practice) is incompatible with what we know from decades of cognitive and classroom research". [6]

The need for change is not new and should be considered part of the continuum of change our society is going through. The same need existed in the middle of the 20th century in the United States as summarized in:

- President Barack Obama's Remarks at the April 27th, 2009 National Academy of Science Annual Meeting:

  "A half century ago, this nation made a commitment to lead the world in scientific and technological innovation; to invest in education, in research, in engineering; to set a goal of reaching space and engaging every citizen in that historic mission. That was the high water mark of America's investment in research and development. And since then our investments have steadily declined as a share of our national income. As a result, other countries are now beginning to pull ahead in the pursuit of this generation's great discoveries ... That's why my administration has set a goal that will greatly enhance our ability to compete for the high-wage, high-tech jobs of the future –- and to foster the next generation of scientists and engineers. In the next decade –- by 2020 –- America will once again have the highest proportion of college graduates in the world. That is a goal that we are going to set." [7]

It is in the context of a defined need for change, the call for change, and the *Educating the Engineer of 2020's* call for system level approach that the IRE model was developed.

Rationale Supporting IRE Model

The same sources that have called for a change in engineering education have also given directions for this change that led to the aspects of the IRE model of student empowered development of technical and professional knowledge and competencies in context of industry sponsored project-based learning.

The call for engineering education to be **student empowered** (or centered) **development of** competencies is summarized in the:

- *Educating the Engineer of 2020* focus on the need for student focus in the curriculum development:

  *"Pursue Student-Centered Education - One should address how students learn as well as what they learn in order to ensure that student learning outcomes focus on the performance

characteristics needed in future engineers. Two major tasks define this focus: (1) better alignment of engineering curricula and the nature of academic experiences with the challenges and opportunities graduates will face in the workplace and (2) better alignment of faculty skill sets with those needed to deliver the desired curriculum in light of the different learning styles of students." [1]

The focus on **technical competencies** has been a hallmark of engineering education, but the need for **professional competencies** to be addressed as an equal are more than evident in the:

- *Educating the Engineer of 2020's* recognition that "the disconnect between the system of engineering education and the practice of engineering appears to be accelerating. This is due to the explosion of knowledge, the growing complexity and interdependence of societal problems, the worldwide reach of those problems, and the need to operate in a global economy" [3]
- ABET Criterion 3, program outcomes; where out of the 11 outcomes that programs must demonstrate their students attain, the following 7 have a professional component to them [8]:
  (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
  (d) an ability to function on multidisciplinary team
  (f) an understanding of professional and ethical responsibility
  (g) an ability to communicate effectively
  (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
  (i) a recognition of the need for, and an ability to engage in life-long learning
  (j) a knowledge of contemporary issues.

The IRE model is designed to specifically meet the model of engineering education being called for by those leading the way for engineering education to meet the engineering needs of the future.

Description of Revolutionary Model for Engineering Education in the United States
The IRE model was delivered for the first time starting in January 2010 in Virginia, Minnesota as a collaboration between Itasca Community College and Minnesota State University Mankato.

The IRE Model is:

Student empowered **development of** technical and professional **knowledge and competencies in context** of industry/entrepreneur sponsored project-based learning, leading to regional economic development

Project-based-learning (PjBL):
In an adaptation of the Aalborg Model of PjBL (Figure 1), IRE students combine learning of technical information with the execution of engineering design projects (note: this model is 100% project based and does not include traditional courses).

Entering students are community college graduates or transfer students from other universities who have all completed lower division requirements for a BS in Mechanical Engineering. The IRE model is the four semester upper division portion of a student's education. Graduates will be conferred a bachelors degree in mechanical engineering. Students execute one to two project cycles per semester.

During the proposal stage, students, in collaboration with faculty and clients, develop two plans: a design "work plan" which details the entire execution of the deliverable to the client; and a "learning plan" which addresses professional learning objectives, technical learning objectives, and the learning modes that will be employed to meet the objectives (self-directed learning, peer-directed learning, faculty-directed learning, and external expert-directed learning as well as methods for formative assessment and reflection).

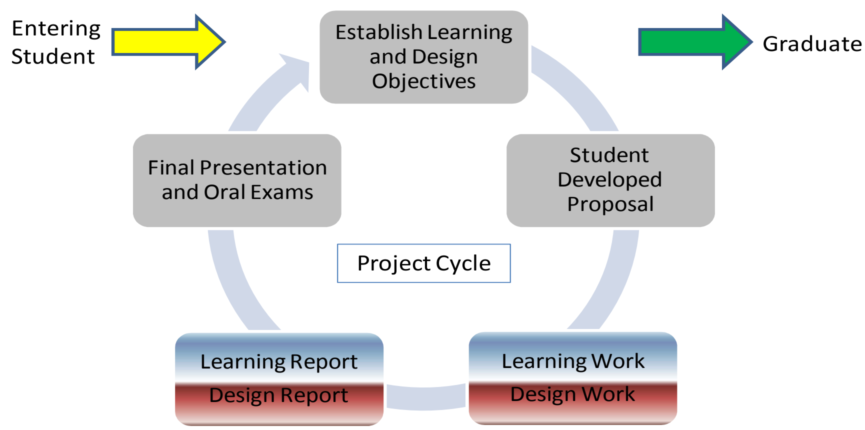

Figure 1. An adaptation of the Aalborg Model of PjBL for use in the Iron Range Engineering Program [9]

Projects are industry or entrepreneur sponsored. IRE is located in the heart of Minnesota's Iron Range. Within short driving distance there are five iron mines, two coal generation power plants, a wind-turbine farm, two paper mills, a new precious metals mine, and proposed steel mill. The managers and engineers in these industries have embraced this program and committed to providing projects, project guidance, technical expertise for student learning, and assistance in assessment. As an example of a project – In Spring 2010, an IRE student group designed and implemented a condenser performance test to be applied to the power generation condenser on a 400 MW power plant. The performance test will give several indications of efficiency both before and after the condenser is retrofitted. The results of the testing will give Minnesota Power vital information on the cost savings and payback period. To perform the project, the student group learned cycle analysis, conduction heat transfer, convection heat transfer, heat exchanger design, engineering economics, evaluation theory, and studied the environmental implications all in the context of a real deliverable for a major client. A technical report was published and five oral presentations were made.

As another example of the PjBL model effectiveness, four design projects were entered into a statewide business plan competition with over 1000 total entries. The IRE program placed 3 of the four in the top 10 in their respective divisions, with one placing in the top 3 as a finalist.

Technical and Professional Knowledge and Competencies:
The IRE developers have broken technical and professional knowledge and competencies down into a finite number of measurable outcomes. For each outcome, a continuum from novice to expert using Bloom's 2D taxonomy (see Figure 2.) is being applied.

In the beginning of each student's first semester, she works with faculty to establish her individual starting point on each outcome. In this way, the IRE model recognizes each student's different starting points and empowers all students to build on their strengths and overcome their weaknesses as they navigate their education. To graduate, each student has to attain "work ready" competency.

Student empowered design and monitoring
A guiding principle for the IRE model is that students own the responsibility for their learning. At the beginning of each project cycle, students identify which outcomes will be addressed during the project. Working with faculty, they determine which learning modes will be applied and determine what types of evidence they will need to acquire to demonstrate outcome attainment by the end of the project cycle. Each project cycle concludes with the presentation of two reports - a design report for the deliverable and a learning report that reflects on the learning process and provides evidence of outcome attainment. In addition to written reports, there is a student presentation made to faculty and external clients. The final presentation includes an extensive oral exam session in which students demonstrate their understanding of technical engineering knowledge gained and competencies acquired. At the conclusion of each project cycle, students have a new view of their levels of knowledge and competencies.

Brief History
In March 2009, the Minnesota Iron Range Resources Board (a group of eight members of the Minnesota State Legislature) decided to establish a new engineering program on the Iron Range in Minnesota. The program is the result of five years of planning and development by a small team of engineering educators from across the country. This group sought to use the new knowledge on how people learn to empower students to take ownership of their education and gain their knowledge and competencies, with special emphasis on the professional competencies as they are articulated in ABET a-k and Engineer 2020, in the context of learning engineering by practicing engineering side-by-side with engineers.

Iron Range Engineering is an extension of Itasca Community College Engineering in Grand Rapids, Minnesota. The ICC Engineering program, under the direction of Ron Ulseth, reached national prominence in engineering education through building learning communities, and providing an outstanding foundation in the first two years of an engineering program.

Today the IRE program is directed by Dr. Dan Ewert who comes to IRE after 19 years at North Dakota State University, the last 7 as a department chair. IRE has two distinct advisory boards - one from industry which provides significant input on how IRE meets the region's engineering and economic needs and another advisory board from academia that includes engineering education experts who provide guidance on learning outcomes, concrete expectations for when students have achieved competency levels, how students should be assessed with respect to learning outcomes, how progress with respect to these learning outcomes is made transparent to the students, what processes should be in place to support assessment, student learning, student development, and student growth, etc. The IRE Academic Advisory Board meets monthly to provide developmental guidance. Members are: Dr. Sheri Sheppard, Stanford University; Dr. Jeffrey Froyd, Texas A&M; Dr. Denny Davis, Washington State University; Dr. Thomas Litzinger, Penn State University; Dr. Edwin Jones, Iowa State University and St. Thomas University.

Knowledge Dimension	Process Knowledge							
	Conceptual Knowledge							
	Factual Knowledge							
		No Exposure (0)	Remember (1)	Understand (2)	Apply (3)	Analyze (4)	Evaluate (5)	Create (6)
	Cognitive Dimension ==>							

A. Factual Knowledge: The basic elements that students must know to be acquainted with a discipline or solve problems in it.

Aa. Knowledge of terminology

Bb. Knowledge of specific details and elements

B. Conceptual Knowledge: The interrelationships among the basic elements within a larger structure that enable them to function together.

Ba. Knowledge of classifications and categories

Bb. Knowledge of principles and generalizations

Bc. Knowledge of theories, models, and structures

C. Procedural Knowledge: How to do something; methods of inquiry, and criteria for using skills, algorithms, techniques, and methods.

Ca. Knowledge of subject-specific skills and algorithms

Cb. Knowledge of subject-specific techniques and methods

Cc. Knowledge of criteria for determining when to use appropriate procedures

1.0 Remember: Retrieving relevant knowledge from long-term memory.
- 1.1 Recognizing
- 1.2 Recalling

2.0 Understand: Determining the meaning of instructional messages. Including oral and graphic communication.
- 2.1 Interpreting
- 2.2 Exemplifying
- 2.3 Classifying
- 2.4 Summarizing
- 2.5 Inferring
- 2.6 Comparing
- 2.7 Explaining

3.0 Apply: Carrying out or using a procedure in a given situation.
- 3.1 Executing
- 3.2 Implementing

4.0 Analyze: Breaking material into constituent parts and detecting how the parts relate to one another and to an overall structure or purpose.
- 4.1 Differentiating
- 4.2 Organizing
- 4.3 Attributing

5.0 Evaluate: Making judgment based on criteria and standards.
- 5.1 Checking
- 5.2 Critiquing

6.0 Create: Putting elements together to form a novel, coherent whole or make an original product.
- 6.1 Generating
- 6.2 Planning
- 6.3 Producing

Figure 2. Bloom's 2D Taxonomy as utilized to chart student acquisition of technical competency through oral exams, design reviews, portfolio assessment, and the presentation of other evidence. At graduation an "A" student is expected to have an average 4.5 across all technical and professional competencies.

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Implementing Social Learning Strategies: Team Testing

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ABSTRACT

This paper describes how to provide collaborative learning opportunities and fast feedback on exam performance by adding a team component to examinations. The method is supported by research in collaborative and active learning pedagogy and has been applied to computer science courses ranging from first-year programming to graduate-level artificial intelligence. This paper relates the use of team tests in two different university settings, with a range of implementations. Furthermore, it offers suggestions for customizing the technique to fit a specific classroom environment.

1. INTRODUCTION

Finding the time and opportunity to incorporate active and collaborative learning in your classes can be challenging. Team testing is a collaborative learning activity with low implementation costs and multiple advantages for both students and faculty. Along with the obvious benefit of developing team problem solving and discussion skills, students receive fast feedback on their performance, the instructor spends less time reviewing the exam (in class and with individuals), and the classroom environment benefits from the added value placed on collaboration and reciprocal learning. This paper describes a number of variations on the team testing idea and discusses how factors in the course affect the type of team test to develop.

In a team test, the students complete an individual test paper as well as a group test paper. The individual component enforces individual accountability and allows the instructor to ask questions in formats that do not naturally benefit from a group discussion. The group component asks the students to evaluate others' ideas and to synthesize a solution that incorporates the best ideas generated by the members of the group. Due to the need to compare and defend ideas, questions on the group test naturally elicit and evaluate higher-level cognitive functions like analysis, evaluation and transfer [1]. By doing so, team testing converts the evaluation environment into a learning environment. Depending on instructor goals, team tests can be structured to reinforce evaluation goals or learning environment goals.

Conventional wisdom holds that test periods are lost instructional time, but we recall that in our own experience as students, good exams often led to a more complete understanding of the material by forging relationships between domains and encouraging deeper insights. One student who participated in a team test reported, "You can collaborate and discuss what the general consensus of the answer is. … You [can] see why their answer might be more correct." By leveraging the motivation that an examination conveys, team testing encourages active discussions between well-prepared individuals and fosters an ideal collaborative learning environment.

In addition to evaluating and encouraging higher levels of proficiency, team testing reduces the latency between evaluation and feedback. Exams give faculty an important opportunity to evaluate students, but they also serve to inform students of their progress and to point out areas where work is needed. Feedback should be timely to reduce exposure to content misperceptions and reinforcement of correct understandings [3, 10], but the time required to provide feedback to students is dependent on faculty time and the availability of grading support. The pressures on faculty time are discussed at length at conferences and meetings, and institutional budgets dictate whether grading support is available. In practice, this means that feedback is provided more slowly than desired, but team testing provides immediate feedback by exposing students to their peers' understanding of the material and testing their ability to contribute to the group's solution. By providing students with more timely feedback, team testing reinforces foundational knowledge that the remainder of the course requires.

In the next section, we describe the baseline team testing implementation. Section 3 provides the pedagogical theory supporting the idea, and Section 4 presents our experiences using variants on the baseline team testing implementation in the classroom.

2. IMPLEMENTING TEAM TESTING

2.1 Giving the Exam

The exam format depends on the ultimate goal of the group exam: evaluating content knowledge in a group context or creating a learning environment. To assess individual ability, an exam is given to each student. The individual exam is evaluated and typically forms the majority component of the student's score. After the individual exam, there is a group component, which can either be a required part of the exam (evaluation goal) or considered a bonus (learning environment goal). Groups of 3 to 4 students collaborate on the group test. Larger groups reduce the impact of individual voices, and groups of two often suffer from a dominant (but not necessarily stronger) partner. The group exam can be given in the same class period, if time is available, or in the following period. Providing a gap between the two exams can be beneficial because students can shore up weaknesses in their understanding brought to light by the individual exam. However, not too much time should be allowed, since more misconceptions in understanding will be uncovered by the group exam than by the individual exam, and it is important to provide fast feedback.

Before the exam, students must prepare sufficiently to be ready to actively engage during the exam. Without adequate preparation, students may find it too easy to passively rely on the group consciousness and may not be capable of identifying gaps in their own knowledge during the discussion. To encourage individual accountability and active discussion during the exam, the students must follow two rules.

1. Each student must write some of the answers.
2. All students must agree on every answer submitted.

When there is a "hung jury", students can be encouraged to record the top two positions with a supporting argument for each. This becomes an answer the group can agree on.

During the group exam, the instructor's job is to facilitate discussion. As with any type of classroom problem solving, the instructor should move from group to group to keep students on task, to refocus or raising questions when necessary. If the goal is to facilitate learning rather than evaluate current knowledge, instructors can provide hints or feedback about trains of thought. At the same time, the instructor can encourage individual accountability by drawing out students not actively participating or by keeping time and calling for groups to select a new student to record answers.

2.2 Setting the Questions

The individual component and group component should test the same domain of material so that the students gain the benefit of fast feedback. The questions on the two components may be the same or may differ in the level of proficiency exercised and evaluated. The type of questions featured on a group component will differ based on the level of the students in the class and the instructor's learning objectives. The instructor may generate new questions for the group exam, but in many cases, asking the students to compare, analyze, or evaluate their answers from the individual exam enables a deeper exploration of the question in the collaborative context.

In early classes, where goals are often related to content knowledge and application within a defined setting and where students are less experienced learners, the questions will focus on factual or procedural knowledge and may not differ from the individual exam. Presenting the same problem on both exams prepares the students for discussion and encourages them to have a stake in a specific answer. Students at this level benefit from comparing answers and debating which is most correct [1].

For more advanced courses with mature learners, questions that focus on factual knowledge are less useful on the group exam as they do not foster in-depth discussion. The format favors open-ended problems that require students to evaluate and compare several possible solutions to reach a solution or that ask them to evaluate the context in which their knowledge is being applied.

3. SUPPORTING IDEAS

3.1 Theoretical Foundations

The theoretical foundation for this teaching method stems first from the work of Vygotsky who described a social constructivist framework for learning. In this type of setting, learning is enhanced by interaction with others beyond that which is possible individually [15,16]. Building community via discussion and collaborative learning can support the integration of academic and social experiences upon which student success has been shown to depend [14,18].

The ideas of active, collaborative, and reciprocal learning stem from Vygotsky's framework. In general, active and collaborative learning promote greater positive attitudes towards learning and the subject matter [6]. In reciprocal learning, students take turns teaching others. This is built into the structure of this approach, which strengthens student understanding of the material for both strong and weak students. Guided instruction [5], where scaffolding built by the teacher is reduced until the student has responsibility for learning, also motivates this approach: exams are used as a source of learning and content discussion, with students building community through their interaction with each other. Along the way, they build communication skills and communication abilities. In terms of team building, this approach has a low time-cost. By using the two simple rules presented in Section 2.1 to guide the process, we address the finding that students succeed best in teamwork when there are specific instructions about listening, leadership, consensus building and conflict resolution [7,12].

Even though collaborative learning has been supported by the National Science Foundation and recommended by the education community, it is still not widely practiced in engineering classrooms [13]. When implementing active learning, faculty sometimes find it difficult to give up their role as controllers of knowledge [2]. However, giving an exam is an expected part of both traditional and active classrooms. As such, team testing may be a relatively comfortable step to take towards a more active classroom. Within computer science, team programming has been shown to enhance learning and community (e.g., [9]). Team testing can augment a class using team programming or provide similar benefits when used alone.

Feedback is generally considered important in learning and there is a growing body of work (and technology[1]) related to providing fast feedback (e.g., [3,10]). Unfortunately, not much, if anything, has been published on the use of discussion as a fast feedback mechanism or the return speed of graded exams and assignments. However, structured discussion with peers is a well-known method for increasing engagement and enhancing learning [11,17]. Psychology research has shown that reinforcement, through punishment and/or rewards, is important to learning and that learning is easier when the reinforcement closely follows the action [4]. Team testing provides the reward of rapid feedback in two ways. First, it provides students with solution feedback and secondly, it provides feedback about their own performance and how it relates to the performance of their peers.

3.2 Justification

The time spent in collaborative learning is beneficial to the students because they are able to practice group problem solving with likely rewards. The students have spent time considering the problems before discussion, which encourages them to become more involved. In fact, team-testing discussions are amongst the most lively and energetic in our courses, in part because of emotional reactions to learning answers but also because each students is prepared for the discussion. The students are clearly connecting the content to a social learning environment.

Many teachers spend a significant amount of class time going over the correct responses to an exam, or worry that they cannot take the time to do this without losing content coverage. Rather than spend the same amount of time going over the exam, a team test allows students to discover, justify and own the answers. By having students spend time working through the exam with each other, the students become teachers, participating in reciprocal learning.

For planning teacher-to-classroom feedback, the group exams give a better picture of which concepts were globally missed or were difficult. As with any exam, this can be useful feedback about the teaching of the content, with even more weight because the results have been filtered through both individual minds and group consideration. When the teacher discusses the exam, the concepts missed after the group exam can be the focus, thus reducing faculty review time.

3.3 Benefits

One model of active learning separates "doing" from "observing" and differentiates between dialog "with self" and "with others" [6]. Group tests contain room for both types of dialog. First, the solo test forces to the student to hold a dialog with self, with the instructor as audience. Next, the group section asks the students to enter into a dialog with others -- potentially with problems they have already considered and prepared answers for. While this dialog enhances learning, it

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[1] The Web-based Interactive Science and Engineering Learning Tool at Oregon State University is an example of fast-feedback technology [8].

also enhances the sense of community. Rather than prolonging a competitive evaluation atmosphere, a collaborative environment is available for students who prefer collaboration over competition.

In terms of feedback, after taking a team test, especially one identical to the individual exam, students leave the room knowing which of their answers are likely to be correct. One problem in test-taking is when smart students apply their own logic to problem solving but do not necessarily have the grounding knowledge. The logic may be solid but the answer is not correct. Discussion and skeptical questioning leads the group closer to a correct answer. As one student reported, "It was pretty productive because you could give an answer … but someone could give a rebuttal. … It would help you out in your understanding."

Comparing performance on team and individual tests has made it possible to give students feedback not only on their content knowledge but also on their confidence in their knowledge. One student reported, "Having someone else's word that something is correct feels like you are given more confidence in what is right and wrong." Another was the only one of his group to get the answer correct on the individual test but was unable to persuade his peers to change their minds. After written and verbal encouragement, this student began to advocate his knowledge more strongly. At other times, we have observed students who are prepared but not confident in their knowledge be pleasantly surprised to find that they are at the same level, if not higher, than their peers.

4. TEAM TESTING IN THE CLASSROOM

Team testing has been employed in a total of nine different courses at two separate institutions: Minnesota State University, Mankato (MSU) and the University of Toronto Mississauga (UTM). The classes spanned the curriculum, ranging from first year programming to third year operating systems to graduate level natural language processing, so they display a variety of sizes (5-50 students), learners (novice to independent), and content (logical and algorithmic problem solving as well as design of large systems).

In this section, we introduce factors that affect the effectiveness of team testing and influence how it should be deployed. We report anecdotal evidence from our own experiences with team testing, relating students concerns and feedback wherever possible. The discussion focuses on the conditions in the classes that caused us to alter the team testing implementation.

4.1 Class Size

Team testing has been successfully used in classes of up to 50 students. However, the physical space should be large enough to allow space between the groups. Because discussion can get lively and faculty interaction is helpful, it works especially well in classes from 20-30. On the other end of the spectrum, it has been done with as few as 5-6 students. In this case, a single discussion group works, even though there are more than the preferred 3-4 students, because in very small classes, a group dynamic of discussion and problem solving often exists already.

4.2 Reward Systems

The most important variable that affects how students perceive team testing is its impact on their final grade. In its original form, we imagined team testing to be an opportunity to practice good discussions and to convert an evaluation environment into a learning environment. Students in a learning environment should feel comfortable practicing new skills, which suggests that the evaluation weight should be low or nonexistent. At the same time, team tests work because the students come to the activity prepared and motivated, so we cannot simply eliminate the “test” component of team tests.

The original versions of team testing at MSU made the team test voluntary and offered extra credit for participating. In our experience, offering just 5% bonus credit on the individual exam causes an overwhelming fraction of students to remain for the team-test. The bonus points offer a tangible reward to the students, countering the stress that comes with exams and grades, while providing motivation to invest energy and preparation in a good outcome. As a result, students did not appear to feel stressed by the addition of the group component of the exam, but they did actively engage in the exercise.

In contrast, the academic culture at UTM made it difficult to offer bonus credit on an exam, so the group component of the exam was weighted as a small fraction (10%) of the overall exam mark. As a result, initial student reaction to the team test was quite different at UTM, with students expressing concern about being placed in a group with perceived “weaker” members and feeling stress preparing for the group activity. Instead of viewing the team test as an opportunity to collaborate, the students reacted negatively to a personal evaluation being affected by a factor outside of their control.

The instructors also perceived noticeable differences between the two exam environments. By offering extra credit for the team test, the MSU instructor was able to treat the exercise as a collaborative *learning* activity. She circulated among the groups, asked questions, and redirected groups that strayed off track. The UTM instructor, however, felt uncomfortable intervening in individual groups and felt that the exercise was an *evaluation*.

Nevertheless, in both cases, discussion within the groups was vigorous, and after the experience, students were pleased with the group exam. Both sets of students viewed the group discussion as a means for improving their overall mark, and many students enjoyed the activity.

4.3 Marking

The reward system chosen also impacts how the team test is marked. When assessing collaborative learning, the basic approach is to provide independent and interdependent assessment for group work [6]. The independent component of the exam maintains individual responsibility. If the reward is minimal and the focus is on learning, rather than evaluation, then the grades for group exams can be coarse, reducing grading time and ignoring small differences between groups. If the focus is on evaluation, then more care needs to be spent on the marking to provide formative feedback on the group’s effectiveness.

In our experience, due to the low weight of the group component and the focus on learning rather than evaluation, grading on group exams can be generous, not requiring a 100% correct answer to get full marks, making the reward positive for the students while still allowing for fast feedback. One student in particular was concerned that the other members of the group would not share his desire for excellence: “I really have a hard time doing the group thing as I strive to get the best grade and working in a group seldom allows for that opportunity.” A small reward provides motivation, and keeping the reward small enough to avoid further stress about the results of the group exam reduces complaints and classroom tension if a student feels he or she has been placed in a “bad” group.

4.4 Exam Composition

Team testing supports many different kinds of questions, and the relationship between questions on the individual exam varies depending on the instructor's objectives. At both MSU and UTM, the instructors favored reusing questions from the independent component of the test. In our experience, relating the questions on the two exam components increases discussion since each student has spent some time thinking about the question and formulating an answer to which they have some emotional attachment. MSU had some success reusing exactly the same questions, and they found that solutions to group exam questions were noticeably stronger than typical answers on the individual exam. UTM tended to ask follow-on questions and saw similar results. Re-using questions also relieves one concern students reported about team tests – that the material on the group component would be significantly more difficult.

Regardless of the type of questions used, the group component should contain far less material than the individual component. When using a reduced set of problems rather than a full test, we found that students would delve deeply into related issues, starting discussions about theory and context that are rare in a regular classroom. In an electric circuit theory class, team testing was used on weekly quizzes. A short, two-problem quiz was given and then the same two problems were given to student pairs. After the first week, the team quiz was reduced to one problem, because students spent so much time discussing the application of theory. As a result, they were often able to show better understanding during this phase than on their individual quiz.

4.5 Instructor Time

Team testing does create some additional work for the teacher: creating a second exam and grading additional questions. This can be minimized by using the same (or at least related) questions on the group component and by coarsely grading the team work. Furthermore, marking time on the individual component is reduced since less feedback needs to be provided. Since the students have discussed the questions, they often better understand how they earned their grade, so students ask fewer questions about marking in office hours and by email. Instead, some student groups used office hours to continue the group discussion with instructor adjudication.

4.6 Exam Timing

When giving the team tests, the class structure made a difference in the method and the time allowed for team tests. When the class session is long enough (1.5 to 2 hours), immediately following the individual exam with the group exam works well. When there are recitation sections or labs, a portion of that time can be used for the team test instead of using extra lecture time. Giving a team test in the next class period, especially with time at the end for classroom discussion and questions also works, but it weakens the feedback link.

Students who have become accustomed to both the feedback and reward of group exams have asked for them at the final exam. In these cases, a slightly reduced exam time, e.g., from 120 minutes to 90 minutes, allows time for a team test as well as comprehensive coverage of course content. This gives students feedback they might not otherwise receive at the end of a term.

We have not yet tried giving a group exam before the individual exam. We feel this would increase exam preparation time since the group exam questions and individual exam questions would need to be more decoupled for a fair individual assessment. We are also concerned that discussion would be weaker, since the students would enter the group component with less preparation.

4.7 Group Formation

For any type of team work, the selection of the teams and the roles assigned to the team members has an impact on the team's success. The goal of group formation is to create effective groups, giving students a fair chance to do well while minimizing the problems that come with group work. We have used a wide variety of heuristics including student physical proximity (both close and distant), splitting up friends/lab partners/long term groups, and coupling weaker and stronger students. With one notable exception, the groups functioned well regardless of their method of creation. In that case, a student acknowledged as being exceptionally strong inadvertently dominated discussion, since his group was unprepared to challenge his ideas. Teacher intervention is required in this situation. The other students may be encouraged to enter the discussion by asking them to justify why they agree with the proposed solution.

At UTM, where the group component is a fraction of the test mark, some students requested that they be informed of group pairings before the exam to facilitate the formation of study groups. Despite some initial concern that releasing the pairings would result in the responsibility for studying material being split up among members of the group, we found that the individual exam led students to study all of the material. As a side benefit, some of the study groups that were formed because of the team test continued to meet later in the term.

We have not investigated assigning teams on a long-term basis but believe it would be an interesting avenue for future study. This approach would reinforce the social learning aspect and allow for more flexibility in negotiation of roles within a team.

5. SUMMARY

Team testing enhances student learning by providing faster feedback and using collaborative learning to develop higher order cognitive skills. It leverages student desire to thoroughly prepare for evaluation to increase engagement in a focused small-group discussion. In doing so, team testing converts an evaluation environment into a learning environment.

Team testing is a flexible idea which we have successfully implemented in many types of courses for a broad range of students, learning goals, and content foci. Since the exercise often repurposes material already generated for the individual component of the exam and decreases time spent reviewing exam solutions, we have found team testing to be a low-cost method for introducing collaborative learning into the classroom. More importantly, students have responded extremely positively – even going so far as to request a team test for the final exam!

6. ACKNOWLEDGMENTS

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Problem-Based Learning in Engineering Education: Reflections, Practices, and Challenges

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Abstract

This paper focuses on the utilization of problem–based learning (PBL) in an engineering program, and argues that implementation of problem-based learning needs to be placed in a context and must be developed with careful consideration of the social, economic, and ethnic diversity of the student population and the university academic culture and prevailing norms. The paper includes a brief history, selected PBL models, strategies to infuse PBL in an engineering program, and suggestions for redesigning classes and courses to catalyze change in the classroom environment through student engagement. The paper, also, addresses the potential difficulties that could arise during implementation of PBL, and argues for the need to conduct research in order to guide the process of transition from the old to the new paradigm.

Introduction

Achieving change via engineering education reform is a formidable challenge to any college of engineering, whether in North America or anywhere else in the world. In the past two decades, engineering educators have tried to implement relatively new methodologies in the classroom, primarily characterized by students' active engagement or involvement in his or her academic work, resulting in better retention of new knowledge and acquisition of desirable personal traits. Any such method that engages students in the learning process is labeled as: "active learning" method. In essence, active learning requires doing meaningful learning activities in groups under the guidance of an informed and experienced teacher. As stated by Christensen et al (1991), "To teach is to engage students in learning." The main point is that engaging students in learning is principally the responsibility of the teacher, who becomes less an imparter of knowledge and more a designer and a facilitator of learning experiences and opportunities. In other words, the real challenge in college teaching today is not covering the material for the students, but rather uncovering the material with the students (Smith et al 2005).

There are several strands of pedagogies of engagement under the umbrella of active learning methods that have received attention by engineering educators world-wide (Smith et al 2005; Prince 2004). These methods/approaches are known to increase students' active engagement in learning and also, promote cognitive elaboration, enhance critical thinking, and contribute toward social and emotional development. The most utilized pedagogies in engineering education today, and moving in the same broad direction, are: problem-based learning, cooperative learning, and collaborative learning (Smith et al 2005).

Problem-based learning (PBL) starts when students are confronted with an open-ended, ill-structured, real-world problem and work in teams to identify learning needs and develop a viable solution, with instructors acting as facilitators rather than primary sources of information (Prince 2004). There are numerous PBL teaching models, and are all equally valid and appear to work depending on factors and prevailing circumstances such as: 1) characteristics of the curriculum, 2) attitudes, knowledge, and skills of the academic staff, 3) underpinning academic culture of teaching and learning, and, 4) socio-economic background and abilities of the student body (Smith et al 2005; Prince 2004; Prince and Felder 2006). The paper examines different variations of PBL, selects suitable versions for potential adoption at the start, identifies essential elements of a well-structured learning strategy, and illustrates faculty role in implementing PBL.

Proven methodologies and knowledge generated elsewhere, if and when properly adapted, should make it possible for institutions to devise their own PBL models that meet their classroom setting, objectives, and aspirations. The paper sheds light on the nature of such models and argues for the need to conduct research in order to guide the process of transition from the old to the new paradigm, to ensure the vitality and currency of engineering education.

Active Learning: Definitions and Interpretations

It is difficult to come to grip with all the cited definitions, meanings, and interpretations of the term *"active learning"*, since different contributors in the field have interpreted some terms differently. However, by gleaming at the literature, it is possible to arrive at general consensus of what appears to be widely accepted definitions, and shed light on how common terms are used. *Active learning* is generally defined as any instructional method that *engages* students in the learning process. It is widely accepted that *active learning* requires students to take part in "pre-planned" learning-related activities, believed to spark and stimulate their learning, while in the classroom(Bloom 1956; Randolph 2000) .These activities would include: reading, writing, solving problems, answering questions, participating in a discussion, etc.; and most important, students must be engaged in thinking tasks while actively involved. It is generally understood that during *active learning*, less emphasis is placed on transmission of information and more on developing students' skills. Additionally, during an *active learning* cycle, emphasis is placed on students' exploration of their own abilities, including: their thinking process, their value system, their intellect, and their courage to express themselves orally and in writing. *Active learning* is contrasted to the *traditional lecture* where students passively receive information from the instructor (Bloom 1956; Kolb 1984; Frederick 1987).

Collaborative learning refers to any and all of the instructional methods where students work together in small groups towards a common goal (Smith et al 2005; Prince 2004). It can be viewed as encompassing all group-based instructional methods, including *cooperative learning* (Frederick 1987; Millis and Cottell 1998). The central element of *collaborative learning* is collaboration vs. individual work (Prince 2004). Meta-analysis supports the view that collaboration does promote a broad range of learning outcomes. In particular, collaboration enhances academic achievement, and student attitudes. It also reduces attrition (Prince 2004). *Cooperative learning* is a formalized active learning structure where students work together in small groups to accomplish shared learning goals and to maximize their own and each others learning. The most common model of *cooperative learning* in engineering is that of Johnson, Johnson and Smith (1991) .This model has five specific elements: mutual *interdependence*, individual *accountability*, face to face *interaction*, *interpersonal* and small group *skills*, and individual *assessment* of group *functioning* (Johnson et al 1991). Although different cooperative models exist (Springer et al 1999), the core element in all, is the emphasis on cooperative incentives rather than competition in the promotion of learning. Some researchers view *cooperative and collaborative learning* as having two distinct historical developments and differing philosophical roots (Wales and Stager 1978). Despite differences and similarity of the two approaches (*collaborative vs. cooperative*), the fact is: that the core element of both is the emphasis on interactions, as the primary source of learning, rather than learning as individuals.

Problem-based learning (PBL) is an instructional method where relevant problems are introduced during the course to provide the context and motivation for the learning that follows (Mourtos 1997). PBL, by and large, is self-directed learning that helps develop positive student attitudes, foster a deeper approach to learning, and helps students retain knowledge longer than traditional instruction. It is appropriate here to mention that several approaches go under the name of *problem-based-learning*. These approaches to PBL have as many differences as they have elements in common, making interpretation of outcome rather difficult (Mayo et al 1993).

Before adopting a specific method of *active learning*, faculty members need to become familiar with the literature, and, in particular, the various strategies that promote *active learning* in the classroom. Despite familiarity with the literature, ambiguity and confusion may result, at times, from reading the literature; particularly when the effectiveness of any instructional method is compared with another method. Assessing “what works” requires looking at a broad range of learning outcomes, interpreting results carefully, and quantifying the magnitude of any reported improvement. To assess “what works” for a given set of conditions, the reader has to attain sufficient knowledge and familiarity with the subject matter (Prince 2004; Smith et al 2005).

Reported studies, by and large, tell us about success stories and seldom reveal what has not worked. Irrespective of how data, results, and interpretations are presented in the literature, faculty adopting a specific method with the expectations of experiencing similar results to those in the literature, should be aware of the limitations of any reported piece of research, i.e., such reports may not reveal all factors and details; and therefore, extrapolating without a thorough investigation could be misleading. This should not, by any means, discourage faculty from moving toward *active learning*; but rather intended as a “precautionary” observation, to new instructors: Not “to make too much” out of what they have read unless it is credible, thorough, and substantiated with facts and figures. Despite some pitfalls, engineering faculty should be strongly encouraged to examine the literature on *active learning*, including: the empirical research on its use, and the common barriers that may arise as a consequence of its application.

The author believes that learning “about” things is not enough to enable students to acquire the skills they will need in the future. Rather pedagogies of engagement, such as PBL, when properly implemented, will turn out the kinds of resourceful, engaged professionals that engineering practice needs. In the sections that follow, the author presents: i) relevant information on PBL*, its practices and working models*; ii) *cooperative learning* as a priori to PBL ; and, iii) the *lecture format*, if and when combined with a selected *active learning strategy, such as* PBL- and its potential utilization in a traditional classroom setting.

Problem-Based Learning: Historical Origin, Precepts, Practices, and Working Models

The modern history of PBL begins in the 1970s at the medical school at McMaster University in Canada. Until recently, the PBL approach has flourished mainly in medical and professional schools. Slowly the sciences, have begun taking it up. PBL does not have a store of transferable techniques like *cooperative learning*, no "jigsaw," no "think-pair-share" or that sort of thing. Opinions vary on whether PBL should be implemented for entire courses or merely in parts of courses. Generally, advocates accept easing into it piecemeal, but favor course-long continuity.

In some ways what PBL is, seems self-evident: It's learning that results from working with problems. Official descriptions generally describe it as: *an instructional strategy in which students confront contextualized, ill-structured problems and strive to find meaningful solutions*. In other words, in PBL, learning results from the process of working toward the understanding or resolution of a problem. The problem is encountered first in the process (Barrows and Tamblyn 1980). Barrows (1996) identifies six core features of PBL: i) Learning is student-centered. ii) Learning is best accomplished in small groups. iii) Problems are the main focus for learning. iv) Problems are the vehicle for the acquisition of problem–solving skills. v) Teachers are facilitators of learning. And, VI) New information is acquired through self-directed learning.

The list of reasons for the deployment of PBL includes the fact that problem-based learning (PBL) ends up orienting students toward meaning-making over fact-collecting. Students learn via contextualized problem sets and situations. Because of that, and all that goes with it, namely the dynamics of group work and independent investigation, they achieve higher levels of comprehension, develop more learning and knowledge-forming skills and more social skills as well. This approach to teaching brings prior knowledge into play more rapidly and ends up fostering learning that adapts to new situations and related domains quickly and effectively. According to Woods (1994), PBL is suitable for introductory sciences and engineering classes – as it is for medicine- because it helps students develop skills and confidence for formulating problems they have never seen before. But where does PBL fit compared with all the other "learning methods". Faculty hear about--"cooperative learning," "collaborative learning," and "active learning"? The proliferation of "learnings" and their attendant partisan camps invites the reawakening of long-standing faculty prejudice against educational fads and "methods." Even so, interest in PBL grows because not only does research show a higher quality of learning (though not a greater amount if "amount" equates with the number of facts), but problem-based learning simply feels right intuitively. It seems to reflect the way the mind actually works, not a set of parlor-game procedures for manipulating students into learning .Unfortunately, while there is agreement on the general definition of PBL, implementation has varied widely(Prince 2004)..The large variation in PBL practices makes the analysis of its effectiveness a bit complex. Many studies comparing PBL to traditional programs are simply not talking about the same thing. As reported by Prince (2004), " For meta-studies of PBL to show any significant effect compared to traditional programs, the signal from the common elements of PBL would have to be greater than the noise produced by differences in the implementation of both PBL and traditional curricula." Despite this, there are positive findings that do emerge from the literature, which support the following: i) PBL produces positive student attitudes, ii) provides more motivating and enjoyable approach to education, iii) improves long-term retention of knowledge compared to traditional instruction, and iv) promotes deep learning and problem–solving skills(Prince 2004).

A. Essentials of PBL: Problem–based learning is a philosophy that has to be adapted to the specific conditions and situation of an institution, and the nature of the specific field in which it is to be implemented. This is apparent in the different models of PBL implementation through out the world. Therefore, there is no *one –size-fits-all* approach to PBL that can simply be implemented from one institution to another (Allen et al 1996). There are required steps that have to be mobilized at the start of PBL. At the start of learning in PBL is the selection of real problem(s). This is, in fact, the major driving force for learning. Effort and time dedicated to the selection of problem(s) is time well-spent and will eventually pay off. The problem(s) should be well crafted to engage and immerse students in learning new materials, as well as challenging existing knowledge, skills, and attitude. It is important to note that PBL is not only about giving problems and solving them in classroom, but it is also about creating opportunities for students to construct knowledge through interactions and collaborative inquiry (Allen et al 1996).

In PBL, the instructor is primarily a facilitator, whose role is to make the learning process visible, instead of making the content visible as in traditional lectures. Since assessment drives learning, the modes of assessment must also be modified to appropriately evaluate students for the desired outcomes that have been designed for the problem. For students to become problem solvers, they have to be actively involved in the learning process. When students are exposed to PBL for the first time, they must be guided, prepared, and motivated. It is not fair to expect students to readily have the skills for PBL, particularly when they have been exposed solely to traditional classroom environment. Therefore, students need to be prepared by exposing them to informal *cooperative learning*, where students are to work together to achieve a joint learning goal in temporary, ad-hoc groups that may last from a few minutes to one class period (Johnson et al 1998). Informal *cooperative learning* groups also ensure that misconceptions and gaps in understanding are identified and corrected. Using procedures such as informal *cooperative learning* guarantees their exposure to active and interactive methods prior to engaging in PBL.

B. Infusing PBL in the Curriculum: There are several strategies that may be utilized to infuse PBL in an engineering curriculum. The selected strategy depends upon: 1) the commitment of the institution, as a whole, to the process of deploying active learning schemes in general, and PBL in particular, 2) the readiness of the teaching staff, and 3) available recourses, facilities, and support services. Table 1 illustrates three approaches to infuse PBL in the curriculum as suggested by Tan (2003): at the **mega**, **macro** and **micro** levels. Implementing PBL at the mega level requires commitment from the administration as well as from the teaching staff. As shown in Table1, an example of such an implementation is when students acquire their course work in its entirety, during the third or fourth year, by means of PBL. This would require a major revamp of the curriculum, along with realignment of program's objectives and outcomes. At the macro level, certain courses in the curriculum are designated to be taught utilizing PBL, irrespective of who is in charge of the course. A macro implementation requires departmental approval and a firm commitment by the instructors teaching the course. Courses offered in multiple sections require coordination between instructors. The micro-level approach requires the least amount of resources. Its implementation is flexible, non-binding and amendable. This is where PBL can be used on a trial basis for certain topics in a selected course(s) within a certain time limit. Hence, this approach is highly recommended for trying out PBL for the first time.

C. The Start up of PBL: A gradual, step at a time approach, should be taken when infusing PBL in a program. At the start, steps should be taken to raise awareness and educate instructors and students on key issues, techniques and potential hurdles that may arise when using PBL for the first time. During this initial period, it is advisable to form a central committee from experienced or semi-experienced lecturers, who are at ease with active learning strategies in general and PBL in particular, to facilitate the promotion of PBL at all levels of the academic community. This is a challenging time that requires patience, persistence, and social skills on the part of the committee members entrusted with the task of embarking on the process- where the committee will be moving against the tide in trying to plant the seeds of change. The major tasks that would be undertaken at this stage are: introduce PBL gradually and properly, convince teachers and students of its merits, and help train potential lecturers of when and how to use PBL. As instructors gain familiarity with PBL, they begin to develop their own techniques.

Level	Range of Application	Details
Mega Level	PBL is applied to the entire 3rd or 4th year of a selected program	• Major revamp of curriculum • Needed commitment at all levels
Macro Level	PBL applied to two or three subjects in the 3rd or 4th year of a selected program	• Need departmental approval and firm commitment from the lecturers teaching the selected subjects
Micro Level	PBL is applied to specific topics in a selected one or two courses	• Recommended for new starters • Will require proper coordination when implemented in courses with multi sections

Table 1. Different approaches of infusing PBL

Student Engagement Using Cooperative Learning Structures: A Priori to PBL

As noted earlier, relying solely on the traditional lecture approach, no matter how competent the lecturer is, fails to engage students in learning; thus indirectly depriving students of learning experiences and opportunities that could only materialize utilizing *engagement strategies*. Under the umbrella of *engagement strategies*, there are numerous models available to select from, including the models predicated on cooperation - working together to accomplish shared goals. Within cooperative strategies, individuals seek outcomes that are beneficial to themselves and beneficial to all group members within the class (Johnson et al 1991; Smith et al 2005). The work by Johnson et al (1991) reveals that students exhibit a higher level of individual achievement, develop more positive interpersonal relationships, and achieve greater levels of academic self-esteem when participating in a successful cooperative learning environment.

Cooperative learning researchers and practitioners have shown that positive peer relations are essential to success in college. The positive interpersonal relationships, promoted through cooperative learning, are regarded by most as crucial to today's learning communities. The underlying precept of *cooperative* and *problem-based learning* is "interdependence". Cooperation is more than being physically near other students. It is the will to open up to others, exchange information and views with others, and accept the fact that working together is more beneficial to all involved in the exercise. For a cooperative learning to be successful, it is imperative that the following be integrated into the class activity (Lowman 1984; McLeod 1996):

- *Positive Interdependence*- Students should perceive the need for one another to perform the planned activity.
- *Face to Face Interaction*- Students should work together in planning, executing, and arriving at conclusions. They should share the work load, and share the credit.
- *Accountability*- Each student's role and performance is to be assessed, and the results are those of the group (and for the group). Keeping track of the contribution and knowledge gained by each member could be monitored, as well, by either testing every student in the group, or by randomly selecting a group member to be tested and thus proxy for the group.
- *Sharing known skills*- Students who possess certain skills (examples: computer skills, laboratory skills, data reduction skills, presentation skills) should be willing to pass it on, and/or share it with their group members.
- *Collaborative Skills*- Groups cannot function effectively if members do not have (be willing to learn) or use some needed social skills. These skills include leadership, decision making, trust building, and conflict management.
- *Monitoring Progress*- Groups need to discuss amongst each other whether they are achieving set goals; they also need to prioritize the scheduled activities, solicit advice and assistance with the consent of the instructor, and maintain working relationships among the members.

Success in implementing problem-based cooperative learning is attributable, in large measure, to: proper planning, efforts, dedication, and foresight of the instructor. Experience definitely is a major factor. A proper start for instructors wanting to try any of the active learning strategies for the first time (including *problem-based cooperative learning*) is to step into it gradually, and to seek feedback as to how the course is going and how the students feel about it. Also, he/she can tap into documented sources, and discuss planned activities with experienced colleagues.

The Lecture Format together with Active Learning Strategies

When asked why he lectures, one faculty responded: *"It is tradition. It was part of my training, and seems to dwell in me and seems like what I should be doing. I feel guilty when I am not lecturing"* (Creed 1986). This candid statement suggests one of the great dilemmas faced by all who teach at the post-secondary level. Lecturing is virtually synonymous with teaching. It was the dominant method by which we were taught - and it is the method by which most of us teach. When discussing potential change in current *teaching–learning* strategies, many faculty members become defensive, and discussions may quickly degenerate into heated debates where sides are clearly drawn. Over-exuberant advocates of *active learning* have, unfortunately, not been able to persuade the majority of those who have grown accustomed to traditional teaching methods. More efforts and better approaches in persuading the traditionalists appear necessary. The challenge is to choose a suitable method at the appropriate time. Understanding the *pros and cons* of the lecture method is a helpful start.

Lectures have a number of characteristics that does make them, for the right subject matter, desirable in the classroom (Creed 1986). It does, to a great extent, depend on the abilities and experience of the lecturer. An able and committed lecturer can accomplish the following:

1. Relate the material proficiently and effectively, in a manner that reflects lecturer's personal conviction and grasp of the subject matter;
2. Provide students with a thoughtful, scholarly role model to emulate;

3. Supplement the subject matter with current developments not yet published, or interject lecturer's own views derived from his/her own experience whenever applicable;
4. Organize material in ways to meet the particular needs of a given audience;
5. Efficiently deliver large amounts of information when the need arises without confusion;
6. Underscore key points, simplify complexities, illustrate with facts and figures.

In addition, lectures are presumably cost-effective in that they can reach many listeners at one time, they present a minimum threat to students in that they are not required to actively participate, and they provide an advantage for those students who find learning by listening enjoyable (Creed 1986). As most students will attest, not all lectures or lecturers achieve these goals. Research findings suggest that a number of identifiable attributes must be implemented to make a lecture truly effective. For instance, students remember material presented at the beginning of a lecture better than information presented in the middle or at the end of the lecture. Also, the effectiveness of the lecture varies inversely with the difficulty of the material presented, and listeners retain factual material better when presented in short sentences rather than in long sentences. These characteristics presume that the lecturer is an enthusiastic and knowledgeable scholar. But, we realize that most campuses have a few that fit this description, and could keep most students interested during the formal 50- minute lecture. Even if it is assumed that most engineering lecturers possess these necessary characteristics, research has shown that *the exclusive use of the lecture in the classroom constrains students' learning.*

An important problems associated with *total* reliance on the lecture method is the inability of most students to listen effectively to any lecturer, no matter how skillful, over a sustained period. Ten to 20 minutes into the lecture, however, confusion and boredom set in and assimilation fell rapidly, remaining at a low state until a brief period toward the end of the session when students were revived by the knowledge that the lecture would soon be over (Penner 1984).There are too many reports in the literature on lack of concentration by the audience, even when the lecturer is brilliant and the attendees are highly motivated, including medical students (Bonwell 1991). When it comes to "note-taking" during a 50 minute lecture, research has shown that students have noted 40 percent of the content presented during the first 15 minutes, 25 percent of the total content in a 30 minute-period, and only 20 percent during 45 minutes (Penner 1984). Even with competent students listening to an interesting topic, several problems remain, including:

1. Course content is often presented via lecture in unorganized and uneven fashion. This makes it difficult for students to determine the most important aspects of the lecture;
2. Many college students do not know how to take effective notes. Although formats for effective "note-taking" have been identified. The fact is: that "note-taking" is seldom taught;
3. The listening, language, and motor skill deficits of students make it difficult to identify important lecture content and write it correctly and quickly enough during a lecture;
4. Instructors sometimes get off-track from the primary objectives of the lecture. Professors—especially those who really know and love their disciplines—are famous for going off on tangents. Although getting off-track breaks the monotony, it could make it difficult for even the most skilled note-takers to determine the most important content.

For those instructors who would like to go beyond the traditional methods of lecturing, a number of effective strategies promoting *active learning* are available to choose from. If a faculty member is hesitant about selecting one or more of these *active learning strategies* because some questions exist about its comparative effectiveness with the lecture method, he or she should consider the following: research has shown, beyond the shadow of doubt, *that these strategies do deliver content as well as lectures while providing diverse presentations that enhances students' motivation and achievement, and helps in building up desirable personal traits.*

Concluding Remarks

On the whole, the intended move towards encouraging instructors to adopt *problem-based learning* (PBL) seems farfetched and difficult to accomplish, especially in the initial stage. This is because time is needed for those undertaking the task to be trained to implement and gain the experience necessary to move the process forward. Time is also needed for other stakeholders to be convinced and to provide the support needed to prescribe the change. Most importantly, those promoting the change must be able to show that PBL is effective for engineering education.

It is highly recommended that an Active Learning Taskforce be formed of experienced faculty, to initiate, infuse, and oversee the progress made. Their determination, patience, and resilience are required to successfully promote college-wide implementation of PBL. Nevertheless, with clear intentions, goals and plans of action, coupled with support from the highest level of the University's key personnel, the Taskforce and other core groups, should be able to move the process forward. Success would almost be guaranteed, when a well-coordinated university-wide implementation of PBL is underway in other colleges of the University.

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Use of Student Surveys to Improve Efficacy of Lab Experience and Guide Lab Development

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Abstract

One way to refocus the importance of hands-on education is to allow students to have ownership of their lab experience so that, in time, the lab curriculum is tailored to their needs and wants. This paper discusses the use of student surveys to help improve the efficacy of lab experience for undergraduate Civil & Environmental Engineering students at the University of Iowa. At the end of each semester, students complete a survey to evaluate the condition of the lab, curriculum, and equipment, what they felt worked well and not so well, and to note any tests or materials that were not done which they would have liked to do. This evaluation was then summarized and used to guide further development of the lab space and the curriculum. The use of the surveys together with significant equipment upgrades and purchases has led to a substantial improvement in the lab experience for the students.

Introduction

As a "practical" profession, it can be argued that engineering is intrinsically hands-on, but at the undergraduate engineering education level, a solid laboratory experience is often met with several challenges. Feisel and Rosa (2005) point out that engineering laboratories often lack clear objectives while engineering curricula have become more theoretical with a shift from experimental activities to computational simulations due to the relatively high cost of purchasing and maintaining laboratory equipment as opposed to the relatively low cost and increasing realism of modeling software. However, there are many arguments for adding and strengthening laboratory components in the undergraduate curricula. For the students, laboratories present an opportunity to take concepts and formulae from lectures and textbooks and test them in a controlled environment. In some cases, such as designing, mixing, and testing Portland cement concrete, the lab experience may be the only opportunity a student has to work intimately with a material system before heading off into the workforce. The lab experience also provides an opportunity to establish cooperative approaches to problem solving, completing tasks, and conveying results via reports and presentations, all of which are imperative for the workplace, but difficult to gain in a lecture environment (Felder, Woods et al. 2000; Edward 2002). Furthermore, in a laboratory environment where the number of students is usually smaller and the setting less formal, it is easier to accommodate a variety of learning styles (Felder and Silverman 1988). From an instructor's perspective, laboratory activities offer a natural venue to achieve deeper learning in accordance with Bloom's Taxonomy (Bloom and Krathwohl 1956):

- Knowledge: students will be able to recall information from lecture
- Comprehension: students will be able to explain concepts to each other

- Application: students will be able to solve problems using concepts/formulae
- Analysis: students will be able to develop experimental plans and troubleshoot equipment
- Synthesis: students will be able to design and conduct experiments
- Evaluation: students will be able to discuss and critique procedures and results.

One way in which to help streamline hands-on laboratory education in terms of objectives, equipment, and products is to make the lab activities as relevant as possible to their interests, goals and future careers. This involves giving the students ownership of their lab experience. The concept of student ownership has many facets, including letting students plan educational objectives and activities, select educational materials, teach other students, and reflect critically on their expectations and experiences (Fletcher 2008).

One of the objectives of the civil and environmental curriculum at The University of Iowa is to produce graduates who have a strong foundation of scientific and technical knowledge and are equipped with problem solving, teamwork, and communication skills that will serve them throughout their careers. To this end, there are five stated outcomes pertaining to this objective that can be tied to hands-on experimental education (CEE 2008):

- The ability to apply knowledge of mathematics, science and engineering in their chosen fields within civil engineering.
- The ability to design and conduct experiments, and to analyze and interpret experimental results.
- The ability to work as members of multidisciplinary project and/or research teams, and have an understanding of leadership in teams and organizations.
- The ability to identify, formulate, and solve engineering problems.
- The ability to communicate effectively in written, oral, and graphical forms.

At The University of Iowa, a reorganization of the undergraduate Civil & Environmental Engineering in 2005 included combining a 3.0 semester-hour (s.h.) senior level elective lecture course entitled “Construction Materials” with a 1.0 s.h. required laboratory class entitled “Experiments in CEE” into a single required 3.0 s.h. lecture and lab course entitled “Civil Engineering Materials”. This newly integrated course required lab experiments that would tie in conceptually and chronologically with the lecture. At the time, the lab space required almost complete redevelopment after a building renovation had eliminated a high-ceiling structural testing laboratory and movement into a space with 15-foot ceiling heights. The re-located Structural Testing Laboratory (STL) could not accommodate large-scale structural testing capabilities but did contain a compression test machine, a small universal test machine, and a torsion machine. During the first two years the course was taught, the universal test machine was used to test a variety steel and aluminum specimens that had undergone different heat treatments in monotonic tension. The compression test machine was used in compression and split-cylinder tension testing of Portland cement concrete specimens. Finally, hot-mix asphalt was tested in a separate Asphalt Research Laboratory.

As a preliminary assessment of the effectiveness of the laboratory experience of the Civil Engineering Materials course and to help direct both the development of the laboratory and the experiments performed in the lab component of the course, an open-ended survey was given at the end of the semester. The survey was given to obtain student reflections on their experience with the understanding that their feedback would be used to guide both the laboratory and experiment development for subsequent teachings of the course. An ulterior motive of the surveys was to give the students a sense of ownership of their laboratory experience - that their connection to the laboratory goes beyond the course and the semester.

Civil Engineering Materials End-of-Semester Survey

In the present curriculum at The University of Iowa, "Civil Engineering Materials" is a junior level course that provides a survey of common materials, their behavior and analyses. The course is offered every spring semester with a typical enrollment of up to sixty students, which breaks down into four laboratory sections of about fifteen students each. The laboratory component of the course is concentrated on testing four material systems: structural metals, Portland cement concrete (PCC), hot-mix asphalt (HMA), and fiber-reinforced polymer (FRP) composites. At the end of each semester that the course is taught, each student receives a survey consisting of open-ended questions, allowing them to critique the experiments they conducted and help direct the further development of the lab by suggesting additional experiments and materials. At present, completion of the surveys has been voluntary with 39 responses in 2005, 20 in 2006, 21 in 2007, and 13 in 2010. Data is not available for 2008 and 2009. The survey questions are listed in Table 1 along with typical responses over the past five years.

Table 1. Lab survey and typical responses.

End-of-semester Civil Engineering Materials Survey

1. What did you like about the labs?
   - *Hands-on experience (14/39 – 2005, 5/20 – 2006, 14/21 – 2007, 7/13 – 2010)*
   - *Realistic/practical civil engineering applications (5/39 – 2005, 2/20 – 2006, 3/21 – 2007, 2/13 – 2010)*
   - *Using different equipment (3/39 – 2005, 1/20 – 2006, 5/21 – 2007, 1/13 – 2010)*
   - *Designing, mixing, and testing concrete (4/39 – 2005, 13/20 – 2006, 2/21 – 2007, 2/13 – 2010)*
   - *Breaking stuff (2/39 – 2005, 2/20 – 2006, 3/21 – 2007)*
   - *Group size/participation (3/20 – 2006, 2/13 – 2010)*
   - *"Helped me understand what we were talking about in the class."*
   - *"Hands on. Got to see what we had been talking about since [mechanics of deformable bodies]. (i.e. ultimate strength, modulus of elasticity)"*
   - *"Making [stress and strain] curves for metals."*
   - *"Good hands-on experience, introduction to computerized testing equipment."*
2. What did you <u>not</u> like about the labs?
   - *Writing lab reports (4/20 – 2006, 8/21 – 2007, 2/13 – 2010)*
   - *Time (too early) (15/39 – 2005, 10/20 – 2006, 7/21 – 2007, 1/13 – 2010)*
   - *Problems with equipment (7/39 – 2005, 2/20 – 2006, 2/21 – 2007)*
   - *Some experiments did not sync with lecture (2/39 -2005, 1/13 – 2010)*
   - *Some labs (i.e. tension test) could be combined (4/39 – 2005, 3/20 – 2006)*
   - *Giving presentations (2/13 – 2010)*

- *Unorganized (4/13 – 2010)*

3. Of the materials that we did test, are there any other tests that you would have liked to conduct?
    - *Testing of steel beam (2/39 – 2005)*
    - *Testing of structures (2/21 – 2007)*
    - *3-pt. bend tests (4/39 – 2005, 2/20 – 2006, 2/13 – 2010)*
    - *Placement of concrete (1/39 – 2005, 2/20 – 2006, 1/13 – 2010)*
    - *More tests on asphalt (2/39 – 2005, 1/21 – 2007, 1/13 – 2010)*
    - *Different annealing processes and their effects (1/21 – 2007)*
    - *Application of strain gages (2/20 – 2006, 3/21 – 2007)*
    - *Torsion testing (1/13 – 2010)*
    - *Charpy impact test (1/13 – 2010)*
    - *Strength of aggregate (2/13 – 2010)*

4. Are there any tests that were conducted that you thought were not beneficial?
    - *Torsion test (problems with equipment) (1/39 – 2005, 2/20 – 2006, 4/21 – 2007)*
    - *Charpy impact test (problems with equipment) (11/39 – 2005, 3/20 – 2006, 5/21 – 2007)*
    - *Air-entrainment of concrete (1/13 – 2010)*
    - *Asphalt binder testing (1/13 – 2010)*

5. What materials were not tested that you would have liked to?
    - *Wood (11/39 – 2005, 7/20 – 2006, 10/21 – 2007, 4/13 – 2010)*
    - *Polymers (4/39 – 2005,*
    - *Masonry (2/20 – 2006, 5/21 – 2007, 1/13 – 2010)*
    - *Different types of concrete/reinforced concrete (2/39 – 2005, 1/21 – 2007, 2/13 – 2010)*
    - *Other types of asphalt (2/20 – 2006)*
    - *Other metals (3/39 – 2005, 1/20 – 2006, 2/13 – 2010)*
    - *More composites (5/39 – 2005, 4/20 – 2006, 6/21 – 2007, 1/13 – 2010)*

6. Were the supplied written materials (lab manual) helpful in conducting the tests?
    - *Yes (34/39 – 2005, 20/20 – 2006, 20/21 – 2007, 13/13 – 2010)*
    - *Could use more detail (2/39 – 2005,)*

7. Was there enough background to the tests included in the lab write-ups?
    - *Yes (31/39 – 2005, 18/20 – 2006, 19/21 – 2007, 10/13 – 2010)*
    - *Could use more basic knowledge about how the tests worked (1/20 – 2006, 1/13 – 2010)*

8. Any other comments?
    - *"One of the few class labs I liked" (2005)*
    - *"Best lab so far at school" (2005)*

- *"Organized/fun lab!" (2006)*
- *"… field trip to see how things are done on the jobsite would be good…" (2006)*
- *"Field trip – definitely" (2007)*
- *"[Labs] were interesting and I could see the direct correlation to the lectures" (2010)*

Discussion

It is noted that since this preliminary survey is open-ended, responses are difficult to summarize and risk being somewhat subjective. With that being said, the results of the survey have been very beneficial in gauging what has and has not worked in the laboratory. For example, since many students have pointed out issues with equipment, emphasis is made to remedy the problems before the start of the next academic year. While it is the rare student who enjoys writing lab reports, survey responses are used to help adapt the lab manual and the lab report guidelines to help make the lab reports clear, concise and relevant. Most importantly, the results of the survey have helped drive the renovation and organization of the lab over the past five years. Over the summer of 2005, money invested in the STL was used to purchase three new computers, *LabView* software, and National Instruments hardware, and a single degree-of-freedom shaker table. Two additional universal test machines were brought in from other laboratories. During the next two years, several lab stations were setup:

- ***Tension test station:*** A small *Tinius-Olsen* universal test machine instrumented to a computer using NI hardware with *LabView* software. Stress and strain data are acquired and plots are shown real-time on the screen. Current experiments test steel, aluminum, and composite materials.
- ***Torsion test station:*** A *Tinius-Olsen* Torsion machine instrumented to a computer using NI hardware with *LabView* software. Shear stress and shear strain data are acquired and plots are shown real-time on the screen. Current experiments test steel and aluminum materials.
- ***Concrete testing station:*** A *Satec* compression test machine is instrumented to a computer where machine control and data acquisition is done with *Partner* software. Stress and strain data are acquired and plots are shown real-time on the screen. Current experiments testing capabilities include compression, split-cylinder tension, three and four point bend tests. Current experiments test Portland cement concrete.
- ***Structural component testing station:*** a large *Tinius-Olsen* universal test machine that has been modified to apply loads to common structural components such as wide flange beams, trusses and frames using a variety of connections (i.e. pins, rollers, fixed-end). A computer with *LabView* is used to collect stress and strain data via a load cell and strain gage rosettes.
- ***Shaker table station:*** A single degree-of-freedom (1DOF) shaker table is used in dynamic analysis of structures. A computer with *LabView* is used to control the shaker table as well as collect data.

As the survey results have helped to direct the development of the STL, additional opportunities for hands-on engineering education have been fostered. In the spring of 2008, new equipment was purchased, including vibration analysis hardware and software and an optical strain gage system for real-time measuring capabilities with an emphasis on structure health monitoring (SHM). This has led to the development of a new course, Structural Modeling and Health Monitoring (SMHM) that was first taught in the spring of 2009. This course includes having students apply various types of strain gages and accelerometers to beams, trusses, and frames in order to compare the behavior of "real-life" structures to their corresponding finite element models. In addition, the laboratory has been used as a central location where demonstrations are developed for other courses such as Statics, Mechanics of Deformable Bodies and Fundamentals of Vibrations.

Future Directions

While the investment in time and money for the structural teachings labs has been substantial, the faculty has recognized the importance of the lab experience and has outlined several goals and directions. While *LabView* is used to collect data, it also has the ability to control the equipment. A minor complication to this is that many of the testing machines are older and require some electrical retrofit in order to allow computer control. Within the next year, a goal is to have all of the machines controlled by computer, allowing for possible "closed-loop" testing. Other projects include developing a course in which students will gain instrumentation experience by obtaining real-time data from local civil engineering infrastructure such as buildings and bridges.

Since the student surveys have been recognized as an important factor in addressing the needs and wants of the undergraduate laboratory experience, the survey, itself, needs further development. The survey should be modified to tie in more explicitly with individual lab objectives. Further, completion of the survey up to this point has been voluntary, and with the end of the semester rush, return has less than optimal. Future surveys should be made mandatory and structured in a way so that results are more objective. Finally, additional efforts could look to the vast network of alumni to determine how the hands-on instruction they received relates to their careers in engineering.

Conclusion

In order to help evaluate the efficacy of the laboratory component of Civil Engineering Materials, students were given an opportunity for the ownership of their lab experience through an open-ended survey. Results of the survey have had two main outcomes: (1) assessment of what did and did not work in the lab experience; and (2) direction of lab objectives, renovation, organization, and equipment purchases. The use of student surveys has been very beneficial in the enhancement of the undergraduate laboratory experience and should be further developed to help direct the hands-on education necessary to produce engaged and competent engineers.

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Integrating Hardware and Software Filtering in Embedded System Audio Data Processing: An Embedded Systems Course Project

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Abstract

This paper describes a course laboratory project for an embedded systems course. The project is intended to provide a real world embedded development task for the students to accomplish in a few week time using a predefined microcontroller and suggested circuit components. The task combines audio sound recording, off-processor storage and filtered audio data replay. The paper includes a brief summary of the course concepts and the particular topics related to the project, an overview of the project goals and suggested circuit and constraints and a possible solution to satisfy the task goals including a complete circuit design and software design. Finally, the paper concludes with a discussion of the in-class results of assigning this project to students, their feedback and possible future changes to enhance the learning experience in future offerings.

Project Summary

The project was designed around a target processor (microcontroller) from Microchip Co. to exercise the student's knowledge of the SPI (Serial Peripheral Interface) protocol and its implementation in the processor. In addition, the students were required to apply knowledge of digital and analog circuit design to complete a working demonstration. The embedded systems course gives the students an opportunity to put to practice the skills gained through previous coursework and electronics laboratory experimentation. This paper describes the course concepts associated with the audio system project, the project itself including the instructor's example hardware design intended as a possible interfacing option for the students, and some conclusions based on multiple course offerings of this project.

The embedded systems course covers many topics concerning the interfacing of sensors, actuators, peripherals, I/O (Input/Output) and communication methods within an embedded design. The course is conducted using a combination of lecture material covering embedded hardware and software theory as well as project based laboratory experiences. This provides an environment for project teams to apply the concepts from lecture taking design specifications from prototype design to implementation, test, and demonstration. All projects have a required demonstration to showcase the results from team activities.

The audio project discussed in this paper is described below. All students are provided with the following project specifications:

Project Description

This project involves the construction of an external memory circuit using a low voltage Flash memory device. The memory interface is implemented using the Serial Peripheral Interface (SPI) protocol. A circuit diagram is included. The goal of the project is to enable data recording and play back for digital and/or analog data at frequencies up to 3 kHz. Each team has two options for the completion of the project, one of which must be completed. All graduate students must complete Option 2.

Option 1: Record variable frequency logic data (50% duty cycle) for five seconds with signal frequencies up to 3 kHz. Then, play the recorded data through the protoboard speaker using appropriate interface circuitry. An eight Ohm speaker requires a driver and cannot be adequately driven directly from the pic18f8680 processor. The record and playback interface must occur using the USART peripheral and HyperTerminal. All circuits must be powered using the SSE 8680 5V source.

Option 2: Record analog voice data (Note: The diagram for a possible microphone interface circuit is available) for five seconds. Then, play the recorded data through the protoboard speaker using sufficient filtering and interface circuitry. An eight Ohm speaker requires a driver and cannot be adequately driven directly from the pic18f8680 processor. The record and playback interface must occur using the USART peripheral and HyperTerminal. All circuits must be powered using the SSE 8680 5V source.

These specifications do not come with many restrictions and this is to allow the student project teams to add an element of design to the project completion. For example, the project discussed in this paper explicitly requires consideration the SPI protocol and its implementation in the target processor, but also required the students to research (on their own) viable options for efficiently storing digitized data with a limited bandwidth and converting the stored data back to sound. In particular, Option 2 requires the storage and playback of voice data. This requires the students to research the appropriate sampling frequency, data storage event frequency, data filtering and playback. The students were not required to complete the data conversion (digital to analog) for the playback using a hardware converter (Note: The target PIC microcontroller does not have a built in D/A hardware converter.) but were free to determine and implement possible hardware and /or software solutions. The instructor example solution will describe a software conversion solution.

The target processor is one of the class of PIC18 8-bit (data path) microcontrollers available through Microchip Co. The engineering and technology department has utilized PIC microcontrollers for multiple courses and laboratory experiences as well as encouraged their use in senior design experiences due to their low relative cost, freely available student versions of a fully integrated IDE (Integrated Development Environment) and because of the department's investment in programming hardware used to write/erase the onboard Flash memory. The embedded course covers an overview and tutorial of the Microchip IDE software package called MPLAB. The IDE allows development in Assembly Language as well as C-programming. The course is taught emphasizing programming in C and the solution code described in the paper is written in C. The project requires interfacing with a SPI Flash external memory device (M25P16). The device provided is from STMicroelectronics however, compatible devices can also be used with possibly small changes to the software. This device was specifically chosen for four reasons: 1) It is an SPI interfaced memory device requiring the implementer to carefully read the specifics of the datasheet, 2) It can be operated at speeds which exceed the instruction rate of the target microcontroller so that the target processor is the speed limiter for the project, 3) It is a 3.3V device requiring care to interface with the target processor which is a 5V device, 4) It is a surface mount device (SOIC) requiring the student teams to exercise surface mount soldering. To power a 3.3V device, one can use a 3.3V voltage regulator. The LT1121 was chosen based on the current sourcing capability, robustness and the low dropout capability. As with the SPI memory device, this device was chosen with the hope that the limitations associated with the project designs/prototyping are due to those aspects of the project controlled by the students.

The diagram below was provided to the students along with the project description. The top circuit is used only with the Option 2 portion of the project and it is a typical combined level shifting signal gain design found in the literature and within many electronics suppliers application documentation. This design was influenced by the WM Series Electret Circuit available on the www.Digikey.com website. The bottom circuit was influenced by the information in the datasheets for the memory and regulator devices. Resistors are used between all signals coming from the target processor to the SPI memory device to drop the excess voltage from the target processor. This is not the only way to provide an interface and in fact is not very robust since the current draw of the SPI memory device varies between different manufacturers and the resistor values need to be configured specifically for the specific device. There are devices available which specifically facilitate this interface such as 74LVC4245 Octal Bus Transceiver and level shifter. Alternatively, one could use opto-isolators to interface 5V to 3.3V I/O. Other options are also possible and the students were encouraged to attempt other implementations.

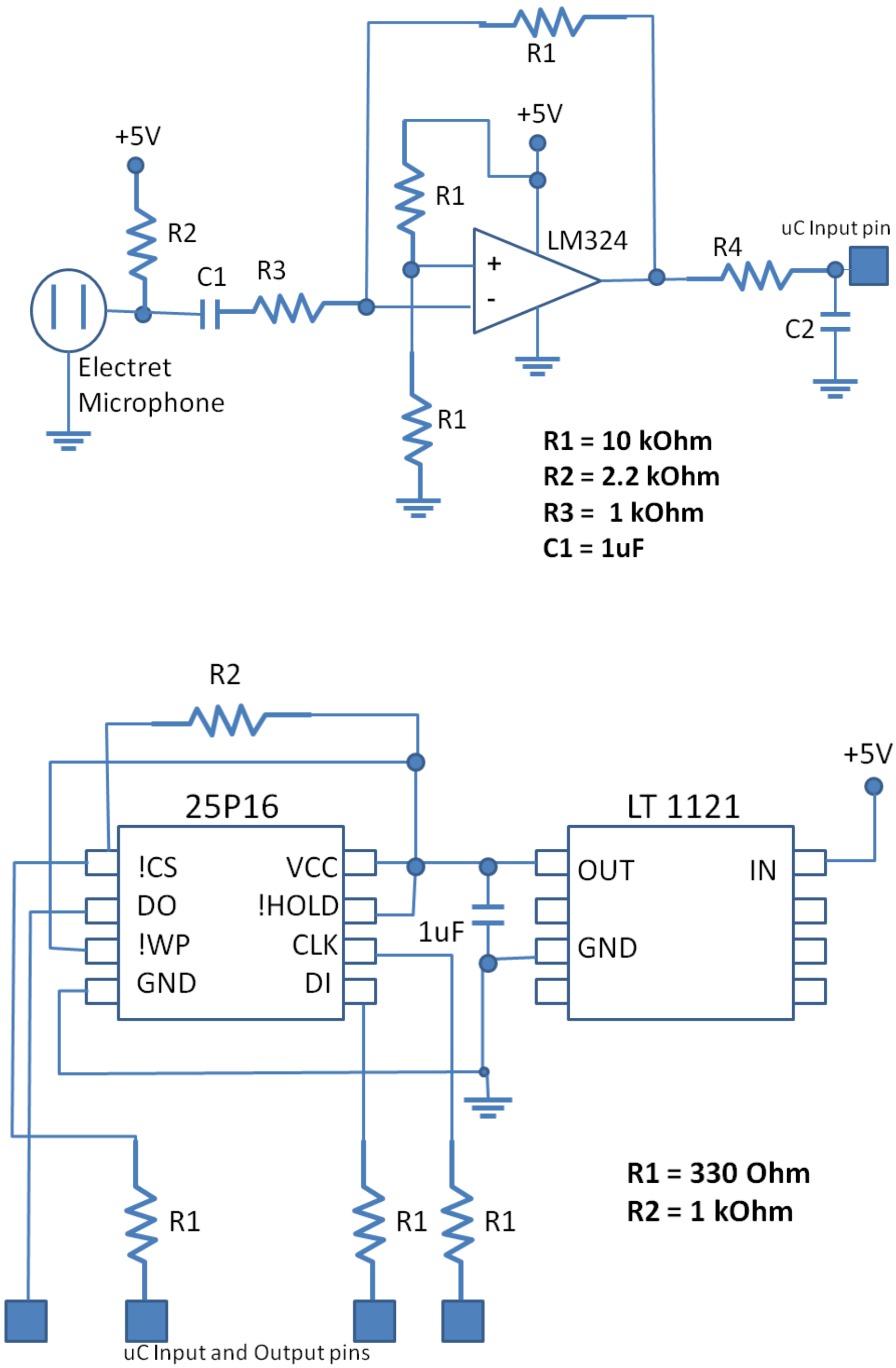

Figure 1: Circuit template available for use by students during the project.

For the software development, MPLAB includes many built-in functions to simplify the software development when using processor peripherals, however this is usually not encouraged by the instructor in an effort to instead encourage the students to consider the specific registers involved and to understand the functionality of the peripherals at the register level. The memory device is interfaced using the SPI (Serial Peripheral Interface) protocol. The specifications and functionality of this protocol is covered in the embedded systems course and the target processor does include the SPI protocol with assigned pins for three or four wire interfacing. The SPI can be configured to interface with (slave) devices in parallel or in series. The processor assigned slave select pin toggles at the beginning and end of all bytes sent through the interface. As with most applications, one size does not fit all. The memory device requires this toggling only at the beginning and end of a packet of bytes. Inter-packet toggling causes improper responses from the memory device. To get around this problem, a supplemental pin is designated as the slave select and the processor assigned slave select pin is not used. In the instructor solution, PORT C pin 2 was used (Refer to the Appendix for details). The processor facilitates the transfer of bytes through straightforward register bit toggling. The project does require the careful sequencing of the proper bytes to initiate stored data transfer.

Replaying the stored data through a speaker required the students to implement appropriate driver circuitry. Possible options include a simple filtered transistor-based driver or an amplifier circuit designed around a device such as the LA4510 power amplifier. In addition, to complete Option 2 of the project, the data is stored digitally but must be delivered to the speaker as an analog signal. Possible options include an external D/A interface (The target processor does not include an on-board D/A converter) or internal approximate D/A conversion coupled with an external filter. This could be implemented by generating a sequence of logic zeros and ones each having duration a function of the digitized sample magnitude. There are multiple functions which could be used. Two possible functions are shown in the figure below.

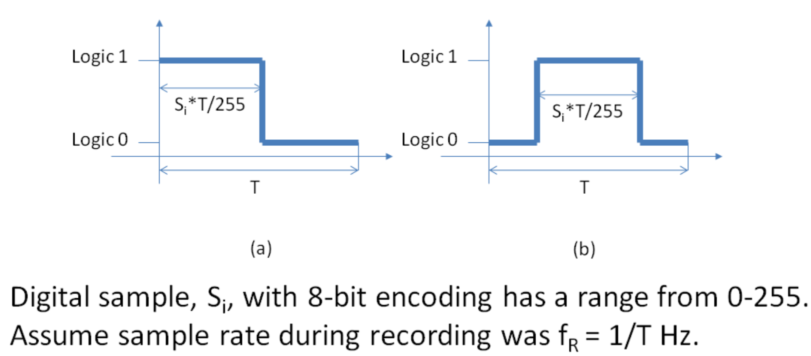

Figure 2: Example D/A conversion sequence.

The instructor solution utilized the method (a) from Figure 2 with each stored sample being translated into two digital bit segments. The first segment is logic one and the last segment is logic zero. The combined pulse width of the two segments taken together remains constant, but the first segment pulse width varies in proportion to the stored sample magnitude. See the Appendix for details.

Results

This project was well received for a few reasons. First, the students are challenged with a hardware circuit design which is simple but requires soldering SOIC devices. Second, the project relates to a very familiar application to the students, namely MP3 players. Third, this project integrates user I/O, external memory, flexible data storage and some data processing requiring the students to consider multiple design options for implementation. This allowed the students some flexibility in their design and presented a competitive aspect to the project.

The students found the hardware aspects of the project to be understandable, but challenging. Many student groups assumed their interface design would work “out of the box”. The project did challenge their circuit diagnostics skills. The instructor did provide a basic program which could be used to test the memory device interface implemented by each student group. As with most embedded system projects, problems can surface in the hardware and software portions of the design. Isolating these problems is critical in yielding proper functionality. The students were encouraged to design their own test software for projects like this as part of a systematic approach to design verification. This project has been offered multiple times over the span of three years. The last offering utilized an alternative processor, but with the same project goals. Most student groups were at least partially successful in the completion of the project and felt the experience was valuable.

References

Microchip Technology Inc. (2004), *PIC18F6585/8585/6680/8680 Data Sheet*, Available from the www.microchip.com website.

Student versions of MPLAB IDE and MPLAB C18 compiler is available from the www.microchip.com website.

Biography

VINCENT WINSTEAD
Dr. Vincent Winstead is an associate professor in the electrical and computer engineering and technology department at Minnesota State University, Mankato. He completed his Ph.D. degree at the University of Wisconsin, Madison in Electrical Engineering.

Appendix:

```
#include <p18f8680.h>
#include "lcd.h"
#include "serial.h"

void high_isr(void);

char LF = 0x0a; // line feed
char CR = 0x0d; // carriage return
char send_WE = 0x06;  // write enable
char send_CE = 0xc7;  // chip erase
char send_WS[2] = {0x01, 0x02};  // WEL set, write status register address and data for global memory
access
char read_ID[6] = {0x90, 0x00, 0x00, 0x00, 0x00, 0x00};  // read ID address and placeholder bytes
char read_ID2[4] = {0x9f, 0x00, 0x00, 0x00};
char read_data[4] = {0x03, 0x00, 0x00, 0x00};
char read_status = 0x05;
char send_PP[14]; // page program command, address and data bytes
char PP_A1 = 0x00; // store at memory locations 0x000000 - 0x00000A
char PP_A2 = 0x00;
char PP_A3 = 0x00;

char send_data[11]="abcdefghij";
unsigned char rec_data[10];
unsigned char TEMP_info[20] = {0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0};

unsigned char S_Rec, Temp_Rec[2], Play_loop;
int i;
unsigned long Add_Start, Num_Addresses;
unsigned int Record_Seconds=0, Record_count=0;

rom char *msg1 = "I am very happy.";
rom char *blank = "                    ";
rom char *msg_complete = "Operation Complete!";
rom char *msg_page = "Page ";
rom char *msg_write = " written";
rom char *C19200 = "Connection established at 19200 baud...";
rom char *Windbond = "Winbond Serial Flash Device Detected";
rom char *P80 = "Device ID: W25P80 (8Mbit or 1MByte)";
rom char *P16 = "Device ID: W25P16 (16Mbit or 2MByte)";
rom char *EC = "Enter command (0=exit, 1=record, 2=playback, 3=display, 4=delete, 5=stats): ";
rom char *NS = "Number of seconds (1-200): ";
```

```
rom char *SA = "Starting address (hex): ";
rom char *SS = "Starting sector (decimal): ";
rom char *NA = "Number of addresses (decimal): ";
rom char *NSectors = "Number of sectors (decimal): ";
rom char *msg_recording = "Recording...";
rom char *AW = "Last Address Written: ";
rom char *PR = "Memory Remaining: ";



void Data_To_M25P80(char xc)
{
	char temp;
	PORTCbits.RC2 = 0;  // CS active low
	SSPBUF = xc;
	while (!SSPSTATbits.BF);
	temp = SSPBUF; // clear BF flag
	PORTCbits.RC2 = 1;  // end of transmission
}

void RepeatedChar_To_M25P80(char *ptr, unsigned char length, char xc, unsigned int num)
{
	char temp;
	PORTCbits.RC2 = 0;  // CS active low
	while (length)
	{
		SSPBUF = *(ptr++);
		while (!SSPSTATbits.BF);
		temp = SSPBUF; // clear BF flag
		length--;
	}
	while (num)
	{
		SSPBUF = xc;
		while (!SSPSTATbits.BF);
		temp = SSPBUF; // clear BF flag
		num--;
	}
	PORTCbits.RC2 = 1;  // end of transmission
}

void StrData_To_M25P80(char *ptr, unsigned char length)
{
	char temp;
	PORTCbits.RC2 = 0;  // CS active low
	while (length)
	{
		SSPBUF = *(ptr++);
		while (!SSPSTATbits.BF);
		temp = SSPBUF; // clear BF flag
		length--;
	}
	PORTCbits.RC2 = 1;  // end of string transmission
}

void StrData_To_From_M25P80(char *ptr, unsigned char s_len, unsigned char r_len)
```

```
{
	char temp;
	int index = 0;
	PORTCbits.RC2 = 0;  // CS active low
	while (s_len)
	{
		SSPBUF = *(ptr++);
		while (!SSPSTATbits.BF);
		temp = SSPBUF;  // clear BF flag
		s_len--;
	}
	while (r_len)
	{
		SSPBUF = 0x00;
		while (!SSPSTATbits.BF);
		rec_data[index++] = SSPBUF;
		r_len--;
	}
	rec_data[index] = '\0';
	PORTCbits.RC2 = 1;  // end of transmission
}

void Run_Record(int num_sec)
{
	unsigned char local_num;
	PORTD = num_sec;
	local_num = PORTD;
	//while(1);

	// clear memory
	Data_To_M25P80(send_WE);  // enable memory writes
	do
	{
		StrData_To_From_M25P80(&read_status, 1, 1);
	} while (rec_data[0] & 0x01);
	Data_To_M25P80(send_CE);  // chip erase
	do
	{
		StrData_To_From_M25P80(&read_status, 1, 1);
	} while (rec_data[0] & 0x01);

	// initialize
	Record_Seconds = 0;
	Record_count = 0;
	Add_Start = 0x00000A;

	// configure ADC
	ADCON0 = 0x01;  // activate ADC module with channel AD0
	ADCON1 = 0x0E;  // allow ADC on PORTA pin 0, Vref+ = Vdd, Vref- = Vss
	ADCON2 = 0x26;  // Tad = 2us, 8*Tad acquisition time, left justified

	// configure timer 0
	T0CON = 0x08;  // 1:1 prescale, 16-bit timer (8 MHz rate)
	TMR0H = 0xFC;
	TMR0L = 0x18; // overflow in 125us (8 kHz sampling)
	RCON = 0x00;  // disable priority levels
```

```
	INTCON = 0x80;  // enable interrupts, zero flags
	T0CONbits.TMR0ON = 1;  // enable timer
	INTCONbits.TMR0IE = 1;  // TMR0 interrupt
	SerialROMStringSend_wLFCR(msg_recording);

	while (Record_Seconds != local_num)
		PORTD = local_num;

	// disable timer 0 interrupt, ADC module and timer 0
	INTCONbits.TMR0IE = 0;
	ADCON0 = 0x00;
	T0CON = 0x00;

	Add_Start -= 2;
	send_PP[0] = 0x02;
	send_PP[1] = 0x00;
	send_PP[2] = 0x00;
	send_PP[3] = 0x00;
	send_PP[4] = (Add_Start >> 16) & 0xff;
	send_PP[5] = (Add_Start >> 8) & 0xff;
	send_PP[6] = Add_Start & 0xff;
	send_PP[7] = 0x00;

	do
	{
		StrData_To_From_M25P80(&read_status, 1, 1);
	} while (rec_data[0] & 0x01);
	Data_To_M25P80(send_WE);  // enable memory writes
	do
	{
		StrData_To_From_M25P80(&read_status, 1, 1);
	} while (rec_data[0] & 0x01);
	StrData_To_M25P80(&send_PP[0], 8); // fill four bytes with last address of record
}

void Run_Playback(unsigned long S_A, unsigned long N_Sec)
{
	unsigned char S_S, S_E, count2=0;
	unsigned long count1=4, last_address;

	// configure PWM (RC1)
	TRISC &= 0xFD;  // PORTC pin 1 configured as output
	T0CON = 0x08;  // 1:1 prescale, 16-bit timer (8 MHz rate)
	last_address = 4 + (N_Sec * 8000);

	// read samples from memory

	for (; count1 < last_address; count1++)
	{
		read_data[1] = (count1 >> 16) & 0xff;
		read_data[2] = (count1 >> 8) & 0xff;
		read_data[3] = count1 & 0xff;
		do
		{
			StrData_To_From_M25P80(&read_status, 1, 1);
		} while (rec_data[0] & 0x01);
```

```
			StrData_To_From_M25P80(&read_data[0], 4, 2); // read 1 byte
			//CCPR2L = rec_data[0];

			TMR0H = 0x00;
			TMR0L = 0x00;  // initialize
			T0CONbits.TMR0ON = 1;  // enable timer
			for (count2=0; count2 < 4; count2++)
			{
				TMR0H = 0xFF;
				TMR0L = 255 - rec_data[0];
				INTCONbits.TMR0IF = 0;
				PORTCbits.RC1 = 1;
				while (!INTCONbits.TMR0IF);
				TMR0H = 0xFF;
				TMR0L = rec_data[0];
				INTCONbits.TMR0IF = 0;
				PORTCbits.RC1 = 0;
				while (!INTCONbits.TMR0IF);
			}
			T0CONbits.TMR0ON = 0;
		}
}

void Run_Display(unsigned long S_A, unsigned long N_A)
{
		unsigned char count1, count2;
		if (N_A % 10)
			N_A -= (N_A % 10);
		for (; N_A > 0; N_A -= 10, S_A += 10)
		{
			read_data[1] = (S_A / 65536) & 0xff;
			read_data[2] = (S_A / 255) & 0xff;
			read_data[3] = S_A & 0xff;
			StrData_To_From_M25P80(&read_data[0], 4, 10); // read 10 bytes
			for (count2 = 0; count2 < 10; count2++)
			{
				SerialStringSend(itoa((int) rec_data[count2], &TEMP_info[0]));
				SerialCharSend(' ');
			}
			SerialCharSend(LF);
			SerialCharSend(CR);
		}
}

void Run_Delete(unsigned long S_A, unsigned long N_A)
{
		unsigned long count1, count2;
		Data_To_M25P80(send_WE);  // enable memory writes
		do
		{
			StrData_To_From_M25P80(&read_status, 1, 1);
		} while (rec_data[0] & 0x01);
		if (N_A == 32)
		{
			Data_To_M25P80(send_CE);  // chip erase
			do
```

```
			{
				StrData_To_From_M25P80(&read_status, 1, 1);
			} while (rec_data[0] & 0x01);
			send_PP[0] = 0x02;
			send_PP[1] = 0x00;
			send_PP[2] = 0x00;
			send_PP[3] = 0x00;
			Data_To_M25P80(send_WE);  // enable memory writes
			RepeatedChar_To_M25P80(&send_PP[0], 4, 0x00, 4); // fill first four bytes with 0x00
(100%)
		}
		else
		{
			for (; N_A > 0; N_A--)
			{
				send_PP[0] = 0xd8;  // sector erase
				send_PP[1] = S_A & 0xff;
				send_PP[2] = 0x00;
				send_PP[3] = 0x00;
				StrData_To_M25P80(&send_PP[0], 4); // fill 64k bytes with 0xff (erase)
				S_A++;
				do
				{
					StrData_To_From_M25P80(&read_status, 1, 1);
				} while (rec_data[0] & 0x01);
			}
		}
}

void Run_Stats(void)
{
		long last_address;
		read_data[1] = 0x00;
		read_data[2] = 0x00;
		read_data[3] = 0x00;
		StrData_To_From_M25P80(&read_data[0], 4, 3); // read the last data byte address written
		last_address = ((long) rec_data[0] * 65536) + ((long) rec_data[1] * 256) + ((long) rec_data[2]);
		if (last_address > 0x1fffff)
			last_address = 0x1fffff;
		SerialROMStringSend(AW);
		SerialStringSend_wLFCR(ltoa(last_address,&TEMP_info[0]));
		SerialROMStringSend(PR);
		SerialStringSend(ltoa((long) (100-((float) last_address/0x1fffff*100)),&TEMP_info[0]));
		SerialCharSend('%');
		SerialCharSend(LF);
		SerialCharSend(CR);
}



#pragma code high_vector = 0x08
void interrupt_high(void)
{
		_asm
		GOTO high_isr
		_endasm
```

```
}
#pragma code // resume general code functions
#pragma interrupt high_isr
void high_isr(void)
{
	if (INTCONbits.TMR0IF)
	{
		TMR0H = 0xFC;
		TMR0L = 0x18;
		INTCONbits.TMR0IF = 0;  // clear flag
		ADCON0bits.GO = 1;  // start AD conversion
		Record_count++;  // increment msec counter
		if (Record_count == 10000)
		{
			Record_count = 0;
			Record_Seconds++;
			PORTD = Record_Seconds;
		}
		send_PP[0] = 0x02;
		send_PP[1] = (Add_Start >> 16) & 0xff;
		send_PP[2] = (Add_Start >> 8) & 0xff;
		send_PP[3] = Add_Start & 0xff;
		while (ADCON0bits.GO);  // wait until conversion is complete

		if (Record_count % 2)
			send_PP[4] = ADRESH;
		else
		{
			send_PP[5] = ADRESH;
			do
			{
				StrData_To_From_M25P80(&read_status, 1, 1);
			} while (rec_data[0] & 0x01);
			Data_To_M25P80(send_WE);  // enable memory writes
			StrData_To_M25P80(&send_PP[0], 6); // fill two bytes with ADC results
			Add_Start += 2;
		}
	}
}

void main(void)
{
	unsigned int count1, count2;
	TRISB |= 0x01;
	TRISD = 0x00;
	TRISA |= 0x01;  // ADC input on PORTA pin 0

	// Test the LCD interface
	ADCON1 = 0x0E;		// configure PortA pins for digital
	openLCD();
	cmd2LCD(0x80);		// set cursor to column 1 row 1
	putromS2LCD(msg1);

	TRISC &= 0xD7; // configure SPI pins
	TRISC |= 0x10;
	SSPCON1 = 0x20;  // 8MHz comm. rate
```

```
SSPSTAT = 0x40;  // CKE, CKP = 1,0

TRISC &= 0xFB;  // PORTC pin 2 output (active low chip select)

PORTCbits.RC2 = 0;
PORTCbits.RC2 = 1; // sequence to reset the interface

StrData_To_From_M25P80(&read_ID[0], 4, 2);  // read Manufacturer and Device ID
//StrData_To_From_M25P80(&read_ID2[0], 1, 3);  // read Manufacturer and Device ID
cmd2LCD(0x80);
putromS2LCD(blank);
while (PORTBbits.RB0);
cmd2LCD(0x80);
for (count1=0; count1 < 2; count1++)
{
        itoa((int) rec_data[count1],&TEMP_info[0]);
        putramS2LCD(&TEMP_info[0]);
        putc2LCD(' ');
}

SerialConfig(0x24,103);
for (count1=0; count1 < 30; count1++)
{
        SerialCharSend(LF);
        SerialCharSend(CR);
}
SerialROMStringSend_wLFCR(C19200);

if (rec_data[0] == 0xef)
        SerialROMStringSend_wLFCR(Windbond);
if (rec_data[1] == 0x13)
        SerialROMStringSend_wLFCR(P80);
if (rec_data[1] == 0x14)
        SerialROMStringSend_wLFCR(P16);

StrData_To_M25P80(&send_WS[0], 2);  // command to write status register to allow global
access
Data_To_M25P80(send_WE);  // enable memory writes
StrData_To_From_M25P80(&read_status, 1, 1);
PORTD = rec_data[0];

do
{
        StrData_To_From_M25P80(&read_status, 1, 1);
        PORTD = rec_data[0];
        SerialROMStringSend(EC);
        S_Rec = RCREG;  // clear receive buffer so LFs do not accumulate
        SerialStrReceive(&TEMP_info[0]);
        S_Rec = TEMP_info[0];
        if (S_Rec == '1')
        {
                SerialROMStringSend(NS);
                SerialStrReceive(&TEMP_info[0]);
                Run_Record(atoi(&TEMP_info[0]));
        }
        else if (S_Rec == '2')
```

```
        {
                SerialROMStringSend(SA);
                SerialStrReceive(&TEMP_info[0]);
                Add_Start = num_to_long(&TEMP_info[0], 16);  // hex conversion
                SerialROMStringSend(NS);
                SerialStrReceive(&TEMP_info[0]);
                Num_Addresses = num_to_long(&TEMP_info[0], 10);  // decimal conversion
                Run_Playback(Add_Start,Num_Addresses);
        }
        else if (S_Rec == '3')
        {
                SerialROMStringSend(SA);
                SerialStrReceive(&TEMP_info[0]);
                Add_Start = num_to_long(&TEMP_info[0], 16);  // hex conversion
                SerialROMStringSend(NA);
                SerialStrReceive(&TEMP_info[0]);
                Num_Addresses = num_to_long(&TEMP_info[0], 10);  // decimal conversion
                Run_Display(Add_Start, Num_Addresses);
        }
        else if (S_Rec == '4')
        {
                SerialROMStringSend(SS);
                SerialStrReceive(&TEMP_info[0]);
                Add_Start = num_to_long(&TEMP_info[0], 16);  // hex conversion
                SerialROMStringSend(NSectors);
                SerialStrReceive(&TEMP_info[0]);
                Num_Addresses = num_to_long(&TEMP_info[0], 10);  // decimal conversion
                Run_Delete(Add_Start, Num_Addresses);
        }
        else if (S_Rec == '5')
                Run_Stats();
} while (S_Rec != '0');

while (1);



send_PP[0] = 0x02;  // page program command
send_PP[1] = PP_A1; // data address (MSByte)
send_PP[2] = PP_A2;
send_PP[3] = PP_A3; // LSByte
//for (count1=0; count1 < 10; count1++)
//      send_PP[4+count1] = send_data[count1];
//StrData_To_M25P80(&send_PP[0], 14);  // send data to the memory locations

for (count2=0; count2 < 8192; count2++)
{
        send_PP[1] = (unsigned char) (count2 >> 8);
        send_PP[2] = (unsigned char) (count2 & 0x00FF);
        send_PP[3] = 0x00;
        RepeatedChar_To_M25P80(&send_PP[0], 4, 0x55, 256);
        cmd2LCD(0xC0);
        putromS2LCD(blank);
        cmd2LCD(0xC0);
        putromS2LCD(msg_page);
        itoa((int) count2,&TEMP_info[0]);
```

```
            putramS2LCD(&TEMP_info[0]);
            putromS2LCD(msg_write);
        }
        cmd2LCD(0xC0);
        putromS2LCD(blank);
        cmd2LCD(0xC0);
        putromS2LCD(msg_complete);
        while(1);
}
```