Preparing the best future engineers through improved teaching methods

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Abstract
Our goal will always be the preparation of excellent engineers for the next generation. However, these new students have different behaviors and aptitudes that limit the effectiveness of traditional teaching methods. This research will focus on how to best approach tomorrow's engineering class with new tools and interactive teaching techniques. Keeping those students engaged and learning for the long term is a challenge. A variety of interactive teaching methods are crucial to make students participate, get more involved at learning in a significant way, that will last their lifetime.

Keywords: excellence in engineering education, interactive teaching methods, hands-on, just in time teaching, peer teaching, clicker, Connect, Jeopardy, Cramster

Introduction

During the last decade of teaching engineering, the quantity of information to learn has increased and the time to acquire this knowledge stayed the same. Maybe the solution to this problem would be to follow the field of medicine, where they now need to have a Bachelor's degree before starting their doctors program. Skills that used to be part of the basic formal education of engineers are gone and replaced by new primordial skills for students of the 21st century. There are skills we expect students to have such as writing a good report, knowing how to use Excel for graph and charts for example. We are not sure if these were taught as time is restricted and materials increased in programs. We witness some gaps in our students' performances across different disciplines. Some are lacking some basic skills and maturity.
Four main issues are prevalent in the new learners of today:

First, today's generation are inundated with a never-ending stream of information throughout their lives. However, they receive this information in non-contiguous bits of visual images– often with no context or reference. Consequently they desire extensive sensory excitement, need to be entertained.

Second, many students arrive without the formal communication skills (report writing) or basic training to use the standard tools (spreadsheets, graphs, tables, word processors).

Third, students have access to resources that might hinder their critical thinking skills and development of a deep understanding of the subject matter. This is due, in part, to access to the popular online study resources such as Cramster[1] where answers to homework are given.

Fourth, students have an expectation that learning is a passive activity and often arrive unprepared for class. With little exposure to the material, the level of retention is significantly reduced.

Both implicated sides need to be examined; the programs with their educators and the tools they use and the learners of tomorrow.
The best way to solve these issues first is to make sure that departments study their programs and lay out a roadmap of all the courses being taught to promote a great flow between courses. This will ensure that no fundamental skills needed to attain excellence in engineering education are missing. In this constantly changing environment, the teachers must take a guidance role to teach all these basic skills, using the best tools available. They need to communicate the required wisdom from the freshman year, all the way up to senior year, to produce the best engineers.

With all the new technologies, the classrooms have changed a lot since 1911. From blackboard and chalk to computers, e-Blackboards, You-tube[18], smart phones and iPads. Students now start to learn in kindergarten with Smart boards in their classrooms, no chalk, no dry marker, just electronics. They have access to Blackboard online in elementary school where they can view information from teachers and their grades on computers. For a school to stay competitive, it must get on board with all this new technology to be relevant and keep the interest of the audience, our students coming from this high technology upbringing. They expect to be entertained and have access to all interactive tools that we can provide to them for learning. This research will try to show that there are many different tools to make your classroom a class of the future and more relevant and reach excellence. It is important to reach all students and give them the best education possible to allow them to succeed in the difficult job market that is the reality of today. Educating the educators might be inevitable as well for them to stay current with all those new technologies.

There are many pieces to this puzzle that we need to figure out in order to teach more information in the same amount of time. We also have several generations of students that learn differently, have greater expectations but also have more passive attitudes. Dealing with these new learners, we need to adapt to take advantage of all this new technology to better educate our students. We also deal with so much access to information that cheating and plagiarism are part of the shared data used to complete homework limiting creativity. Unfortunately a lot of students whether through poor time management or a load too heavy on their semester, copy their homework questions on Cramster[1] or on their friends. The Cramster phenomenon has been shown to be a problem and not a solution in Marc Grams study[2]. Studying the answers and solutions for the exam later is really not the way to understand learning materials, get critical thinking and excel in engineering. This paper will focus on a variety of actions that must be taken to improve the engineering students' quality of learning by promoting a more active role in their own education using more interactive techniques and tools for teaching.

Excellence in Engineering Education

First let's look at what is excellence in engineering education. Forty-seven students took part in a voluntary study[3] about excellence in education in 2007 with questions such as "What is excellence in engineering education? ", "What is education technology?", "What was their role in engineering education?" and finally "What was the role of the Professor?". Content analysis and keyword frequency were use to analyze the results.

Literature on excellence in engineering education was analyzed in this study[3] to bring to light what the stakeholders were expecting for the twenty-first century. A comparison with the students input on the quality of their education and what is expected from major players driving the movement to improve and maintain excellence in engineering was completed. It showed that students have identified similar points with the stakeholders about what is a great education. Additionally they identified different ones, personal to them, not identified by the stakeholders dictating the standards. According to this study[3], students need more examples in class, hands-on applications and more visual aids. The reports showed that they also want smaller classes for more personal connections.

The major factors defining excellence in engineering education are dictated by the National Academy of Engineering and other organizations such as ABET[4]. They have identified worldwide universities that are making the effort to recognize the challenges engineering programs face and plan to make those changes to achieve excellence. ABET[4] are in charge of accrediting Universities against a list of criteria and they have raised the standards. A program developed in 2002 created the Center for the Advancement of Scholarship on Engineering Education (CASEE[5]) which is also an important group in dictating excellence in engineering education. They define what should be taught in engineering and define excellence in education in terms of its effectiveness, engagement and efficiency. The Millennium Project[6] at the University of Michigan studies the future of American Universities providing a joined effort with creative students, faculty and beyond campus to develop new ideas for the University of the future. They propose a learner-centered, affordable and diverse education that is more interactive and adapts to the new era leading to a more sustainable lifelong learning. Balance is the keyword.

Many researchers[5-8,10] have come up with the same basic requirements that undergrad students in engineering should learn: a combination of knowledge and skills but also wisdom. The later being hard to define. Fromm[11] has defined the characteristics our engineers of the future need such as strong bases in science, math and engineering and the way they can apply those fundamentals to real life problems. The students need to have a good base before they start their engineering program to succeed. They also need to interact with faculty to learn more of that wisdom and ethics that need to be taught in addition to the basic material learned. Having the students input has helped understand what are their expectations and views on their education.

Interactions between students and faculty are primordial in significant learning and students have spoken[3]. In two studies[12,13] , these interactions were important; however, they were negligible in some cases as was shown in a report from the National survey of Students Engagement NSSE[9]. Pomales-Garcia's study[3] showed that under 50% (and even under 30% of students in some universities) don't have interactions with their teachers outside of the classroom. I know from experience that even when the teacher reaches out, is accessible and tries to be helpful, students may not be receptive: Students might have limited time or may be intimidated by the professor. Very few make it to your office unfortunately. E-mail is a great communication tool to stay in touch. Using Blackboard with all that it offers is an extension of your time and hopefully reaches them. We really need to improve those numbers.

Interactive Teaching

Not a lot has been written about how to meet these expectations using the new high technology and mass media world. In 2000, the National Survey of Students Engagement (NSSE) report[9] showed that students learned more when they were intensely involved in their education. The old fashion lectures are not enough to achieve the high standards of excellence with the new type of audience. Dr. Mazur[14] has been a pioneer in changing the classroom with his "Just In Time (JIT)" teaching style. He has found a way to get the students energized and more involved in their education, which is just what is needed to attain our goal of the best education for our future engineers. JIT style of teaching is where the student must read the material before they show up for class. Questions are asked before class starts and feedback is given before class starts to the instructor so the material can be adjusted to what the students don't understand or find more challenging. It is really making them own their education, having them know about the material before it is taught. This is a brilliant way of getting the science, engineering and math students to read their books before they show up for class. Figure 1 shows an example of a reading assignment in class ENGR221 at the University of St-Thomas. Often just three questions in Blackboard as a form of assignment are enough to know that the student have read the material and the last question always demands them to think of what was the most difficult for them in what they read. The answers are returned in your grading center as a new column with the points that you allocated for each student. You can then leave them a note and respond to their questions. You can define how many points per assignment that you will allow and fit to attain your total of 100% in your grade center for the semester.

Figure 1: Reading assignment from ENGR221 Fall 2011 at the University of St-Thomas.

A combination of these questions individually asked about their reading before class will direct the educator to the material they find difficult and need more attention[14]. This new teaching technique takes us away from the traditional lecture and engages more the students in participating and evaluating what he/she does not understand before class.

Dr. Yearwood[15] has also been instrumental in changing the face of education, making strides with new techniques to improve students' role in their education. He has lectured to the faculty development center at the University of St. Thomas (in August 2010) on how to reach students in a classroom with the use of tools and technology. He distributed a Jeopardy game format, which is a Power Point form of documents you can write questions and answers that show up only when you click on them. I adapted this format to questions used in my class on the mechanics of materials. This new approach gets the students more interested and awake and assures the materials taught is revisited. Every chapter can be examined including all fundamental concept in the form of a game. Twenty five questions per chapter on basic concepts are debated in class by teams. The students love it as they are competing in a game, in teams while we are making sure that they understand the material, we revisit every single important points of the learning material for each chapter. At the end of every chapter the game would be played. It brings the fun to learning with the game as well as competition skills that they enjoy. It also introduces peer teaching as they try to convince each other on their team of the right answer. Peer teaching has been also shown to improve students ability to learn significantly as they remember their material better when they can explain it to someone else[14]. Figure 2 shows an example of the Jeopardy game for class ENGR221 at the University of St-Thomas.

Figure 2: Jeopardy game chapter 1 for ENGR221 at the University of St-Thomas.

Teachers need to constantly adapt to the tools available to keep the students engaged and connected. McGraw Hill has a new web based system called “Connect”[16] that will allow faculty to provide the student with a more personalized education especially in large classes. These new tools allows the teacher to create homework that needs to be done individually online which remedies copying of homework from friends or a web site such as Cramster[1]. They allow us, the instructors, to identify where every student level is at in their learning and address their more problematic issues. When students copy, they lose the instinct that a good engineer needs to identify what should be done to solve each problem. Their critical thinking skill are not being developed. Once the solution is given, students just learn them by heart and then would not know at all what to do if the problem is a little different. Giving online homework with McGraw Hill Connect[16] in this particular class will remedy that. The problem changes for each student going online to complete the assignment so there is no chance of them just copying. It is a win-win situation as it eliminates the copying, forces them to do the work up front and get involved in their learning. The Connect system is paired with your Blackboard and a grade is automatically created in your Blackboard allowing to view the student’s grades, results and make comments on each. The only difficulty here in a multiple step problem is that only the answer is corrected online. If they got it right, you know they understand and the ones they didn’t get, you can request written copies from them so you can see their work and allocate points for the steps they did get right. A homework sample question from ENGR221 this fall is shown in figure 3. All these new approaches to teaching will make sure we will reach those students and get them invested in there education or at least accountable as the solutions have to be coming from them and not from a copy on Cramster[1] or a friend.

Figure 3: Online Homework from McGraw Hill on Connect.

New video capture with Tegrity for McGraw Hill[18] is also a great new tool that gives students access to the teacher 24/7. Complete classes can be captured or specific remote series of small videos of problem solving and techniques. Additionally, explanation of concepts in detail can be made in advanced and put on Blackboard. The students can listen to them over and over and even change the speed of the video to better understand what the educator is saying. It will change the classroom and improve distance learning as well. In figure 4, a still picture of a class video list shows the options students have with the program.

Figure 4: Picture of a Tegrity class video list in ENGR221 Fall 2011.

Clickers as reinforced by Dr. Yearwood[16] are another part of a direct evaluation of what your students know and a great tool to improve our classrooms. You can ask questions in class and know right away if all the students, half the class or just 10% understands. It's a good way to have a read on all your students before an exam is given or at any time during the semester. It is also a good way to involve your student every class. Mini Quizzes also add to identify readily who understands and who doesn't so you can allocate more points to the mini quizzes than to the homework in case they just copied them, which is not a reflection of their level of understanding. Students need to put in the effort in order to get excellence.

The students' favorite parts of class are the projects, where they get to apply the theory to real engineering problems. Students love the hands-on props, labs and projects where they are directly in charge of their work or can visualized or manipulate equipment to understand concepts they have learned. This can also be accomplished by using animated example, videos and real life example. Students still like the more standard tools for teaching such as board and power point presentations but really like to have more applied and hands-on example that they can relate to. Youtube videos are among their favorite technologies used in class. In just one semester, I have personally seen a difference in student's grades by using these new techniques. I went from a more regular basic lecture to adding a lot of the new technology this last fall semester, adding a Jeopardy game and many animated example, You-tube videos and "Myth Buster" episodes. The students responded really well and succeeded.

Conclusion

There are many things that need to be addressed in a classroom. To maintain excellence in engineering education, everyone involved needs to step up and take charge. Departments need to make sure they have a great program that has all that is needed new and old skills the students should have to be prepared for the future. Teachers need to offer dynamic and interactive classes to engage their students and provide them with great knowledge, great skills but also professional wisdom and ethics which they would not get anywhere else before they start on the job market. The students also need to be more involved in their learning and not the rote learning typical when cramming before an exam and forgetting it all in a couple of weeks. The educators with all the new interactive tools and technique will get the students interested and accountable, will individualize their homework evaluation online from using clickers, adding some hands-on work in class and some dynamic example on the book website, using You-tube or video capturing they have prepared for them, using games, props and examples they need. An increase in performance and average in classes and excellence in engineering education is guaranteed. Do we need to consider extending engineering programs by a year or two so students can get a more fundamental base in engineering and then go into a specialty such as doctors in medicine need to do?

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Academic Integrity in the Classroom

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This paper will explore issues of **academic integrity (AI)** in the classroom:

- Define several meanings of academic integrity
- Explore how and why students cheat
- Describe techniques to enhance student integrity

The work is based on personal observations and informal discussions with many students throughout my career as a student and as an instructor.

Academic Integrity is a term used to describe the expectation of honest, open, and responsible conduct while engaged in scholarly activity - be it research, teaching, service, learning, or administrating. It is a public and private commitment to moral and ethical behavior. A lack of integrity is associated with behaviors like cheating, plagiarism, falsification of one's and others work, or misrepresentation of one's efforts. However, academic integrity is more than just not cheating (or not getting caught cheating).

The Center for Intellectual Property[1] identifies five fundamental values that encompass academic integrity:

- Honesty in all endeavors,
- Trust and confidence in others that allows a free exchange of ideas and provides the intellectual infrastructure that allows all to reach their highest potential,
- Fairness in assessing others work and contributions,
- Respect for oneself and others, especially when their views are different from others,
- Responsibility for one's own actions and to take action when a breach of academic integrity occurs.

The focus of this paper is academic integrity in the classroom – for students and instructors. It is important for educators to be aware of these concepts if they want to help their students to successfully develop their integrity in class and after they graduate. Engineering students will become engineering professionals and are assumed to have the public good as a core value. If an engineer is dishonest they harm themselves (no one will work with an engineer who has an untrustworthy reputation if they can avoid it) and the profession. An open, honest classroom is more comfortable for students and instructors, which allows better learning to take place. Watching for cheating is time consuming and unproductive – and it does not help students learn the material. It can also put the instructor into a mindset of me vs. them, which may harm their relationship with a class.

How do Students Cheat

There are many ways a student can cheat in a class[3]. The type of cheating depends on the nature of the assessment activity. A few examples include:

Homework: Many students have access to copies of the previous year's homework problems from older students. Some will also have a copy of the instructor's version of the text, with notes and worked out solutions to all the homework problems.

Exams: The two most common methods seem to be the use of cheat sheets (real and virtual) and looking at or sharing answers with another students paper. Cheat sheets can be extremely difficult to detect by the instructor as the variety is as inventive as students are desperate. A short sampling includes writing on their hand, sleeve, arm, pencil or pen, and on their notepaper. They also can scan solution sets to view on their calculator (which may be their phone also). Some calculators can store scanned images of entire textbooks. Sharing answers can be as simple as look/show, or may be done through coded messages – foot taps, pen clicks, passing notes (or text messages).

Papers: Many students do not like to write. It is hard and time consuming to do well. The easy shortcuts include having another student write for them, copying or buying a paper from the web, plagiarizing from a book or paper.

Projects: The great variety in types of projects precludes a list of common cheats. However the use of resources they should not use may sum it up. This might include talking to or working with other students, accessing information on forbidden sources (like asking for expert help on a website).

Class participation: This usually involves some sort of attendance requirement that is overcome such as by having another student sign in for them.

Some of these methods are clearly dishonest and with forethought, while others are dishonest with opportunity, while others may not seem dishonest from the student's point of view.

Why do Students Cheat

Next, there are many justifications used by students that choose to cheat. Informal conversations with students have helped me develop this list (which is certainly not exhaustive):

It is easy to cheat – this justification occurs when students believe that the risk of being caught is low, so there is no reason not to do it.

Other students do it, so they must to compete – a common feeling in competitive situations.

Not enough time – they didn't budget their time well and must find a short-cut.

Project is just busy work - project time vs. worthiness is not viewed as appropriate.

Cheating is more fun than class material – they want a different challenge, even if it means spending more time on cheating than on the project.

Assessment is too hard – they don't believe they can do what is needed to get a good grade.

Curve is set too high – they don't believe they can do what is needed to get a good grade.

Instructor needs to fail some students, and I don't want to fail – they believe some percentage of class must fail (even if they do good work).

Instructor doesn't care about this class, so why should I? – assessment activities are same as last years (and the years before that) so students perceive that instructor does not want to spend time/ effort on class. They want to follow the instructors lead.

Instructor doesn't care about me – difficult to generalize but they may be expecting a different type of relationship with instructor.

Instructor doesn't like [men, women, minorities, my religion, way I look, ...] so I will be treated unfairly. Therefore I will cheat.

Instructor is not fair - cheating can even the odds

I don't like the instructor – cheating allows me to get even.

There are several common themes among these justifications. Many revolve around the environment that the instructor builds for a class. Others have nothing to do with the instructor and are more related to the student's study skills, self-confidence, and self-motivation. Instructors can do much about the class environment, and may be able to help improve a student's study skills.

What to do About It

There are many approaches to dealing with AI issues. No approach is completely effective - students are different, faculty are different, and the goals and assessment of each class are different. A positive approach focuses effort on identifying and encouraging academic integrity. This will not work for dishonest students and they may take advantage of it. A negative approach focuses effort on identifying and punishing cheating. This does not work for honest students and may encourage them to cheat, or to view the instructor as unfair. A disengaged approach does not deal with the issues and just ignores or wishes them away. This does not help any of the students. A mixture of positive and negative actions can be used to help the most students, while being considerate of your time.

Each class is different. The size, level, expected skills, goals, and assessment will vary. Larger class size makes it easier for students to cheat because it is easier to hide and there is often less connection between student and instructor. Freshmen are less aware of AI or consequences for cheating. Freshman may also have been raised in a culture of cheating such as exists at many junior and senior high schools. Simpler skills and assessments are easier to cheat –

memorization, definitions, true/false, and multiple-choice assess very limited skill sets and are easier to cheat.

There are many ideas an instructor can use to encourage student academic integrity and to reduce dishonest behavior. For both I will offer tips to help during class design and during assessment activities. Hopefully, some of this advice may be useful.

Encouraging Academic Integrity

Design of class:

Discuss AI several times during semester – at the beginning and several times during semester as appropriate. The discussion does not need to take much time; a few minutes can be more than adequate. As an introduction on the first day – tell them about AI, what it means and why it is important. Bring it up again when major assessment activities are given to the class. Let the students know you expect honest and fair behavior from them. When students know that the instructor values something they are more likely to pay attention and try to do it.

Make them practice AI skills - Have them reference each other on a short paper, perhaps about an in class discussion. Have them create a note sheet for an exam and hand it in with the exam. This can give you feedback on what they perceive about class expectations.

Have clear course goals[2]. What do you want to students to learn? What should they remember after the final and after they graduate? What should they remember for their first job? If you are clear, they will know what to expect and will study the important information. Do not have too many goals and do not add extra things just because someone else thinks you should (i.e., textbook content tyranny).

Assess for your goals and only for your goals. If they know the goals, and they know you will assess for just them, they will perceive you as being fair. If you assess things not in your goals, they will not know how to study for your class, thus making it 'unfair'. They may perceive this as you cheating to trick them to bring down their grade.

Lead by example. Use AI skills whenever appropriate in your class - give credit when you use someone else's figure in a lecture (perhaps just a reference on bottom of slide).

During assessment activities:

Honor codes. Consider using one to help students remember that they are expected to be honorable. A very simple one is to have them sign an honor pledge on all assessments.

Honor Pledge: I have neither given nor received aid on this exam.

Clearly explain the learning objectives of the assessment. Students do not always know or understand what you are doing and why. They may think an assignment is just busy work, when you actually want them to practice more or to learn a time consuming skill. Also, when they understand an assignment they can start to self-assess.

Design assessments that fit the teaching goals. If your goal is to improve their problem solving skills, do not assess for spelling or definitions. The assessment should involve problem solving and you should look at how they solve a problem as well as what answer they arrive at.

Design assessments that respect the students time. Make an assignment as short as necessary to achieve your goals. Do not give busy work. If they know your assignment is focused, they will put in the time. If it is perceived as extra-long and busy work, they feel justified in working together, taking shortcuts,... i.e. not doing the learning you wanted.

Be fair in grading and assessment - confront your prejudices (we all have them!). Have them only place name on cover and no peeking during grading.

Decide on partial credit before starting grading, but be flexible for those students that find unique solutions or new ways of perceiving the problem.

Discouraging dishonest behavior

Design of class:

You want to decide beforehand what you will do when you suspect someone of cheating, and this process should be shared with the class. I do this as part of my course syllabus (a written document each student receives on the first day of class).

> *Student academic integrity:* **ALL EXAMS MUST BE DONE INDEPENDENTLY**. Academic misconduct will result in a failing grade for the class or other appropriate action.

During assessment activities:

Do not assess topics that you have not discussed in class/ readings/ assignments. If you expect them to remember information from prior classes make sure all have had those classes and then tell them they will need to recall it, and remind them before the exam. Items that seem easy but can be difficult to recall during an exam – quadratic equation, surface of a sphere, trigonometry functions and their use.

Give them typically known info - open book, open notes, allow one sheet of own notes, unless you are testing memorizing ability (no one designs a bridge based on their memory only, so ...)

Give partial credit. This allows you to check their work and reduces their ability to cheat by looking at someone else's answers.

Specific Activities to Reduce Cheating

Here, several specific ideas are provided to consider in your courses to help students with AI and to avoid situations that make it easy to cheat.

Homework

Solution files: Know that some students have access to worked solutions for all the homework problems. You can only prevent this by creating new problems every time you teach a course.

Alternatively, do not treat them as an assessment. Homework is actually a learning exercise and it may be unfair to treat it as an assessment.

Exams

Cheat sheets: Provide a common note page for all students so they do not need to memorize equations. Alternatively, allow students to create their own page of notes, to use their text, or their class notes. If the use of the text makes the assessment too easy, you may be only be assessing memory skills and not really challenging students understanding of the material.

Looking / sharing information on exams: Proctor exams; find large room so students do not need to sit close together. Discuss and use an honor code so students know and understand what is expected. Design exams that require students to show all intermediate steps in determining their solution and give partial credit for their work – this is too much information for sharing by foot tapping codes or by just looking at someone else's paper.

Papers and Plagiarizing

- Make sure students know and understand what is acceptable and what is not (it is not obvious to all students).
- Teach them how to correctly use original source material and how to give credit for others work – This one is a skill even seniors have trouble with.
- There are programs to search the web for copied material, but this requires the papers be in a specific format and requires you to run the program on each paper.
- Create unique ideas for paper topics. Do not assign biographies, rather use topics like compare / contrast between three or more sources, study of a local business, effects of a local project. These are interesting papers to read and it is unlikely a student will find much specific information on the web or in books.
- Give each student a different topic. This will make grading more interesting and you can then allow student to discuss the paper with each other.
- Do not use same topics as previous years unless you want to read the same papers.
- Require copies of outline, draft, and final version to show their work. This also has the advantage of not letting them procrastinate and allows you to provide feedback before the final version is submitted.
- Require some writing in class, which is collected before they leave. Use this to learn their writing voice.

Projects

Make sure students know and understand what resources are acceptable. Is it ok to discuss with classmates? With students who have already had the course? With anyone else? Can they use their book and notes? Can they look up information on the web (they may not think using the web for commonly known formulae is actually using the web)?

Ideas that may not work well

Make assessment activity worth trivial amount of credit. Some students will cheat for even one point out of 1000, others will see that the value is so low that it is not worth putting time into it.

Make it too hard to cheat. This will be perceived as extremely unfair and may even be viewed as collective punishment.

Oral exams. They are very time consuming except in the smallest classes. They may be useful as a make-up exam where you don't have to worry about someone helping them or making new exams just for them.

Finally, what happens when I suspect a student of cheating? I tell at least one other faculty (department head usually), then I confront the student with my suspicions and my evidence. Then I ask for their view on what I observed. This will get a confession in 3 / 4 of the cases. This then provides a teachable moment – a vulnerable time when they may really listen to advice. I will also tell them what sort of punishment I am considering – zero for the project, shared points for a group effort, or something else that is appropriate. In the other 1 / 4 cases they usually say nothing – neither admitting nor denying. These are much more difficult as they know how the system works and abuse it. There does not seem to be a teachable moment with these students, so I simply explain what my punishment will be and ask if they understand.

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Biographical Information

Dr. Sternberg obtained his PhD from Purdue University, West Lafayette in 1994. He has worked as a professor at the University of Detroit Mercy, University of North Dakota, and University Minnesota Duluth. Before attending graduate school he worked as a system engineer designing industrial waste water treatment plants. He had his first incident of student dishonesty in his very first class when a group of students felt changing the font and letter size was enough difference to not be considered plagiarizing.

The Engineering Advisory Committee – One Solution
Closing the Gap in the Iron Range's
Engineering Education: K-14

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Abstract: The Iron Range will never be the same. A powerful and influential group from communities surrounding Hibbing Minnesota has aligned to ensure area students have every opportunity to discover engineering as their lifelong passion. "Powerful" is not based on any organizational chart but rather an attitude of "we-will-make-it-happen." The group started as the *Hibbing High School Engineering Advisory Committee.* Creating an ad-hoc partnership with local businesses, industry, higher education and regional development, this committee has sponsored activities such as: Curriculum development in the High School, Mentoring with young practicing engineers (representing multiple organizations from diverse backgrounds), job-shadowing with engineers to discover the nuts and bolts of a day in the life of an engineer, a business / engineering Pro-E computer lab at the High School, and a Junior Engineers' Club among other things. The committee is comprised of instructors from Hibbing High School, Hibbing Community College and the University of Minnesota-Duluth; industry leaders from Cliffs Natural Resources, Jasper Engineering, BARR Engineering and NORAMCO; and leaders from regional support agencies such as the Hibbing Chamber of Commerce, Iron Mining Association, Applied Learning Institute, Engineers' Club of Northern Minnesota and Iron Range Resource and Rehabilitation Board. This paper seeks to address the need for locally grown engineers on the Iron Range, the formation, challenges and successes of this committee, the committee-sponsored events, and the review of the spectrum of Engineering Exposure to students in the region. Further, the paper will describe how this committee works to identify and close any gaps in curriculum opportunities in order to create a continuum for multiple age/education levels, how Team-teaching accentuates the pre-engineering educational process and how the committee works to convert the perception of "can't-be-done" and into ways that can be. We will discuss the necessity of championing a vision through to completion not only individual projects but also the Engineering Education concept itself.

The need for locally grown engineers

As a matter of statistical interest, Northeastern Minnesota is on the verge of a deficit in the engineering profession, with an even greater decline in trained engineers on the horizon as more senior engineers retire. According to the Minnesota Department of Employment and Economic Development (DEED), the demand for engineering and architecture occupations in Northeastern Minnesota alone is expected to increase by 9.9% in the decade of 2009-2019.[1] Nationally, it is expected that the overall growth in engineering fields will be 11% in the 2008-2018 decade, and for mining and geological engineers topping 15%.[2] Further, the U.S. as a whole has only 4.5% of its undergraduates completing engineering degrees compared to Asia and the European Union at 21.1% and 12.6% respectively.[3]

Central to the Iron Range, Hibbing is a hub for the engineering industry in Northeastern Minnesota, with a demand for engineers at the local mining companies and engineering consultant firms. Local leaders, including Mr. Robert Bolf, principal recruiting executive of Cliffs Natural Resources, consistently report the need for engineers at area production facilities such as Hibbing Taconite Company and United Taconite Company. As Mr. Bolf travels the nation courting engineering graduates, he mentions that the area's recreational opportunities are a real selling point for potential employees, but finds that many leave the area after a few years of employment, seeking careers in other industries and regions of the state and country. It is generally true that Iron Range born and raised high school and even college graduates who have come back and have entered the mining companies are more likely to stay in the region for the long term. The next logical question to ask therefore is "how do we interest young Iron Range students to pursue engineering in order to keep engineers in the region for the long term?" Local graduates are very familiar with the area, have family and friends that keep the graduate interested in the area and those have a vested interest in improving their local communities and therefore have a vested interest in supporting their principal employer. But, according to Rich Rojeski of Hibbing Taconite Company, it can be a tough sell, even for his own two children. "They both say they won't come back to the range…My son said he would never come back. He just doesn't think there is anything up here for him."[4] The challenge for local business, industry and educators, is therefore to provide the scaffold by which students can achieve their educational goals while remaining in their home communities. More importantly, for educators, the problem is how to attract students to this often poorly understood profession *early in their schooling.* The Engineering Advisory Committee has attempted to provide an answer to this difficult challenge. And now, the area is offering a smorgasbord of hands on opportunities with students saying: "I didn't even realize I liked doing this kind of stuff or even that I could!"

While attracting local graduates to the industry may be difficult, the opportunities for local students to pursue engineering careers has never been better, a fact that we believe can be beneficial in encouraging our students to consider pursuing engineering. Our two-year institutions, Hibbing Community College, Itasca Community College (ICC) and Mesabi Range Community and Technical College (MRCTC), all have 2-year pre-engineering degree programs leading to the level of Associate in Science. Recently, Iron Range Engineering (IRE), a program hosted at MRCTC and delivered by Minnesota State University-Mankato (MSUM) in conjunction with ICC has added a 4-year baccalaureate in Engineering. Our local graduates may now enter the IRE program with an AAS or AS and complete their engineering training on the Range with integrated experience through project work at local industries. As well, the University of Minnesota Duluth has added a Graduate Engineering degree program based at the

MRCTC campus and accessible at HCC and ICC - allowing regional engineers the option to either seamlessly transition from secondary school through graduate education without leaving the region.

However, the engineering profession remains rather misunderstood by the general public, not to mention the average career-seeking student. One interpretation is simply that *"They Don't Know*." School counselors, teachers and even parents are limited on their exposure to the intricacies of each engineering discipline or what it takes to become an engineer. Some extremely talented students may never reach their full potential because they are unaware of the possibilities or how to get there. Non-engineering parents typically will not steer their child in this direction. Even parents who are engineers may not know enough about other disciplines to be able to help create a burning desire in their daughters and sons. Indeed, student perception of engineering may be a significant limiting factor in the enrollment of future engineering students, especially high school students who might feel that they "…are not intelligent enough to become engineers."[5] As an example, a 2009 survey (Figure 1) of Hibbing High School graduates, courses and concepts perceived to be "difficult" and the perceived inability to pursue engineering comprised more than a third of the deficit in student engineering enrollment.

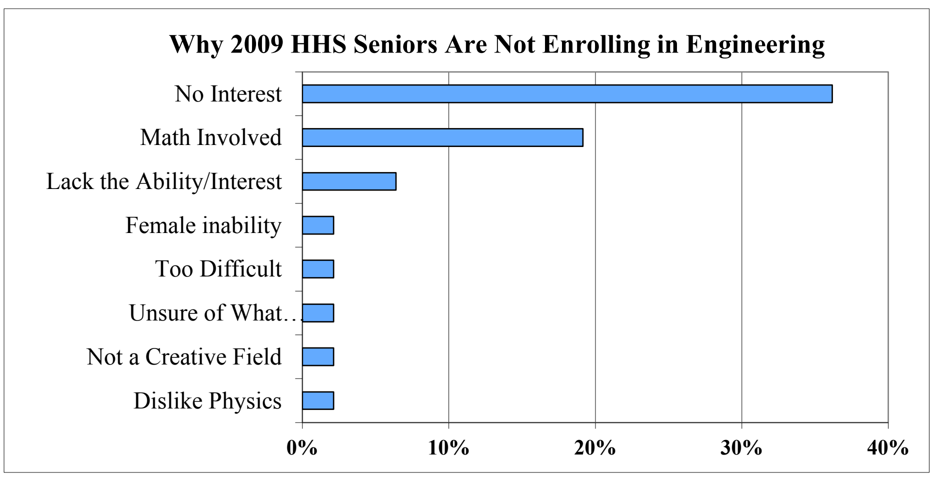

Figure 1. Hibbing High School Seniors 2009 Survey of Engineering Interest

From the same graduating class, data was collected regarding collegiate enrollment plans for the following fall of the same year. The results are summarized in Figure 2.

Interestingly, Engineering placed 2^{nd} only to Health Sciences (physicians, nursing, dentists and dental hygienists). Similar data from 2008 showed only 9% of graduates selecting engineering. We believe that overall, our coursework has had some positive correlation in career selection of our graduating seniors.

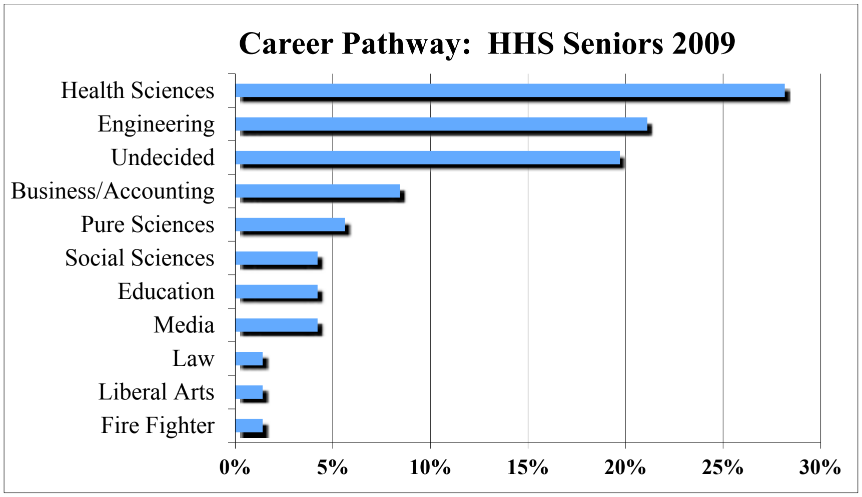

Figure 2. Hibbing High School Seniors 2009 Career Pathway

The advisory committee

The advisory committee is made up of professionals who serve no term, who have not been elected, but volunteer with energy and capability to support the students of the Iron Range and are in their way working to ensure a solid future for the Iron Range rife with innovation and opportunity. This powerful and influential committee comes from communities surrounding Hibbing Minnesota and has aligned itself to ensure area students have every opportunity to discover engineering as their lifelong passion (or not!). "Powerful" is not based on any organizational chart but rather an attitude of "we-will-make-it-happen." The group started as an ad-hoc partnership with local industry, higher education and regional development in order to complete one project: a computer lab for Hibbing High School which turned into the Business and Engineering Computational Center for the school. In undertaking this project, Tom Jamar, president of Jasper Engineering and others provided financial and design support. From that effort, it became apparent to Mr. Jamar that this was the tip of the iceberg – that so much more could be done. There was a lot of interest and energy but there was no vehicle to harness it. The students were interested, but the schools needed the guidance and external funding. Jamar began reaching out to other organizations (letter 9/1/06 to Robert Belluzzo, Superintendent Hibbing Public Schools). Soon after, the Hibbing Chamber of Commerce, Iron Range Resources and Iron Mining Association joined in and Jamar et al became the Engineering Advisory Committee. These same organizations still play an active roll.

Five years later, the committee is now comprised of other organizations as well: instructors from Hibbing High School, Hibbing Community College and the University of Minnesota-Duluth; industry leaders from Cliffs Natural Resources, Jasper Engineering, BARR Engineering and NORAMCO; and leaders from regional support agencies such as the Hibbing Chamber of Commerce, Iron Mining Association, Applied Learning Institute (ALI), Engineers' Club of

Northern Minnesota, Society for Mining Metallurgy and Exploration, and Iron Range Resource and Rehabilitation Board. The people are in place – now the infrastructure.

Mechanics

So, how does this all work? Monthly, the committee meets at a central location and is facilitated by Tom Jamar. The high school teachers talk about what they've been doing and what they need. The committee looks to each other to support the 'what' that is needed and to offer ideas for improving the curriculum. Additionally, the committee discusses and directly sponsors activities strongly in the upper grades (seven of which are described below) and is working to develop ways in which to reach the rest of the K-14 spectrum.

First (11^{th} 12^{th} grade): Perhaps the crowning jewel of the advisory committee has been the \$100,000 Business and Engineering Laboratory that was completed during the summer of 2007. This facility resides in the old study hall on the second floor of Hibbing High School and houses 30 Dell Precision 390 workstations, a central server, printers and full network access. With support from the HHS Administration and Building and Grounds, this facility has been central to course content delivery. Recent additions through the Applied Learning Institute and Carl Perkins funding including upgraded memory for the computers and a new Dimension series prototyper for generating plastic 3D models from student CAD creations.

Second (9^{th} – 14^{th}): An annual engineering mentoring session is held in November at BARR Engineering in Hibbing. Local mining and engineering firms call for volunteer engineers to meet with students over hors d'oeuvres to discuss the future employment outlook, engineering careers, engineering colleges and offer a general question-answer session for students to learn exactly what engineers do in the region. In addition, it provides an opportunity for the students to meet one on one with practicing engineers discussing job details, college experiences and opportunities. Parents have also used this session to learn more about what engineers do on a daily basis and to obtain advice for preparing their children for college.

Third (11^{th} – 12^{th}): Through the inspiration of Robert Bolf from Cliffs Natural Resources, each spring the mining and engineering firms offer job-shadowing opportunities for students interested in capturing a "day-in-the-life" of an engineer. Roughly 12 students each year spend a half-day one-on-one with an engineer in the field from local mines, engineering consultant groups, the city, and other area manufactures. This is clearly one of the most popular events for our students, who return glowing with enthusiasm.

Fourth (6^{th}): Each Fall, members of the local engineering community volunteer to teach a unit in an after-school series entitled "Engineering Cool," in which the 6^{th} grade students learn about engineering careers through activities in science and engineering. This program was the result of collaboration between the Hibbing Chamber of Commerce, the Hibbing School District and two highly engaging engineers; Julie Elkington and Christy Kearney. This Fall (2011) marks the second year of this series and the students and parents have shown excitement for continued involvement. 25 students registered for the first year, and early applications for the second year exceeded 40! Due to the short duration since inception and the current gulf between middle school and high school enrollments, the data suggest no conclusion as to its effect, but it is expected to have a large influence on initial student enrollment in pre-engineering courses at the high school level.

Fifth (9^{th} – 14^{th}): Jason Janisch of Jasper Engineering, J. Moe Benda from the University of Minnesota Duluth, Bob Zbikowski from HCC, Jason Slattery from MRCTC and Carl Sandness from HHS have started a Junior Engineer's Club of Northern Minnesota, based at HCC with groups in Hibbing and Virginia. This newly founded club is directly sponsored by the Engineer's Club of Northern Minnesota and the Society for Mining, Metallurgy and Exploration and meets in the evening bi-monthly to showcase a particular engineering discipline. Members are students from the areas respective schools (HHS and HCC in the central area of the Range and Virginia area high schools and MRCTC in the east). During the 2010-2011 school year, representatives from chemical, mechanical, civil, biomedical and renewable energy engineering presented a snap-shot of their respective discipline as well as providing an activity relevant to the discipline at hand. The club attendance for the past year averaged eight per night, with four returning this year. It is our hope to incorporate a regional challenge between the groups and perhaps add a third group on the western range.

Sixth (7^{th} - 8^{th}): The committee supports the Lego League competition coordinated by Shanna Eskeli, a junior high school science teacher. In 2010, they had two teams compete in local competition. To prepare, each team delivered an oral presentation to the Engineering Advisory Committee who provided industry feedback. As well, the committee also provided financial support.

Seventh (11^{th} - 12^{th}): As part of the FIDEARS (Fundamentals of Industrial Design, Engineering Applications, Robotics and Sustainability Studies) class, the students compete in Lake Superior College's Battlebots competition which is also supported by the engineering advisory committee, ALI and the American Manufacturers and Fabricators Association (AMFA).

With all of these efforts, the committee is working to provide students opportunities to see engineering for themselves and experience engineering first hand to be better able to make informed career life decisions. Some find a particular engineering discipline suits them more, or some see that Engineering is not for them at all. The cost of this decision increases exponentially with each post high school year that passes. Better to decide now when it's free, than $159,000 of tuition later.

The curriculum development

Bob Zbikowski of Hibbing Community College (HCC) and Carl Sandness of Hibbing High School (HHS), had been discussing how engineering education is necessary prior to leaving high school since the early 2000s.

In July of 2006, they met with Tom Jamar of Jasper Engineering to discuss their cooperative strategy for bringing a team-taught, co-enrollment, *Introduction to Engineering* course to students of Hibbing High School. Met with a healthy enthusiasm, Jamar began to contact local business, industry and engineering leaders together in a meeting with educational leaders of ISD 701 (district) and Hibbing Community College (HCC) to discuss the need for the start to an engineering education curriculum. Zbikowski had a course in place at HCC that would serve as a platform to bring fundamental data analysis skills, group projects, career mentorship and college preparatory skills to students interested in pursuing engineering as a college major. Sandness attended training for Parametric Technology Corporation's Pro/Engineer Wildfire 3.0 (Pro/E) software at St. Cloud State University, granting a site license for the installation of parametric modeling software to institutional computers. Parametric modeling became the secondary tool-set for student study in the proposed course. Further consultation with the advisory committee led to the incorporation of the aforementioned mentoring sessions, job-shadowing activities, and site visits.

The *Introduction to Engineering* course has been a successful venture and has had five successful sections complete this course (106 students), of which we estimate 27 have continued their collegiate study in engineering. Student evaluations of this class has been favorable and consist of a series of statements to which students submit a rating of 1 to 5, where 5 represents "strongly agree" and 1 represents "strongly disagree." Of 20 evaluation categories, the overall rating for the course from 2007 to 2010 is 4, which we interpret as "good." Of those components for which the advisory committee offers support, site visits scored 4.4, guest speakers 4.2, and mentorship programming 4.1. Of those students surveyed, when asked if they would enroll in a second pre-engineering course, the average rating is 3.9. And of particular interest is a question pertaining to whether or not the responding student would recommend the course to another student interested in engineering, for which the average response is 4.5. The success of Intro to Engineering was further recognized with a 2009 University of Minnesota Humphrey Institute Local Government Innovation award.

After the success with *Intro to Engineering*, they continued their discussions of adding conceptual core engineering units in statics, dynamics, fluids and thermodynamics to coursework. Since Intro to Engineering was a semester-based course, there was financially no funding for an additional course to be added to the existing schedule. The advisory committee again came through, and with logistical and financial support, the yearlong FIDEARSS course was first offered during the 2009-2010 school year. The brainchild of Frank Pengal, former president of NORAMCO Engineering (now senior consulting mechanical engineer at BARR Engineering and current advisory committee member), the FIDEARSS course is in its third year. In an advisory committee meeting in 2008, Pengal, an alumnus of HHS, commented on a missing facet to our programming, that being the proverbial "elbow grease" of industrial technology courses – the welding, fabrication, machining and electronics skills that many graduates from high school are lacking, and that these deficiencies can sometimes inhibit engineering undergraduates in their coursework projects. These same sentiments have been points of discussion for the student panelists at the 2009 and 2011 Engineering Education conferences held at the University of St. Thomas and the University of Minnesota. With its conceptual, project-based assessment model, the FIDEARSS course complements well the *Introduction to Engineering* course in providing the additional skills necessary for future student success. Of the 31 graduates of this course in the last two years, 10 had also taken the *Introduction to Engineering* course, giving these graduates nearly two years of pre-engineering education prior to entering college. In June of 2011, the Minnesota Association of Secondary School Principals (MASSP) honored the FIDEARSS course with a "Star of Innovation Award" to recognize its mission in improving student success in the technical and engineering career pathways at Hibbing High School. Without the consult, mentoring and support of the Engineering Advisory Committee, this would not have been possible.

The Teaching Team

With the myriad of skills taught came the need for a better way to teach them. Team teaching spontaneously developed and as such, it offers students many advantages[6] over the traditional instruction:

1. Improvement in quality of scholarship through multidisciplinary approach by complementing one another's expertise.
2. New perspectives and insights from watching each other teach.
3. Stimulation and challenge prevents mental fatigue and burnout.
4. Increased planning clarifies goals, how and why they teach and how to do it better.
5. Applied to education what is valued in industry: shared responsibility, creativity and community

Working together, the Team has determined that their level of satisfaction of content delivery has improved because they are able to rely on each other's content knowledge to provide quality instruction for their students. Not only content knowledge is improved, but also the ascertainment of student content mastery has become better defined because while one is teaching the concept, the other is observing the student behaviors, taking note of the level of attentiveness each student displays. Post-class discussions between instructors have revealed key areas for delivery and curricular improvements. They have also determined that the generation of novel projects has been greatly accentuated due to their different backgrounds enabling the synergistic incorporation of specific components that make each new project engaging.

For the FIDEARSS course, it has been even more important that Russell McConkey and Terry Vesel of the Industrial Technology department have joined the team-teaching effort. With over 50 years of combined automotive, electronics, machining and welding experience between them, Russ and Terry have complemented the team teaching effort seamlessly. Now students benefit from a much greater level of expertise, especially when all four are teaching at the same time. Student projects now have supervision and guidance for project development and execution on multiple levels simultaneously. We are able to address student needs on a much more personal and in a much more attentive manner.

Our teaching team has been fortunate to have the opportunity to team-teach, due in large part to supportive administrators at both Hibbing Community College and Hibbing High School who have strongly supported this unique teaching style and realize its importance to the education of the pre-engineering and technical student. To finance this venture, Mr. Roy Smith of Iron Range Resources and the Applied Learning Institute, a key member of the advisory committee, has championed this effort and found support with cabinet members.

The Challenges

The joining of a fast moving results oriented entity (industry) to a slower moving process focused entity (public institutions) can create challenges in itself. Initially this created frustration from both sides. As well, project championing was initially an issue. Organizational politics are difficult to weave through when one is internal to the organization, and almost impossible when external.

Where this collaboration loses strength is in the external pushing or the internal pulling, but no owner to make it happen. The success of this committee has been through not having one champion, but three – two from within the schools, and one from without. A champion who is internal to their process that can run with action items needed to be done on “their side of the fence.” Sitting across the table from one another, the conversation becomes much different. There is more “What do you need?” and “How soon?” on one side and on the other real needs are expressed. The plan details can then be laid out, and everyone is making progress and is on the same page. Thus, it is absolutely critical to have one or two driving from the inside and one making sure the external parties can get it done. Inter-organizational cooperation fails if each organization doesn’t own the initiative. In this case, the initiative is engineering education. Each member champions activities within her/his own sphere of influence. Once these internal and external drivers of the process became evident, results followed.

Each (public and private sectors) had to work through a learning curve to understand the other's processes better and learn to leverage each other's strengths and overcome any respective weaknesses.

Final Thoughts

The Engineering Advisory committee has demonstrated a commitment to the current students of the Iron Range to ensure the longevity of the region itself. The success to-date has been a result of the *volunteers* from the area, both on the committee and those providing the classes and promoting in their own way opportunities for all the students on the Iron Range the experience and the thrill of innovation and creation which is the heart of Engineering. Perhaps the name should be changed to "The Engineering *Doing* Committee!"

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Student Attitudes on a Collaborative Undergraduate Engineering Program between the USA and China

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Abstract

Today, the globalization of higher education is an important major development of higher education. Shanghai University of Engineering Science [SUES] and Lawrence Technological University [LTU, of Southfield, MI] have had a multifaceted academic collaboration since 2003. Fifteen American engineering faculty and 1200 Chinese engineering undergraduate students have participated in the evolving collaborative effort thus far. The evolving program has several major components: certificates for undergraduate Chinese participants, graduate work for both Chinese and American students, and American undergraduate participation in a Chinese university.

This paper presents a description and assessment of the attitudes of students in the ongoing global cooperation program, concentrating on the international flavor of the China-USA higher education program. In particular, we are concerned about continuous quality improvement.

Index Terms – Engineering education, global engineering education, collaborative engineering education.

INTRODUCTION

SUES is a strong regional engineering college, focusing on undergraduate engineering in China, as is LTU is in Michigan. The initial phase of the collaboration has been a certificate program for SUES students. The SUES students receive a certificate recognizing their achievement of five courses that are taught by LTU American professors, who teach the courses in English in Shanghai. The SUES student undergraduate programs are the Automotive Engineering BS degree and the Electrical Engineering BS degree. The courses include Introduction to Engineering, Introduction to Electrical Engineering, Quality Control, Automotive Microcontrollers, VLSI design, Project Management, Engineering Cost Analysis, Electrical Machines, and Control Systems. This program is ongoing and has been since 2005. Each year, continuous improvements and enhancements are made to the program. Enhancements and variations have included textbooks, course length, course size, and course prerequisites. The program has proved to be very popular with the Chinese students, as it gives them access to global engineering.

ASSESSMENT DESCRIPTION

In order to analyze how the LTU-SUES conjunction study programs work, a questionnaire survey was conducted in one class which were taking one of the eight LTU courses in SUES. The questionnaire contains 3 basic questions about the surveyees' gender, age and grade, and then followed with 6 specific

questions on courses taken, studying purposes, the helpfulness of the courses, the likeness of the course format, and the perception of the final score. The survey had 40 observations, which was the entire class. The class was randomly selected, among all of the classes in Spring 2011 at SUES. Based on the survey, we found out that the age and grade variables have no variance, since the survey was conducted in one class, for them all were 20 years old and was in there sophomore stage, so does the LTU courses taken—4 courses except one student who has taken 5. For the gender distribution, because the surveyees are all engineering students, there are only 7 girls in the class, which is 10.93% of the class, 17.5% of the sample. Thus, all the analysis following was based on a descriptive method, and some of the descriptions included gender differences, where other sorting variables did not have a significant difference.
The analysis was based on some hypotheses the authors set such as the authors assume that students' purpose would be more on English learning than new methods and ideas in the area, and so on. Here are the hypotheses:

Hypothesis 1 is that the main purpose for students who taken LTU course are aimed to improve their English. The results show that only 8 out of the 40 students chose the answer of the improvement of English, which is 9% of the total. While 20 students chose the answer to increase culture experiences, which is 50%. The remaining 12 students chose the answer to learn new ideas and theories, which is 30%. All the numbers are shown in Table 1. Thus, the hypothesis on the main purpose was not coinciding with the data we found. The students are more interested in culture experiences and learning something new than improving their English.

	Frequency	Percentage
English improvement	8	9.0
Cultural experience	20	22.5
Learn new ideas and theories	12	30.0
Sum	40	44.9
Missing	49	55.1
TOTAL	89	100.0

Table 1: Description of Main Purpose

Hypothesis 2 was that the format of LTU-SUES conjunction learning helps students achieve their main purpose. Since the conjunction learning set is in this format, the leaders and courses setter would believe that this format of learning would benefit for students. However, the results found by the survey seems does not support the theory. Based on Table 2, there are only 7.5% of the students which means that only three of them thought this format was very helpful, the rest of them are most likely in either neutral or think it is not very helpful, or 72.5% of the respondents. Six of them answered that they didn't know. The results suggest that either the administrators or the professors might change the format or the settings for the courses.

	Frequency	Percentage
Very helpful	3	3.4
Neutral	17	19.1
Not very helpful	14	15.7
Do not know	6	6.7
Sum	40	44.9
Missing	49	55.1
TOTAL	89	100.0

Table 2: Description of the attitude toward the learning format to help to achieve their main purpose

Hypothesis 3 is that the students would like to have this format of learning

The administrators might have good intentions, but the results show otherwise. Consider that in the second hypothesis, only two people like it very much, three chose 'like', others lay on the 'just fine', "do not like', and "unacceptable' scales. Shown in Table 3, 72.5% of students think this format of courses are just fine, means they just have a neutral position. A dissatisfaction rate of 15% is an average number to present. We will investigate the results of this hypothesis, and suggest other learning formats for the courses.

	Frequency	Percentage
Like it very much	2	2.2
Like	3	3.4
Just fine	29	32.6
Do not like	5	5.6
Unacceptable	1	1.1
Sum	40	44.9
Missing	49	55.1
TOTAL	89	100.0

Table 3: Description of how students like to take this format of learning

Hypothesis 4 is that the students want to improve English listening
Table 4 shows a good result so far which coincides with the authors' perception. Shown in the table, 32 observation or 80% of the students do want to improve their English listening, with oral English followed and then reading and writing. It is interesting that people did not want to improve their oral English, since taking the courses taught by LTU professors are the most direct and efficient ways to improve. The possible reason might be students are too shy, however, we did list the question in the questionnaire, thus, we will keep it in doubt. This hypothesis was one of our most original, and we plan to further investigate other questions in this same vein.

	Frequency	Percentage
Oral English	5	5.6
Listening	32	36.0
Writing	1	1.1
Reading	2	2.2
Sum	40	44.9
Missing	49	55.1
TOTAL	89	100.0

Table 4: Descriptive Chart for English learning Perspective

For the last question, the authors surveyed the perception of scores, for we think most of students would like to have an A or B score. Table 5 just prove our theory, for 85% of students would like to have a B and above score. We did have a final score for these students; however, we cannot connect the final score with the perception score one by one. Thus, we cannot determine whether those perceptions are fit for the final score. For the final score, the mean was 76.78, and highest was 87, lowest 44. Basically, the scores follow a normal distribution curve, which coincides with the perceptions.

	Frequency	Percentage
A(4)	21	23.6
B(3.0-3.9)	13	14.6
C(2.0-2.9)	4	4.5

D(1.0-1.9)	2	2.2
Sum	40	44.9
Missing	49	55.1
TOTAL	89	100.0

Table 5: Description Chart of the Perception GPA

CONCLUSION

The SUES/LTU collaborative undergraduate engineering program will continue to concentrate on the technical aspects of the program, especially since the student attitudes favor this approach. Also, the LTU professors worries about the English competencies of the Chinese students appear to be unfounded, which will lead to more streamlined lectures and classes. In conclusion, this collaborative program is dynamic, and further assessment in the area of pedagogy, stakeholder preference, and program accreditation [i.e. ABET] will be investigated.

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THE GRADUATE COURSE IN ELECTROMAGNETICS: INTEGRATING THE PAST, PRESENT, AND FUTURE

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Abstract

In electrical engineering graduate programs, the first course in electromagnetic theory and applications has been a staple for over 40 years. It has passed through the hands of multiple professors at many different institutions while using only a few standard textbooks in various editions. While a compelling goal has been to introduce students to the main areas of electromagnetic theory in common research use, it often has had a laboratory component. The challenge in the first graduate course is to review and build enough of a foundation to launch the student into product design and research and to wet his or her appetite for advanced study.

Introduction

A half century ago the first course at the graduate level in electromagnetic theory commonly was based on a textbook such as Plonsey and Collin.[1] The course strongly emphasized Maxwell's equations and their analytical solution with applications to open- and closed-structures. In many respects the course outline followed that of its undergraduate cousin, but at the graduate level virtually every topic was approached with increased mathematical rigor. This theoretical emphasis was especially strong in the United States in the wake of Sputnik and the scientific accomplishments of the Soviet Union. For example, the Coulomb's Law review introduced some students to an entirely vector description of electromagnetics problems, many of which required integral calculus for solution. Gauss's flux and divergence theorems quickly led to Poisson's equation, which would be expressed in the three common coordinate systems. The divergence theorem led to Green's first and second identities, proved in detail, with the Dirichlet and Neumann conditions used to derive the Uniqueness Theorem. It should be noted that in a modern course the tendency is to pass over most of the details of the proofs of these theorems due to the compression of a multitude of subjects into one course.

A few years later we find as the principal textbook author Robert E. Collin.[2] He authored several books at different levels that have endured even to the present. The course now involved studies of waveguides using vector potential methods, magneto-ionic media, propagation in the neutral atmosphere, antennas as sources of electromagnetic fields, analytical methods in various coordinate systems, electromagnetics resonators, and so forth. By the 1980's and 1990's, as undergraduate education in electromagnetics was declining at some institutions, electromagnetics educators at the graduate level had to refocus on the basics. This made the work of David M. Pozar[3] and Constantine A. Balanis[4] very useful as these authors brought their readers from the level of undergraduate electrical physics to research levels in electrical engineering. Hardware design studies became more important with some supplementing their courses with textbooks by authors like K. C. Gupta.[5] Along the way Akira Ishimaru[6] authored a book that could be used in the first and subsequent courses.

A 21st century course is now likely to include a review of plane-wave and transmission-line theories since they underlie much of modern high-frequency device analysis and design. Magneto-ionic theory is still useful as a means of introducing effective dielectric constants that are less than unity. Microwave network theory and microline design techniques appeal to students and form a basis for creative laboratory projects. Noise and systems studies introduce the student to some of the realities they will encounter. Students still need explanations of electromagnetics, so they welcome mathematical and theoretical insights that are clear and comprehensively presented. Even some optics can be included, especially as a consequence of a vector potential understanding of guided-wave theory. Since electromagnetics theory is a well-established discipline, almost all of the "old stuff" is still relevant in the 21st century. However, there is a tendency to teach new mathematical and theoretical concepts using a "just-in-time" approach.

What Will Our Students Need?

An important consideration in this course is to develop an approach that reaches the audience of the next few decades. We have worked in a small graduate program that already has had a good record of producing M.S. graduates for about 50 years and Ph.D.'s since the 1980's. We expect only moderate increases in these numbers over the next few years. The electromagnetics course needs to serve those specializing in some area of electromagnetics, but it also would be beneficial to attract good students who are not specialists. The course should be designed for electrical and computer engineers and those from related fields who can benefit from it. Considering that more and more research is focusing on very high-speed or very small devices, the course should serve the traditional electrical and computer engineering (ECE) specialties and those working in material science, nanoscale science and engineering, and areas of applied physics such as the space sciences. An undergraduate background in electromagnetics is assumed, but we can't assume that background is strong. Correspondingly, an undergraduate background in electric circuits, including the use of phasor or time harmonic methods is necessary. This points again to our 16-week course where the first three weeks or so is devoted to a review from a graduate perspective of circuits and fields concepts. Good starting points are transmission line theory, plane wave propagation in a vacuum, and rectangular metallic waveguides. These are foundational to the area and can serve to review and reinforce the major concepts of electromagnetics and circuits. Beyond this, of course, we need to consider where the students will go following this course.

The Contemporary Graduate Electromagnetics Course

Today's graduate electromagnetics course deals with various engineering applications of electromagnetic theory. Topics to be considered include transmission lines, waveguides, microwave networks, passive microstrip devices, antennas, optical waveguides, wave propagation in open and closed structures, and wave propagation in neutral and ionized media.

The current version of the course attempts to introduce and review those concepts the student will need in subsequent courses and in research. As we will explain, we also attempt to present material that has applications to other specialties and career fields. The order of material presented here we feel is quite convenient to the learning process; of course, other arrangements are certainly possible.

The course begins with a review of uniform plane-wave propagation in a vacuum and in isotropic lossy media. This model of propagation adequately describes radio propagation after a wave has left a transmitting antenna and before it reaches the receiving antenna. It also is a close cousin of propagation along a transmission line. A detailed understanding of these simple cases is very valuable to the future practicing engineer or researcher. The process of study includes Maxwell's equations in the time and phasor domains (which includes a review of partial and ordinary differential equations), boundary conditions, and power flow.

It's interesting to review transmission line theory from an electric circuits perspective in both the time and phasor domains and discover the relationships that exist between the transmission line model and the plane-wave model. For transmission lines, it is useful to discuss the various types of impedance transformers along with the general concept of impedance matching. This reviews and reinforces for the student this basic electric circuits concept from their past studies.

After introducing the design and analysis of microstrip transmission lines (printed-circuit lines), various passive devices along with their design and detailed analysis are presented. Typically the student learns about microstrip power dividers and couplers, impedance transformers, and filters. Students are introduced to both low-frequency and high-frequency realizations of these devices and then are guided in designing devices to operate in the lower microwave region (a few gigahertz). This is a great opportunity for the student's general electrical engineering education. They learn how to layout their designs using Agilent's ADS system.[7] They export a gerber file to the department milling machine, and then compare the performance of the device to the theoretical predictions of ADS.

Students then choose a project in which they will apply this process to a more advanced device that they have chosen for study. With the background that now exists, students can move ahead, for the most part, in developing their own projects outside of class. This milestone in the class experience can be a good opportunity to take some class time to talk about ethical issues in the discipline, often taken from current news events. Two possible examples are the health concerns in cell phone usage and the health effects of high-voltage transmission lines. It's likely that the class won't come to any final conclusions on such issues, but at least they will be aware that the engineering profession is aware and concerned about such issues.

We are now ready to tackle something more substantial. First, we solve the classical rectangular waveguide problem using a product solution of the partial differential equations. This problem shows clearly why there can be so many different modes or solutions to this problem. This problem serves as a benchmark for comparison with the results of more advanced methods. It also helps the student to understand what a mode is later when we introduce the optical fiber as a communication channel. But, continuing with the rectangular waveguide, this is an opportunity to introduce the Hertz potential method to solve a variety of waveguide and multilayer microsrip devices or antennas.

The Hertz potential unites the vector and scalar potential commonly encountered in electromagnetics. It is a convenient tool for the study of the rectangular waveguide, the cylindrical waveguide, the coaxial waveguide, and even optical fibers. These structures can also be the occasions for the study of solutions to Maxwell's equations in various coordinate systems.

Antennas are treated in a subsequent course, but system aspects of the antenna are appropriate in the first graduate course in electromagnetics. Here we introduce the concept of the electric field due to a transmitting antenna and the resulting electrical output of a receiving antenna. This is followed by developing the relationships that exist among antenna size, path length, and electrical noise.

A terrestrial radio link involving a transmitting and receiving antenna provides the opportunity for study of such problems over a hypothetical flat earth or a spherical earth. One can also add atmospheric effects such as refraction (the four-thirds earth radius concept) and scattering, and, for longer paths and lower frequencies, we can include anisotropic wave propagation in the ionosphere. Although this is a rather old problem, as was mentioned above, it does give the opportunity to introduce a naturally occurring propagation situation in which the index of refraction can be less than unity. This can prepare the student for the metamaterial problems to be encountered in contemporary research.

We can come back to earth by considering microwave devices from the perspective of matrix methods and physical realizability. Microwave circuits are often considered by using the scattering parameters. A review of matrix methods that should be useful to those in other specialties leads directly to demonstrating the relationship of these parameters to those encountered in other courses: impedance parameters, admittance parameters, and the ABCD parameters. Measurement instruments often give results directly as scattering parameters, and, after a little experience, the engineer starts to think and design directly in the scattering parameter domain. However, at the analysis level, she/he most move back to the circuits level. The relationships involved are shown nicely through well-known matrix properties.

Finally, we have a brief introduction to optical signal transmission to include the calculation of optical fiber numerical aperture through a review of Snell's law at the core-cladding interface followed by a brief introduction to optical fiber mode theory. This latter study is facilitated by our earlier study of waveguides.

Course Project

As was mentioned above, early on students begin work on a course project. Usually there are enough students in class to break up into five or six groups of two each. The two share the workload for the project. This includes designing the devices, implementing and simulating them using ADS, obtaining the resulting circuit boards from the milling machine, and measuring the device performance. These measurements are compared to the ADS simulations or to simulations produced by other software such as Matlab (the standard mathematical package used in the department). Finally, the project teams must present their results to the class at times scheduled at the end of the semester. The oral presentation is given using PowerPoint. Each student presents a portion of the technical presentation, usually limited to about 20 minutes total. The presentation is made to the entire class, and the targeted audience is their classmates. Attendance is required for all students for all presentations. An unexcused absence results in points deducted from the absent student's presentation score. The presentation score is based on several factors:

- the quality of the visual presentation materials
- organization and preparation
- English grammar and speech
- the ability to communicate the topic to the class
- presentation at a level appropriate to the class
- being on time and speaking within time limits.

The project presentation is a good first step in preparation for the eventual graduate degree defense that every student is required to face.

Where Do We Go From Here?

Hopefully students from specialties outside of electromagnetics are helped by the range of studies and activities in this course. But how are students wishing to do research in electromagnetics or in closely related areas like optics served through this course and the offerings in a small graduate program like ours?

The course covers basic concepts and topics in electromagnetics that are essential to the electromagnetics specialist. And the project gives practical design and measurement experience that serves well students doing research in our department. The course is a good fit for what we do, but more is needed. Beyond the mentoring the student receives from a core group of research faculty, the student needs additional course work.

Several additional graduate courses exist to develop the student's research abilities. In electrical engineering, students can choose courses in electronics, signal processing, communications, and control systems that will improve their knowledge of applied physics and mathematics. In electromagnetics we offer courses in antennas, electromagnetic compatibility, and signal integrity. Physics and electrical engineering cooperate in offering courses in optics, optical signal transmission, lasers, and photonics. Physics offers courses in electromagnetics and computational physics that can be useful to some students. Finally, mathematics offers a wide range of courses useful to electromagnetics research; complex variable theory, applied differential equations, and partial differential equations are good examples. Carefully planned courses of study can lead our graduate students to have backgrounds that will facilitate their progress and growth in research.

Undergraduate and graduate education is very important and is a strong emphasis of the ECE Department as a whole. Efforts are underway in ECE to promote research activity. An integration of research and course work is one method of developing a new type of research program.

At this time there are approximately 400 undergraduate and 30 graduate students in the NDSU ECE Department. Contained in this group of students are very talented and bright individuals capable of thinking independently, taking initiative, and leading groups of people. One method of challenging these capable students is to integrate active research programs directly into the courses currently being taught in the ECE curriculum. Over the past few semesters, the authors have been working to bring research activities into the courses in electromagnetics that were mentioned earlier. In particular, research topics associated with flexible antennas, microwave circuitry, and printed antennas have been introduced as projects in these courses. During the semester several milestones have been defined. Some of these milestones involve a literature search, reproduction of published results, new designs or new research, synthesis, and testing. To meet these milestones the daily or weekly homework loads have been reduced, and, in place of this effort, the students are required to write bi-weekly reports and present them to the class. At the end of the course, the students are required to prepare a conference paper summarizing their new results, and part of the final grade depends on this submission. Student feedback on these courses has been outstanding. On a scale of 0 to 5.0 (5.0 = a very good course), the overall course rating has been 4.6, and two journal and four conference papers have been published as a direct result of these courses. Furthermore, several of the most talented students continued their stay at NDSU and enrolled in the graduate program. A future aspect of this integrated research and coursework plan is to extend this concept to include other courses outside of the area of electromagnetics and work with other faculty within and outside of the ECE Department. Results from this broader research integration will be presented in a future paper.

What Goals Should Our Course Have?

Some outcomes that we expect are that: (i) students will be able to analyze and design the devices studied in the course, (ii) they will have the background to work with related but more complex devices, and (iii) they will be able to produce innovations based on the background that they have obtained. There are “softer” outcomes that we also strive for. We would like the student to have an honest opinion of his/her own abilities in the field. Hopefully the course will move them from a “novice” to a “qualified” level. We hope that they will be actively involved in class attendance, assigned readings, and completion of homework assignments. The core concepts in the course should be very familiar to them so that they can perform well in exams without feeling the threat of time pressure. They should become familiar with using the graphical interface for ADS and see their design produce concrete products. They will learn how to use microwave measurement equipment to assess the performance of these products. In general, they will be comfortable using the computer facilities and measurement equipment available in our laboratories. Much of the learning will be done through interaction with their colleagues in class and in the labs. The course should help to build a cooperative climate among graduate students and their research faculty mentors, further stimulating interest in research. This should lead to the development of lifelong friendships. Finally, we hope that many course projects will grow into theses and research publications.

Acknowledgement

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Introducing Software Engineering to General Engineering Students

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The Introduction to Engineering Projects Course

At the University of Wisconsin-Platteville, an Introduction to Engineering Projects is a required one semester credit course that is typically taken by engineering students in their first year. The course is broken down into seven, two week modules that cover each of the engineering disciplines, Civil, Electrical, Environmental, Engineering Physics, Industrial, Mechanical, and Software Engineering, that are taught at our school. Each week the students meet for a two hour lab and every two weeks the semester the students rotate to another engineering lab. Thus, in one semester they obtain some exposure to each of our supported disciplines. The goals of this course is to provide all engineering students some exposure to other engineering disciplines and provide experience and information to students who have not yet decided on their engineering major.

The last two years, this course has also been offered in a one week condensed version during the summer to high school students who are interested in pursuing engineering majors. The summer school version has been very popular and has grown from two sections the first year to four sections plus a long waiting list this past summer. The high school students optionally earn one college credit if the complete all course requirements including a final exam. The four objectives of the summer version are recruiting students to our university, providing high school students some exposure to engineering disciplines to help them decide which disciplines they might want to pursue, exposing engineering to groups that are traditionally underrepresented in engineering programs, and exposing high school students to a flavor and pace difference between high school and college courses.

The Software Engineering Module

This paper describes the Software Engineering module, which as described above is just one of the seven modules in the Introduction to Engineering Projects course. Knowledge of computing and software engineering is important to all engineering disciplines as well as other STEM students. The US Bureau of Labor Statistics reports that 71% of all new STEM jobs will be computing related[5]. In addition the author believes that developing software is a good experience for any student engineer, in that it can help develop mature process development skills that are useful for all engineers. The problem is that it is difficult to teach students to program, let alone develop a project, in just two weeks.

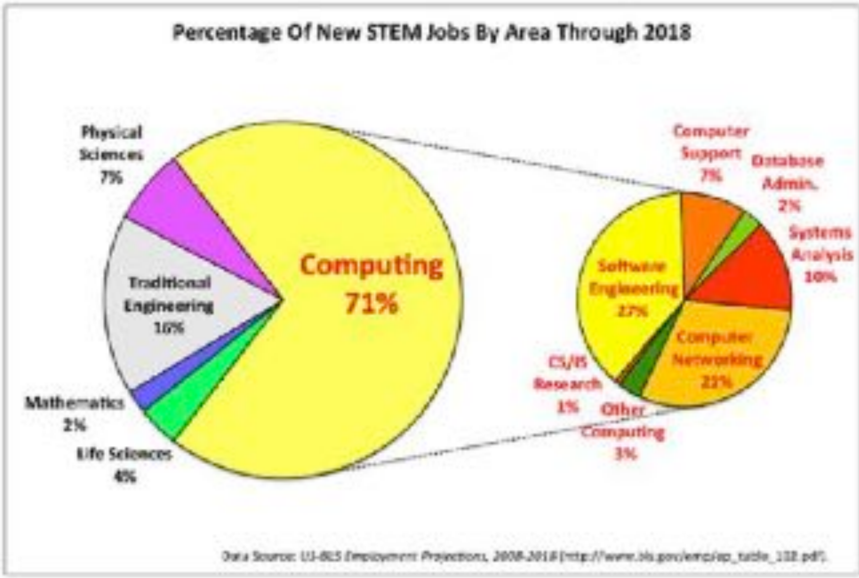

Figure 1: Projection of STEM and Computing job growth through 2018[5]

In the past four semesters and two summers the software engineering module has used a 3-D animation programming environment called Alice. Alice was developed at Carnegie Mellon University under the directorship of the late Dr. Randy Pausch (of the "Last Lecture" fame) as a means for teaching middle school students how to program [3]. Alice provides over 1000 objects that can be added to a virtual world. The objects are supplied with various methods that allow an entire object or parts of an object to perform actions, such as move, turn, play a sound, interact with other objects, etc. The objects also have associated properties that can modify an object's characteristics, such as color, opacity, texture, associated sound files, connectivity to other objects, etc.

There are many advantages associated with using the Alice environment. Alice is free and can easily be downloaded from http://www.alice.org and installed on any Windows or Mac based computer. Alice can even be run directly from a small memory stick in that its memory footprint is only about 360 MB. Alice.org maintains a comprehensive set of class-tested, slide-based tutorials from the "getting started" level to the very advanced level. Alice.org even provides email problem and question support.

The Benefits of Programming in Alice for all Engineering Students

In addition to the importance of having some experience with software development, there are many other important programming constructs that are useful in helping all student engineers appreciate and develop logical thinking skills about complex problem solving and process development. These features include:

- Sequential flow – the concept whereby one step is executed completely followed by the next step, and so on. This concept helps student engineers build an understanding and appreciation of process flow, ordering and the interdependencies of process steps.

- Conditional flow – the concept whereby one of several alternative process paths is executed based on a set of run-time conditions. This concept helps student engineers understand contingencies and the need to plan for all possible process conditions and outcomes.
- Iteration – the concept whereby a set of process steps is repeated over and over again until a specific exit condition is achieved.
- Concurrency – the concept whereby multiple subprocesses are executed at the same time. This may be needed to satisfy requirements of a process, for instance a child proof container may require that one must press and twist the lid concurrently to open. Concurrency may also allow for faster execution of a process.
- Encapsulation – the concept whereby information or details about an object are hidden from other objects and can only be accessed through the object itself. Encapsulation helps promote subprocess abstraction or simplification and assists with the breaking of very large problems and processes into smaller pieces, using a divide and conquer strategy.

In addition to the above process and problem solving skill building, we hope it can help improve recruitment, retention and success rates for introductory computer science and software engineering courses. Although retention and success in introductory computer science courses is not good, as low as 50% at some schools, it is even worse for women[8]. There has also been a decline of 80% in the number of female Computer Science majors between 1998 and 2004[4]. At our university there is no evidence of a reversal of this decline in female enrollment and retention – despite a nearly doubling of total enrollment between 2002 and 2011 it is still rare to have a female student in an upper division software engineering course. Women avoid Computer Science and have lower retention rates than males. Women are the most frequently studied groups at risk in CS1 (CS1 is a generic term used for the first computer science course offered to majors) courses[1, 2, 6, 7]. In these studies, the lower attraction and retention has been attributed to early courses being "overly technical" with little room for creatively[1, 7]. For those student who go on to take a first programming class, Alice experience can be beneficial in increasing the likelihood of success. Without Alice, at risk CS1 students average a C grade and only 47 percent go on to take CS2, with Alice the performance and retention is greatly improved, with CS1 students averaging a B grade and with 88% going on to take CS2[4].

Alice seems to address the issue of programming as being "overly technical". With traditional programming languages students are required to learn complex vocabularies and grammars, in contrast programming in Alice involves dragging and dropping of well formed and valid program statements. Modification of these statements is done by selecting options from dropdown menus. It is impossible to produce the dreaded compile error and very unlikely to produce a program that doesn't run the very first time. This eliminates of the need to memorize a vocabulary and grammar, which subsequently speeds up the opportunity to experience creative expression. It should also be noted that the wide selection of more than a 1000 animation objects with tens of 1000's of methods allow people of practically any interest to find something of interest to animate. For instance there are ballerinas, football players, farm animals, amusement park objects, space objects, plants, cars, trees, flowers, cell phones, etc.

Many students prefer a visual and hands-on learning styles, the author believes that this is even more common among engineering students. Alice addresses this by having a very visual and hands-on development environment. Rather than writing code, compiling it, producing test cases, and so on, the programmer simply selects what they want and clicks the run button to immediately see the result.

Description of Alice

Alice follows a strong object-oriented paradigm similar to popular programming languages like Java, C++, C# and other currently popular languages. If a student is interested in continuing their education in software engineering or computer science, having this object-oriented knowledge and experience is a definite plus. Unlike typical object-oriented programming languages students do not need to learn a programming language vocabulary and grammar. Often with as little as five minutes into a “getting started” tutorial, students are productive and off on their own. Although they don’t need to learn the vocabulary, the language is similar enough to a “real” programming language that they kind of get use to it. One of the current enhancements to Alice is to make the language even more similar to Java[4].

Another significant advantage of Alice is that the Integrated Development Environment (IDE) allows for immediate feedback by running the animation, which enables students to try concepts and immediate see how they works. In conjunction with trying concepts, there is an undo button that allows methods and objects to be easily backed out if the desired functionality is not achieved.

Details of the Alice Environment

A Virtual World

The development of an Alice program starts with the programmer selecting a template world. This provides a background to which objects can be added. One of six different templates may be selected by a mouse click. With the template selected, the programmer can start adding objects. See Figure 2 for the template worlds.

Figure 2: Template worlds.

Object Galleries

Similar to many CAD systems, objects are organized in a hierarchy of galleries. Within a level, galleries are organized alphabetically. The top level gallery contains over 35 subgalleries, such as Amusement Park objects, Animal objects, Beach objects, Old West objects, Skate Park objects, Sport objects, etc., Figure 3. The programmer navigates to a low-level gallery by double clicking on the gallery Figure 4. Objects are added to the world with drag and drop operations. Objects can be positioned and posed by clicking a control and moving the mouse. These position and posing controls allow an object to be place vertically, rotated with respect to the X, Y and Z planes, resized, and replicated Figure 5.

Figure 3: Top-level Object Gallery.

Figure 4: Second-level Gallery – Animals.

Figure 5: Virtual world with Ice Skater and Boar objects.

There are also three camera controls that allow the programmers to set and save camera positions. The camera can be moved and tilted forward and backwards, left and right, and up and down. Once one or more objects have been added to world the programming of the animation can start.

Programming in Alice

True to the object-oriented nature, most Alice objects are aggregations of other objects. For instance a ice skater object is an aggregation of LeftLeg, RightLeg, UpperBody, and Skirt. The LeftLeg consists of a LowerLeg and a Foot. This is shown in the screenshot in Figure 6.

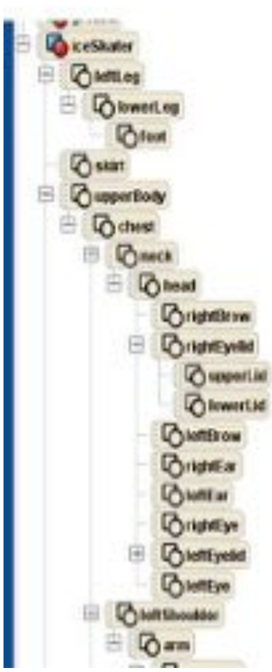

Figure 6: Screenshot of an ice skater object, which shows her as a hierarchical aggregation of other objects.

Each object contains a collection of methods and properties. Methods are action verbs that allow an object to perform an action such as move, roll, spin, play a sound, etc. See figure 7 for some of the methods associates with the ice skater object. Properties are adjectives that allow objects to change color, texture, visibility, etc. These methods and properties can be applied to a top level object, such as the entire ice skater, or one of the lower-level objects such as right eye lid.

Figure 7: Methods (left) and Properties (right) of the ice skater object.

For a more in depth description of how to program in Alice the reader may want to refer to the fine tutorials at http://www.cs.duke.edu/csed/alice/aliceInSchools/workshop08/tutorials.php.

The Software Engineering Assignment

This section describes the Software Engineering module and its assignment. Students were allowed to form teams of three. The instructor spent about 15 minutes introducing what Alice is and playing a selection of three or four animations from previous semesters. While the animations were running, the instructor pointed out different required features that must be satisfied to earn full credit on the project.

After this introduction to Alice, the class read through and discuses the eight project requirements, while examples from the animations that were just played were reiterated. These requirements include:

1. The World shall contain at least 3 scenes.
2. One of the scenes shall contain at least two characters who engage in a dialog. A sample dialog might be
   - Character 1: What is your favorite engineering discipline?
   - Character 2: (Your answer)
   - Character 1: Why do you like that discipline?
   - Character 2: (Explains why)
   - Character 1: Where did you learn about [name of discipline]?
   - Character 2: (Response)
   - You can use a different dialog instead, but it needs to be engineering-related and involve at least 3 questions with responses.
3. In each scene, the world shall contain at least 1 building, 2 characters, and 3 props (trees, flowers, hockey pucks, skateboards, cell phones, aircraft carriers, etc.).
4. In each scene, two characters shall each move to at least three new places.
5. In each scene, two characters shall move parts. For each character, there must be three body parts moved with each part having at least three movements.
6. At least one scene shall contain an Alice vehicle - something that carries another object. The carried object must enter the vehicle in one scene and leave the vehicle in that or some later scene.
7. In each scene, there shall be at least two camera changes to both new positions and new angles. Each of the angle/position pairs must be distinct from the others.
8. There shall be at least two additional, team-selected, significant features such as events, scene fades, or sounds.

At this point, the teams are coached through bring up the Alice environment and a "getting started" tutorial. This particular computer lab contained dual monitor computers, so the students could follow along the tutorial on one monitor while trying Alice on the other monitor. This first tutorial only takes about 10 minutes and covered requirements 2, 3, 4, and 5, which are the easier ones. The students were given about 15 minutes to work to start populating their worlds with objects and start on the first set of requirements. Following this initial hands-on time, a second demonstration, lasting about 10 minutes, was presented that covered the remaining, more difficult requirements. It should be noted that most groups were seriously engaged in their projects and there were frequent spontaneous outbreaks of laughter, which was judged to be a good sign. The final 30 minutes of the first day's lab the student were free to work on their projects and ask questions. Each lab section was limited to 10 groups of three, so with a lab assistant there was generally little delay in getting around to answer any questions that came up.

The lab on the second week of the module consisted of a 20 minute presentation (propaganda) of what software engineers do for a living and the career outlook, salary and placement rates. Following this presentation, the students were given free time to continue with their projects. About 15 percent of the groups satisfactorily finish the lab this second day without any out of class time. The other groups required or choose to put in additional out of class time. It is obvious that some groups put in substantial time to go far and beyond just satisfying the requirements. One such example will be demonstrated at the conference.

Conclusions and Observations

Overall the faculty has been very happy with the outcomes of this Software Engineering module and in general the Introduction to Engineering Projects course. Students report that they find the fast paced, hands on introduction covering the seven engineering disciplines of value. We don't anticipate significant changes in the near term.

With respect to the Software Engineering module, we general have one or more General Engineering students per section inquire about changing there major to Software Engineering. This may be due to an epiphany in the discovery of what they really want to major in or it could be due to dissatisfaction in there currently declared major. We would imagine that other disciples also have similar recruitment experiences. We do not have data indicating whether we have seen a net increase in any particular major due to this module.

Currently, the course has a perquisite of an Introduction to Engineering, which targets helping students transition from high school into our college of engineering. The argued benefit of having students take the Introduction to Engineering Projects course their first semester is that it might help more of them make informed decisions regarding their choice of major one semester earlier. At this moment we have a logistical issue that makes this difficult – we don't have enough faculty to teach both Introduction to Engineering and Introduction to Engineering Projects in the same semester as many of the instructors are teaching these courses on an overload basis.

Although the "summer camp" version of this course has only been running two summers, there seems to be a very rapid growth in interest. We have been fortunate to have some funding to offer scholarships to students from underrepresented groups. We feel that this might be a cost effective vehicle to greatly increase the interest and recruitment of underrepresented students into the engineering field. Despite our best efforts, on our campus Software Engineering has one of the lowest levels of underrepresented students. Hopefully, this course will help with this issue.

The two weeks per each of our seven engineering disciplines fits very nicely into a 15 week semester. Our college of engineering has been experiencing steady grow and there are plans to add at least one additional engineering major in the next couple of years. Adding an eighth module will require adjustment of the course schedule.

Alice 3.0 has been in beta testing for many months and includes many new features. Once version 3.0 is released we will need to evaluate the current requirements of the Software Engineering module's to incorporate some of these features. We have chosen to stay with the older 2.2 version to minimize any difficulties the students might experience with a less stable, beta environment.

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Adapting Digital Design Instruction to a Programmable Logic Device Setting

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Introduction

Programmable Logic Devices have revolutionized the way in which digital circuits are built. Individual Small-Scale- or Medium-Scale-Integration (SSI or MSI) devices are rarely used, and in fact are becoming hard to find. Instead, FPGAs (Field Programmable Gate Arrays) and CPLDs (Complex Programmable Logic Devices) have become the standard for implementing digital systems[1]. FPGAs and CPLDs offer much higher circuit density, higher reliability, and system simplification, all of which make them very attractive to the digital designer. However, with these advantages comes a loss of visibility of the underlying circuit. The designer can "lose touch" with the circuit being designed, and the resulting hardware is really more of a computer-generated black box than it is a carefully crafted, fine-tuned design. Creativity in the design is less visible when using FPGAs or CPLDs, and "elegant" solutions to design problems are not rewarded in the same way as they are with design using SSI and MSI parts.

FPGAs and CPLDs are intended to implement solutions to digital design problems as quickly and efficiently as possible, both qualities that are important in an industrial setting. However, in an educational setting, the solution is not as important as understanding how the solution is reached, and these programmable devices automate and hide that process, making them less attractive as educational tools. Using FPGAs and CPLDs as vehicles for teaching digital circuit design requires that the instructor consciously emphasize what is being done behind the scenes by the synthesis software that configures the programmable device. Otherwise, digital design degenerates into just another programming exercise, albeit using a hardware description language rather than traditional software languages.

Furthermore, using the fixed structures of FPGA or CPLD implementations restricts design strategies and limits possible solutions. Having students design combinational circuits using "all NAND gates" or "all NOR gates" becomes pointless, because the synthesis software that configures the programmable device translates whatever implementation is specified into the standard structure implemented in the device. Combinational circuits that must avoid logic hazards (momentary "glitches" during transitions) cannot be implemented properly in current FPGA structures, and are clumsy to implement in CPLDs. Thus, some digital circuit designs cannot be mapped cleanly to programmable devices. Such designs might continue to need discrete logic gates to demonstrate to students the importance of some techniques.

Programmable Logic Devices, though attractive to the experienced designer, can be awkward and even impossible to use in certain educational settings. Digital design instructors must be aware of these limitations. They must find creative ways around the limitations, and must restrain themselves from being brainwashed by the glitz of FPGAs and CPLDs. This paper identifies techniques for maintaining the excitement and rewards of creative digital design even within the confined restrictions imposed by Programmable Logic Devices.

What is an FPGA?

A Field Programmable Gate Array (FPGA) is a component focused around a large matrix of configurable logic blocks. Each logic block implements a combinational function which is optionally captured in a latch or flip-flop register to allow sequential circuit implementation. Other structures often are present in FPGAs such as RAM memory, special-purpose logic (e.g. multipliers), and input/output circuitry, but the core logic blocks are the topic of interest here. Large digital systems are assembled by connecting logic block inputs and outputs via a programmable interconnection network within the FPGA.

Figure 1 shows a very simplified logic block in a typical FPGA. The logic block receives "n" inputs from the interconnection network in the FPGA and supplies its output to that network for use elsewhere. At the heart of the logic block is a RAM-based look-up table that generates the combinational function to be implemented in that logic block. The look-up table simply stores the truth table for the function to be implemented, and is programmed when the FPGA is configured for the target application.

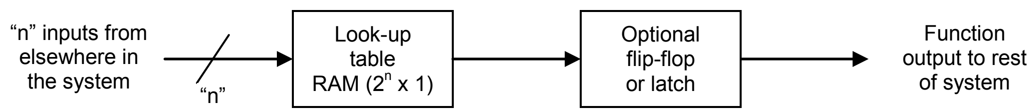

Figure 1. Simplified configurable logic block, the heart of an FPGA

By reading a circuit description defined in a hardware description language such as VHDL[2,3], synthesis software can determine the truth tables for required combinational functions, load the look-up tables with these truth tables, and configure the registered storage in each logic block as needed for the particular application.

What is a CPLD?

A Complex Programmable Logic Device (CPLD) is a component focused around a large number of macrocells. Each macrocell implements a combinational function of "n" variables which is optionally captured in a latch or flip-flop register to allow sequential circuit implementation. The difference between FPGAs and CPLDs is the structure used to implement the combinational function in the macrocell. Whereas the FPGA uses a RAM-based look-up table to store the truth table for the required function, the CPLD implements the function by ORing together implicants for the function generated by a programmable array of AND gates. The AND gates combine selected inputs (or their complements) to produce terms for the function in a typical sum-of-products structure. The result of ORing the implicants is optionally inverted and then optionally captured in a latch or flip-flop to implement a sequential circuit. As in the FPGA case, large digital systems are assembled by interconnecting the macrocells via a programmable interconnection network within the CPLD.

Figure 2 shows a very simplified macrocell in a typical CPLD. The AND gates receive their inputs from the interconnection network in the CPLD, and the macrocell output is supplied to the network for use elsewhere within the CPLD. The combinational function is produced by ORing implicants of the function in traditional sum-of-products form.

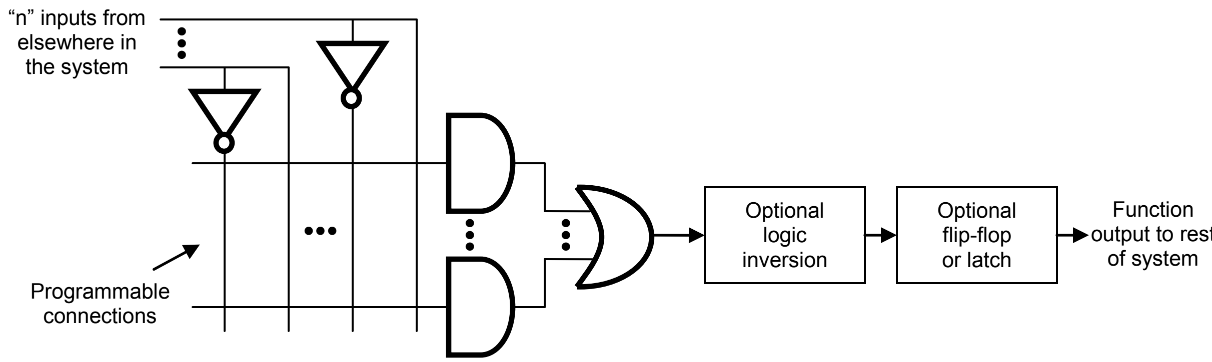

Figure 2. Simplified Macrocell, the heart of a CPLD.

Using the circuit design supplied in a hardware description language such as VHDL, synthesis software analyzes the required combinational logic to determine a minimal sum-of-products form (or product-of-sums form, if the inverting option is used) for each combinational function to be produced, and configures the AND gate connections to produce the required terms for function implementation.

Pedagogy Troubles

Regardless of whether FPGAs or CPLDs are used, the synthesis software that configures the programmable device hides all the details and challenge involved in designing a digital system. Once the system design is defined in a hardware description language, the synthesis software performs all of the optimization and minimization to configure the programmable device to implement the required system. No additional effort is required on the part of the designer. The quality of the design depends upon the quality of the synthesis software, not upon the skill of the designer who wrote the hardware description language design of the system. Clumsy, unrefined system designs are "cleaned up" by the software and produce the same final result as carefully crafted designs. If the only measure of design quality is just how many resources are used in the programmable device, poor designs and high-quality designs will score identically.

This pedagogical problem is evident even in the simplest case of implementing a single combinational function. In the FPGA case, no matter how clumsy or non-minimal the designer's function specification is, the software simply evaluates the truth table for the function, and stores it in the look-up table memory in a logic block. In the CPLD case, specification of non-minimized, redundant functions is immaterial, as the software reduces the function to minimal form. The software even determines whether sum-of-products or product-of-sums form leads to the most economical implementation, so the designer's input to the final implementation is non-existent. In the ultimate insult to a digital designer, it is even possible to simply input the truth table of the desired function(s) and the software will determine the optimal implementation. Where is the design effort to be assessed?

In current CPLD implementations, the flip-flop in each macrocell can be implemented as either a D- or a T-type flip-flop. The configuration software decides which flip-flop type yields the best result, not the circuit designer. If the designer specifies the less-optimal type, the software will change the design, eliminating the designer's input to the final implementation. Again, the design effort expended by the circuit designer is not assessable in the final implementation.

From an instructor's point of view, trying to assess the quality of digital designs cannot rely on the result of configuring an FPGA or CPLD for the particular application. Every designer, regardless of ability, will get the same result! Instead, assessment of design quality must be based on the system description provided by the hardware description language input to the configuration software by the designer, before the synthesis software has a chance to modify it.

A possible approach that may work in assessing the quality of digital designs relies on counting the number and types of component library elements used in a design. All configuration software allows description of digital circuits using libraries of combinational and sequential components. One technique for distinguishing the quality of one design from another is simply to count the number of library elements used. Simple gates and flip-flops count as one point each. More complex, traditionally MSI, components such as counters, shift registers, four-bit adders, etc. would count as perhaps ten points each. A working design with fewer total "points" than another is clearly the better design.

Implementation Troubles

Some characteristics of FPGA and CPLD design structures complicate certain design situations. One such situation is the occasional need to implement combinational logic in non-minimal form. The synthesis software for configuring programmable devices always minimizes functions to simplest form. This sometimes prevents desired implementations from being possible.

Avoiding logic hazards is a particular case where minimizing logic is not the right thing to do. Figure 3 shows the Karnaugh map and minimal sum-of-products implementation for a function of three variables, f(a,b,c) = ab + a'c. As implemented in Figure 3, this function has a static-1 logic hazard, meaning that in at least one case, changing one input variable between values that start and end with the function value being logic 1, might generate a brief logic 0 glitch on the output during the transition. The hazard can be seen in this case by starting with a=b=c=1 and then changing a to 0. The possibility exists that the top AND gate output might become 0 before the bottom AND gate output becomes 1, which could lead to a brief 0 on the OR gate output during that transition, which is a logic hazard. In clocked systems where it is important only that function values achieve their new post-transition value before the next clock transition, hazards do not pose a problem. However, in asynchronous circuits where there is no clock to identify when to look at signals, functions must be valid at all times, including during transitions, so hazards must be avoided in such systems.

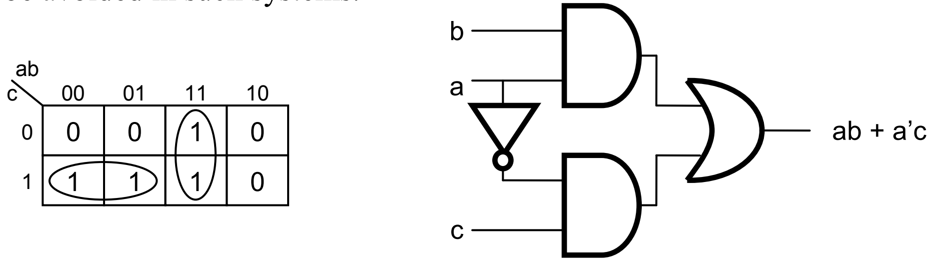

Figure 3. Simple combinational circuit that displays a static-1 logic hazard

Logic hazard problems can always be solved, but sometimes the solution requires adding redundant logic which makes the resulting circuit non-minimal. With sum-of-product implementations, the technique is to be sure that every pair of adjacent 1's in the Karnaugh map is included together in some implicant of the function. In this case, that means that the implicant "bc" must be added to the function implementation, resulting in f(a,b,c) = ab + a'c + bc, as shown in Figure 4. This is a non-minimal implementation of the function f(a,b,c), but it is hazard-free, and in situations that must avoid hazards, it solves the hazard problem.

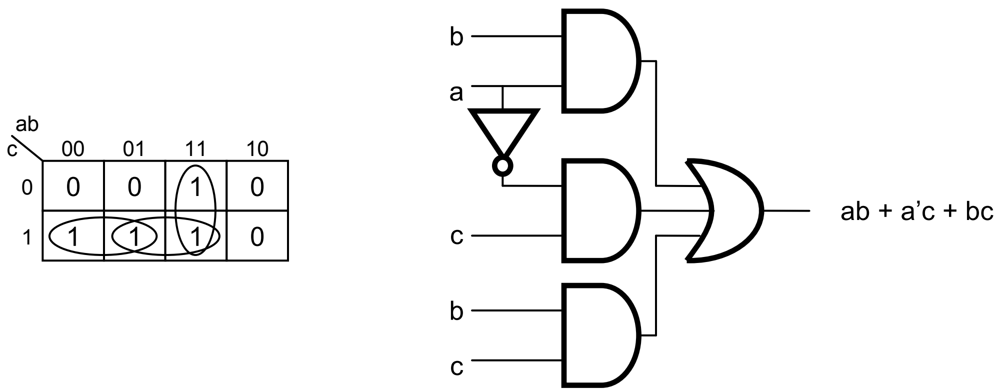

Figure 4. Non-minimal, but hazard-free implementation of Figure 3's function.

Unfortunately, programmable device synthesis software will not allow non-minimal expressions to survive. In the CPLD case, the redundant term in the expression of Figure 4 will be removed, and the CPLD implementation of the function will return to Figure 3's circuit, restoring the hazard. In the FPGA case, the truth table for the function f(a,b,c) will be determined and stored in the look-up table. This implementation essentially makes each minterm of the function a separate implicant, thus forming the function f(a,b,c) = a'b'c + a'bc + abc' + abc, which is loaded with logic hazards. Neither of these implementations is acceptable if hazards must be avoided.

So what can be done to avoid logic hazards? In the FPGA case, nothing can be done. The technique of storing the function truth table in a look-up table forces each minterm to be treated as a separate implicant of the function, which eliminates the chance to solve logic hazard problems. If logic hazards must be avoided, FPGAs cannot be used.

In the CPLD case, the synthesis software will remove redundant terms in functions. However, it is possible to separately generate each needed implicant, including redundant ones, and then separately combine them. This is spectacularly wasteful of CPLD resources, as each implicant must be generated in its own macrocell, and then an addition macrocell is required to combine the implicants to produce the hazard-free function. However, a solution is possible with the CPLD to avoid logic hazards, though very clumsy. Conceivably one could edit the netlist files produced during the configuration software execution to force redundant implicants to survive and thus eliminate logic hazards in CPLD implementations more efficiently. However, editing the netlist files (EDIC format, e.g.) is not a common skill among student digital designers, and should not be a part of the required curriculum in a digital design class. After all, the class is about designing digital circuits, not about how to coerce software tools into performing as desired.

Summary

Programmable devices such as FPGAs and CPLDs are here to stay, and have revolutionized digital design. However, using such devices as the basis for digital circuit education has some serious shortcomings. Assessing the quality of designs implemented on programmable devices requires some creativity on the part of the instructor, since the final implementation reflects more the quality of the configuration software used than it does the quality of the original design. Even worse, some designs cannot be implemented properly at all on FPGAs, and can be implemented only clumsily on CPLDs. When those designs are required in a system, programmable devices may not be the best implementation choice.

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Biography

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Fourier Workbench

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Abstract

In this study, a Java-based program, Fourier Workbench, was developed. This software processes an audio input signal on the fly, displaying both the FFT (Fast Fourier Transform) and the DFT (Discrete Fourier Transform) of the signal at the same time. The software automatically updates these graphs at a user specified interval. This can be paused or updated manually as determined by the user. The time the calculations took for each algorithm is also displayed after every update. The software was designed especially for processing of musical instruments like a guitar. The software includes an option to display lines at the main frequency and harmonics of a well-tuned guitar note. The other options that the user can control include but aren't limited to, sampling frequency, the number of samples per transform, the displayed area on the graph and whether the DFT calculates the whole spectrum or just what is displayed. The main purpose of this program is to demonstrate the effect of these parameters on the resolution and speed of the transforms, and also to demonstrate the difference between the two algorithms. The software can be used for tuning musical instruments, for students' exercises in ECE introductory digital signal processing courses, and also for research in this field. In future studies, some additions can be made to the software to enable students to develop, apply and observe the effects of various filters to recordings.

Introduction

The Discrete time Fourier Transform (DFT) can be used to transform a sampled audio signal into a frequency domain representation. The frequency domain representation can be shown as graphs of variation of magnitude and phase angle with frequency. This representation is called a Bode plot. The Fast Fourier Transform (FFT) is an algorithm to implement the DFT process more efficiently. In this study, a Java-based interactive program has been developed to visualize the DFT and FFT of recorded audio signals. The software is an interesting application of the FFT and DFT algorithms to musical signals like those from an electric guitar. Some researchers have shown in their papers that signal processing techniques can be applied to musical recordings for analysis and synthesis.[1-2] This program is useful for comparing the FFT and DFT and also for exploring the effect of different sampling frequencies and sample sizes. In the future, perhaps the program will also assist in the design of real-time signal processing algorithms. This is still within the scope of an introductory digital signal processing (DSP) course.[3] First, the overall software system is presented in this article. The interface and user options are explained. Some of the results are reported, and usability of the program in an introductory DSP course is discussed.

Fourier Workbench Software

The block diagram of the overall system is shown in Figure 1. The audio/musical signal is processed on the fly. An electrical guitar is plugged into the sound card of the computer.

Sampling rate can be selected by the user between 4 KHz and 96 KHz. A certain number (N) of signal samples are kept in the buffer, which keeps only the most recent N samples. This number is selected by the user between 64 and 8192. The user can obtain magnitude plots of the DFT and the FFT of the signals on the display with the software. The sampling rate and number of samples determine resolution and maximum frequency of the transform.

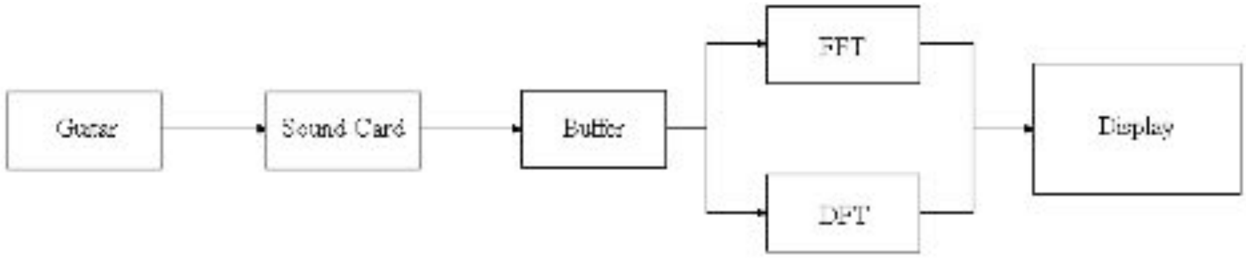

Figure -1. Block diagram of the system.

The Discrete Fourier Transform (DFT) is used to transform a time domain signal x[n] sequence to a frequency domain X(k) sequence.

The frequency response of a sequence and its DFT are related as expressed in equation 1.

$$X(k) = X(e^{j\Theta}),\ \text{where } \Theta=2\pi k/N,\ k=0, 1, 2, \ldots, N-1 \qquad (1)$$

The elements of X(k) as obtained from this equation are at discrete frequencies spaced $2\pi/N$ apart. This is the natural spacing of the transform, which doesn't need time information to perform properly, but to find actual frequencies, we need time information. This is contained in the true frequency spacing of the transform, Δf, as defined in equation (2). Multiplying k by Δf yields the frequency of that point on the transform in Hz.

$$\Delta f = 1/T_0 = f_s/N \qquad (2)$$

In this equation, T_0 is the length of the recorded signal in seconds, f_s is the sampling frequency of the original signal in Hz, and N is again the number of samples in the signal being transformed.

The direct computation of the DFT requires a large number of complex multiplications. The FFT algorithms are employed to compute the DFT much more efficiently. These algorithms use a power of 2 points and exploit the periodic nature of the complex exponential $e^{j2\pi nk/N}$ occurring in the DFT equation. For a 256-point DFT computation, direct DFT computation requires 65536 complex multiplications. However, in a FFT based computation of the same number of points, 1024 multiplications are needed. This is a 64-times reduction. For a 512-point DFT computation, direct DFT computation and FFT based computation require 262144 and 2048 multiplications respectively. This corresponds to a 128-times reduction.[4-5]

The Java-based software developed in this study allows a user to obtain frequency vs. magnitude components for audio signals. The interface of the program is shown in Figure 2. The user can control a number of options not yet mentioned. One group of options involves what is graphed. This includes axis maxima and minima, axis tick spacing, and whether to make the DFT and FFT plot the same space or not. The user can also choose to display lines on the graphs at every point a 22-fret electric guitar in standard tuning will have the fundamental frequency of a note as seen in Figure 3. Other options are specific to the DFT. Because of the nature of the DFT algorithm, it is possible to calculate only a portion of what the FFT calculates. This selectivity is granted to the user in the form of a check box. This gives the user the choice of calculating everything the FFT is calculating or just what the graph is displaying. The user can also choose not to calculate the DFT at all, as sometimes only the FFT is desired and the DFT could bog the system down. Finally, the user may choose to have the software automatically recalculate the transforms and update the graphs. If this option is chosen, recalculation speed may be selected between 50 and 1000 ms.

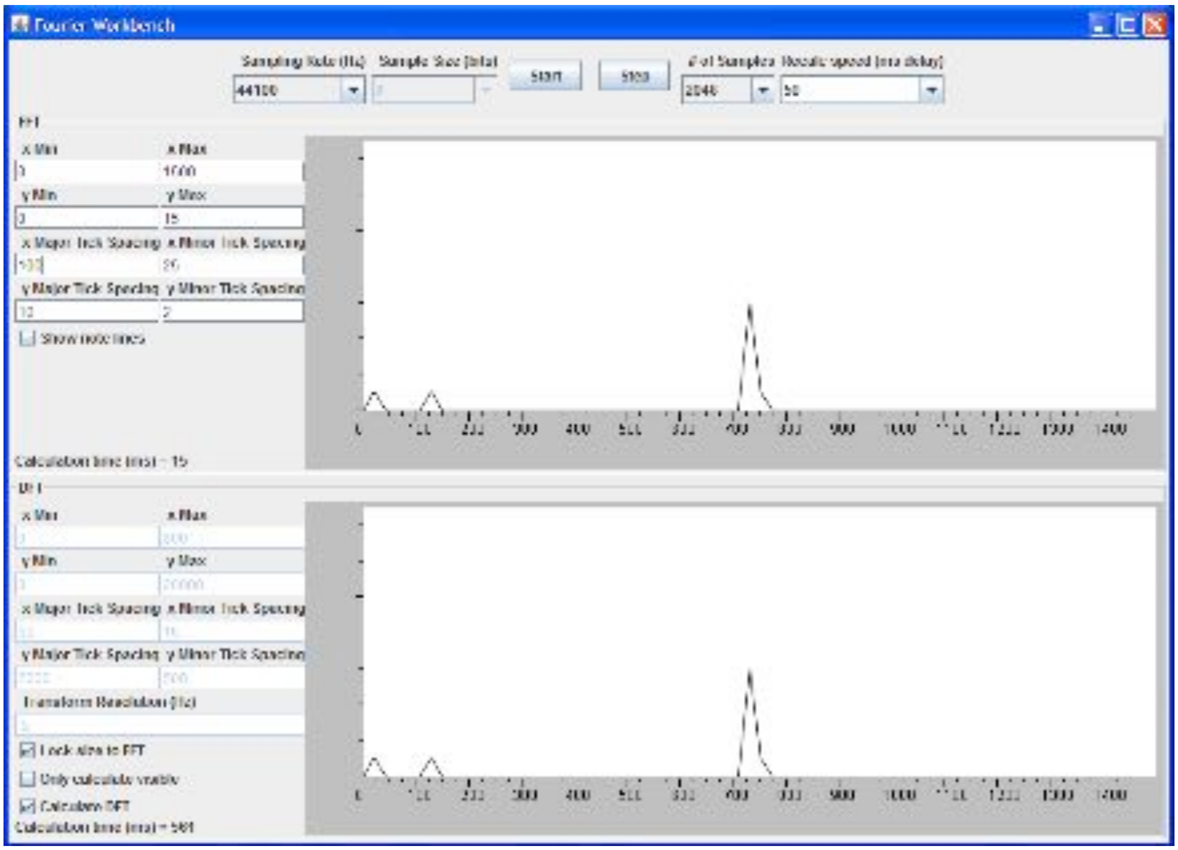

Figure -2: The Fourier Workbench interface

As far as actual numbers go, there's no difference between the FFT and DFT. Given the same series of time domain samples, they will produce exactly the same numbers for the frequency domain representation (see Figure 2). The only difference as far as input/output comparison goes is that the FFT calculates the whole transform (all calculable frequencies) whether it is needed or not, and the DFT can be used to calculate specific points, or a range, within the transform.

The most significant difference between the two algorithms, when it comes to application, is the speed. The FFT is significantly faster than the DFT when sample size (N) is large. The DFT has a runtime, in Landau notation, of $O(N^2)$ and the FFT has a runtime of $O(N\log_2 N)$. Since this program competes for processor time with everything else on the computer, this relationship obviously won't match exactly, but there is still a striking resemblance.

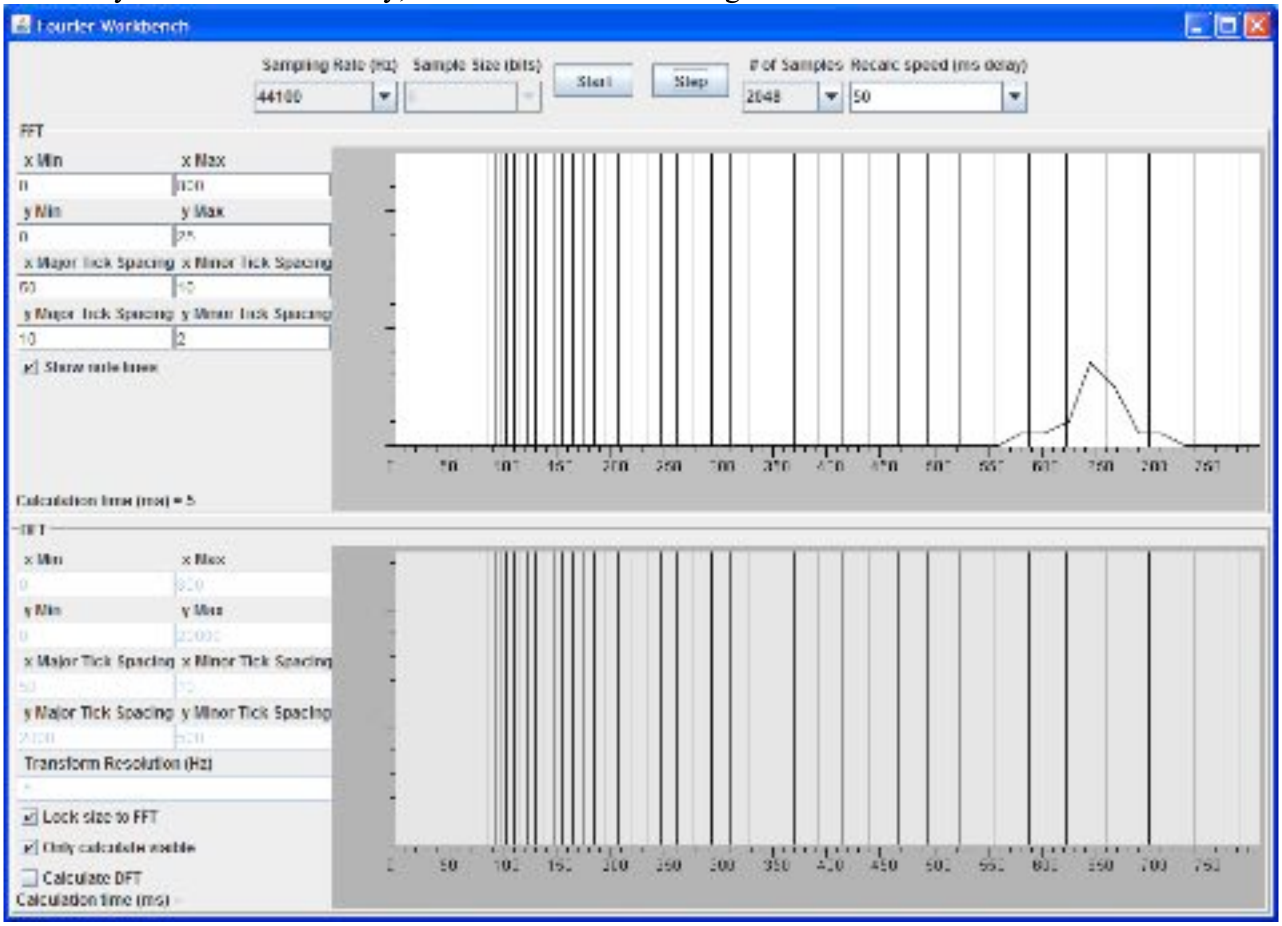

Figure -3: Note lines output

One performance issue, when comparing the DFT and FFT, as mentioned, is the fact that the DFT will allow the user to choose a specific range (whatever is selected as the DFT graph range) of frequencies to calculate. This changes the relationship denoted above because the algorithms are no longer calculating the same thing and the DFT's runtime is now O(N*nk) where nk represents the number of discrete frequencies calculated. From this, it can be concluded that the DFT will only be faster than the FFT when it is calculating less than $\log_2 N$ discrete frequencies. In the case of a 2048 point transform, this means 10 or less discrete frequencies. This time comparison can readily be demonstrated with the Fourier Workbench software.

Different sample sizes and sampling rates:

Sample size (N) and sampling rate (f_s) are important considerations when applying a Fourier transform algorithm. Together, they determine how long it will take to record the data needed for the transform and frequency domain resolution. Sampling frequency will also determine the maximum frequency which can be calculated. This is provided by the Nyquist sampling theorem which states that a sampled signal can't represent a frequency higher than half of the sampling frequency.

The resolution of the transform is determined by $\Delta f = f_s/N$, as mentioned earlier. As can be seen, a higher sampling frequency lowers the resolution of the frequency domain representation of the signal, but a higher sample size increases the resolution. When applied to musical notes, this linear distribution of discrete frequencies is important because musical notes do not distribute themselves at equal intervals. Musical notes are typically denoted A, B, C, D, E, F, or G. This represents one octave of notes and there are several octaves within human hearing range. The octave a note is in is generally denoted by a number after the note letter. A3 is 220 Hz, A4 is 440 Hz, and A5 is 880 Hz. Note that there is the same number of notes between A3 and A4 as there is between A4 and A5 but the number of Hz has doubled. This doubling of frequencies between octaves correlates to the human ear's ability to detect changes in frequency. Because of this relationship, a given frequency-domain resolution may be sufficient to tune an instrument with high notes, but not one with low notes. The Fourier transform may have higher resolution than the human ear at those high frequencies but lower resolution than the human ear for low frequencies.

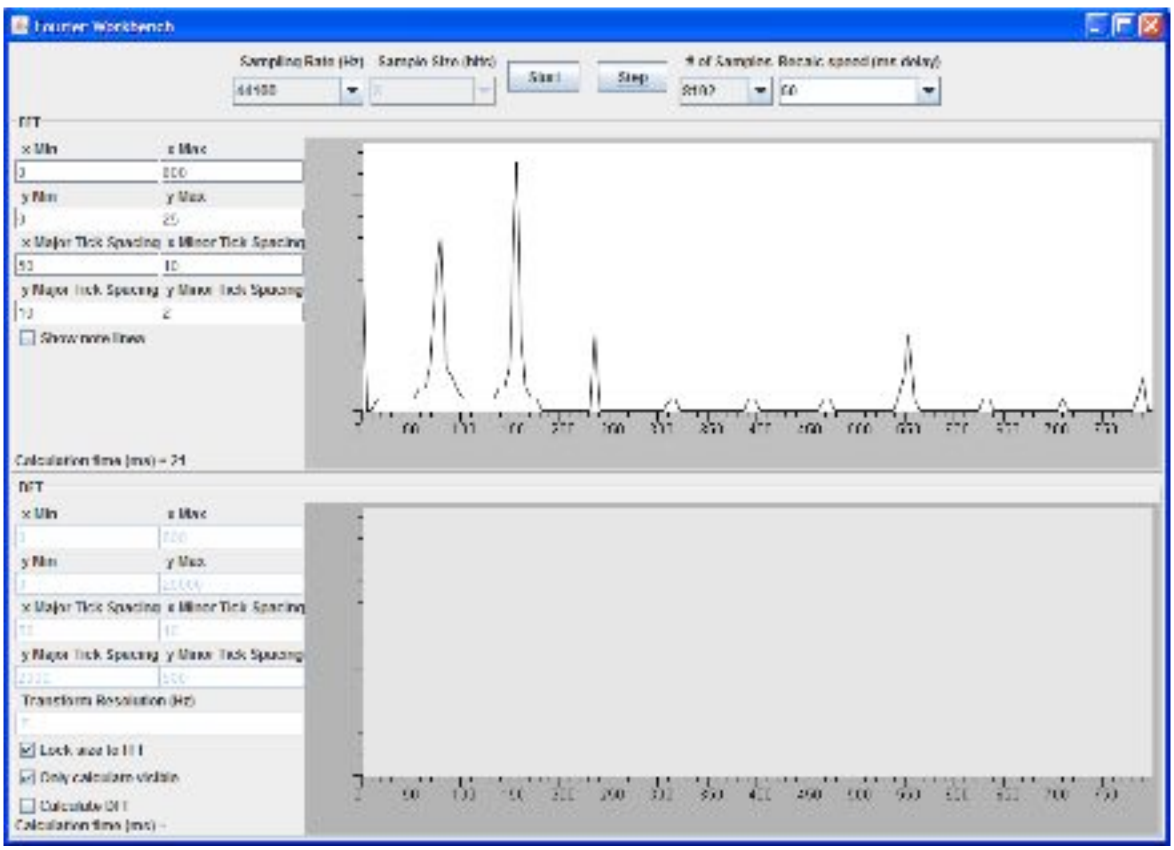

Figure -4: Visualization of a signal with components at several frequency values

Multi-tone signals:

Signals, in the real world, don't happen as pure sine waves. Most musical instruments, for example, produce a unique combination of tones that distinguish one instrument from another. The tone quality of instruments that makes them unique is called timber. This word simply describes a profile of overtones. An overtone is a frequency that is any integer multiple of the fundamental frequency. So any given note has a potentially infinite series of evenly-spaced overtones. The note E2 (82.41 Hz) on an electric guitar is shown in Figure 4. Notice all the "bumps" in the graph beyond the fundamental frequency; these are the overtones. The ratio of intensities between the fundamental frequency and its overtones is what we call timber. This is just one example of a signal that is more complicated than a sine wave, but the world is full of them. Viewing real world signals in the frequency domain is often useful in understanding the signal, the system that produced it, and how one might process the signal for a certain purpose.

Results and Conclusions

The Fourier transform is an incredibly useful construct, but for many students, it can be difficult to understand. For most, a change in one number, say sampling rate, isn't easily followed through the math to discover a property of the Fourier transform. Visual demonstration and the chance to experiment easily and quickly can make the material much more accessible to students.

Processing speed of different Fourier transform algorithms can also be better appreciated if those algorithms can be compared side-by-side. Table 1 and Figure 5 show how long it took the author's computer to calculate the FFT and DFT with different sample sizes in the Fourier Workbench program.

N	FFT time (ms)	DFT time (ms)
64	Less than 1 ms	1
128	Less than 1 ms	2
256	1	10
512	2	37
1024	2	150
2048	5	572
4096	10	2298
8192	23	9324

Table-1: FFT and DFT processing durations

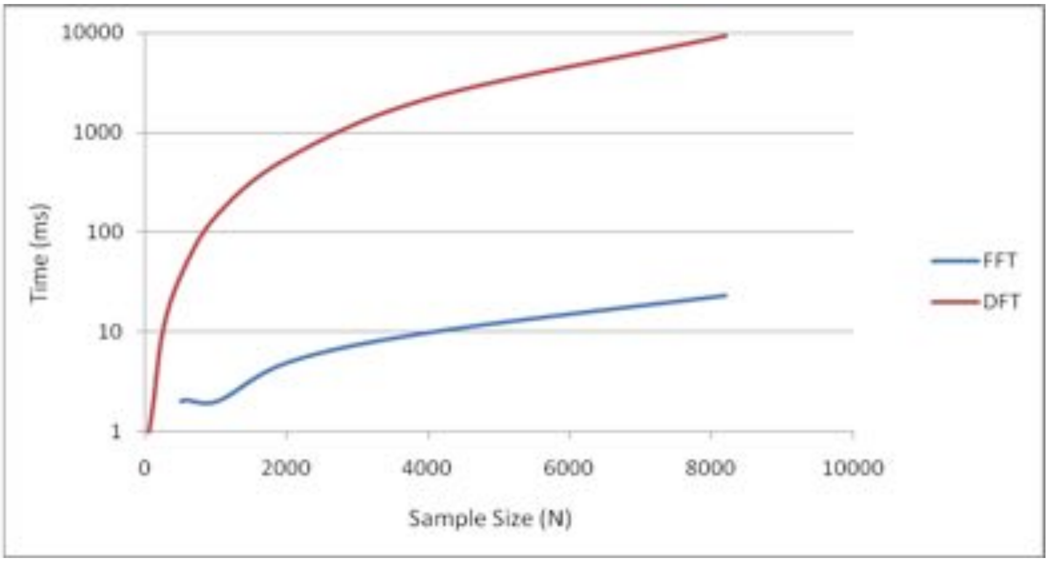

Figure -5: FFT and DFT processing durations

Fourier Workbench offers a chance to view the results of the FFT or DFT while hearing the sound that it relates to. The affects of changing sampling rate and sample size can immediately be seen, and speed comparisons between the two algorithms can easily be made. This can be a valuable tool for students learning about the Fourier transform and its applications, and also for learning about the frequency composition of different sounds, which is important for audio processing and music theory.

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Integrating Energy Modeling Software into Sustainable Energy Systems Curriculum

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The Passive House energy modeling software was integrated into a senior level technical elective on sustainable energy in the Mechanical and Industrial Energy program at the University of Minnesota Duluth. Previous iterations of the course have focused primarily on energy production. Renewable energy technologies were introduced from large-scale utilities to distributed small-scale systems. Students also learned the current methods of energy production as well as the sectors of energy use throughout the country. A significant portion of the energy produced in the United States is consumed in residential and industrial buildings. Smart building design following the Passive House approach was incorporated into the class to add a component of engineering design that can lead to significant reductions in energy use. Passive House design aims to decrease heating and cooling loads by 90% through the use of highly insulated walls, passive solar gain and detailed energy modeling of the building design. Energy modeling is a critical step in the design process and one for which Mechanical Engineering students are well suited to learn and use. The students were taught how to use the energy modeling software during the first half of the class. They were then given a project to design an 800 square foot home that met Passive House certification standards. The energy needs of the home, i.e. heating, cooling and electrical loads were to be met with renewable energy technologies they were introduced to through out the course. They were given a budget of $ 40,000 dollars for the renewable energy systems and were asked to provide estimated payback timeframes for the technologies they chose. The project provided a creative and fun platform for the students to learn the significant impact engineering design can have on energy conservation. Practical experience was gained in learning the software and in sizing photovoltaics, solar hot water systems, and heat recovery ventilation units to meet the building needs. In this paper student design concepts will be presented as well as lessons learned for future implementation of similar projects.

Introduction

ME 5325 Sustainable Energy Systems (SES) is a senior level technical elective that introduces students to renewable and sustainable methods for electrical production and heating, ventilating and air conditioning (HVAC). The course also covers current power plant design utilizing fossil fuels. Specifically the course covers the following:

- Heat Engine
- Thermal Power Generation
- Wind Power
- Solar Energy Basics
- Photovoltaics
- Thermal Solar Energy (Heating and Cooling)
- Distributed Energy Systems: Microturbines, Fuel Cells, Stirling Engines
- Geothermal Power Generation, Heating and Cooling
- Biomass
- Nuclear Energy

A full semester could be devoted to each of the topics listed above, in Sustainable Energy Systems the students are provided an overview of some of these systems while digging deeper into others. The course focuses heavily on wind and solar whereas geothermal, biomass and nuclear energy are presented as an overview. Guest lecturers, from industry and within the university, periodically provided additional expertise on topics that are not discussed in great detail.

This author has taught ME 5325 twice with enrollment varying between 25 – 40 students. The first time the course culminated in a group project researching a sustainable technology of the students choosing. The final deliverables were a presentation to the class and a final report. The topics ranged from solar highways to tidal energy production. The second time the course was taught the student project was changed substantially. The Passive House Planning Package (PHPP) was incorporated into the overall course and was the primary focus of the final project. This paper focuses on an overview of the Passive House technique as well as its implementation in the SES course and its applicability to mechanical engineering students.

Passive House Certification and Modeling Software

Passive solar design is not a new idea. It dates back to antiquity. Nor is the use of very thick walls for insulation a new concept. However, according to the Passive House UK website, the Passive House standard is the fastest growing energy standard for buildings with nearly 30,000 buildings world wide certified to date with the majority occurring since 2000[1]. The Passivhaus Institute was founded by Dr. Wolfgang Feist in 1996 in Darmstadt, Germany. The Institute was developed to study efficient energy use with special focus on buildings[2]. The goal of the standard is to reduce the heating loads of a building by 90%. This goal is significantly higher then that of LEED or Energy Star[3,4]. The Passive House core concept incorporates ultra-insulated walls that are free of thermal bridges, high efficiency windows and a nearly air-tight building envelope. To certify the building as a Passive House the building needs to meet three criteria: ≤ 0.6 air changes per hour (ACH) at 50 Pascal to meet air tightness, heating loads below or equal to 4.75 kBtu/sf/yr and primary energy loads below or equal to 120 kWh/m^2/year. A substantial portion of the heating load is met by passive solar gains through proper building and window orientation and internal heat gains. The indoor air quality is an important consideration due to the airtight construction. Energy recovery ventilation (ERV) or heat recovery ventilation (HRV) systems are used to supply the building with fresh air, thus maintaining healthy indoor air quality. Additional heating requirements, above those met by passive gains, are delivered primarily through the ERV or HRV along with electric radiators or some other small heat source such as pellet stoves.

The quantitative tool used in Passive House design is energy-modeling software called the Passive House Planning Package (PHPP). The software is built in a series of linked Excel worksheets. The modeling worksheets are fairly self explanatory with the help of the manual, however to really understand the nuances and master the software to the point of applying it to a home to be constructed, taking the certification course is a must. For the purposes of the SES course, a local architect with certification, coached the class through any ambiguous sections of the program. When used correctly the software provides an extremely detailed analysis of the heating and cooling loads, electrical energy and primary energy loads of the building. The level of detail and precision go far beyond traditional methods. Along with standard considerations of heat loss through walls and windows, the software takes into account local climate, soil conditions, footing orientation, window frame and wall construction, thermal bridging, summer shading, natural summer ventilation, water usage, internal heat gains from appliances and interior thermal mass and electrical usage, to name a few. Through continued research and monitoring of over 300 completed projects the software has been continually improved and refined[2]. User inputs are balanced with tables providing guidance on typical values for common conditions such as thermal resistance of different types of soil and U-values of insulating materials thus providing a manageable level of knowledge and effort required for building and site data. After all the required data is entered the software's verification page summarizes the heating and primary energy requirements to determine whether the design meets Passive House standards for certification.

Applicability to Mechanical Engineering Students

Architects and builders are the primary people currently being certified as Passive House consultants. When paired on a Passive House project with a mechanical engineer there is often conflict over the sizing and type of mechanical systems to be installed   The architect or builder is not trained in heat transfer and thermodynamics making it difficult for them to understand the science and equations behind the modeling software. Also, the mechanical engineer is trained to calculate heating and cooling loads through traditional methods that are often solely based on square footage and not calculations of a high level of precision based on detailed wall sections and thermal bridging. Passive House projects are currently extending beyond the residential sector to industrial and commercial buildings. With 20% of energy consumption in the U.S. going to the residential sector alone the possibility of significantly impacting our energy consumption with 90% reductions in heating loads is impressive [5]. Energy efficient buildings are the responsible and clear choice for the future. The mechanical engineers graduating today will be well positioned in the market place if they are trained in energy modeling and energy efficient building methodologies.

Project Description

Students worked in groups of three utilizing the PHPP software to design a Passive House that could theoretically be certified. The house the teams designed was constrained to a single story home of 800 square feet with a footprint of 20 ft x 40 ft. The teams were required to design a floor plan including bedrooms, bathrooms, kitchen, living space and laundry. Window location, size and number were also important features included in the design and critical to certifying the home. Exterior window shading by blinds and vegetation needed to be planned for to ensure winter sun was not blocked but also prevented overheating in the summer. The teams chose an ERV or HRV available on the market to provide the ventilation and some heating for the home. PassivHaus Institute recommends only supplying up to a 3 kW coil in the ventilation system, therefore due to Minnesota's climate additional heating systems were required and were part of the design process for the students. Any cooling loads, however small for our area also needed to be addressed. The domestic hot water system was the final mechanical system the students considered, aside from the renewable energy technologies incorporated into the home. The students chose from traditional electric tank, on-demand units or a solar hot water system.

The student teams were required to meet the energy needs of the home through incorporation of renewable energy technologies into the home. This was a critical design element of the home and also an important learning tool for the class. By the end of the semester the students were knowledgeable of the main renewable energy technologies on the market or currently being researched. They were able to draw their own conclusions as to which made the most sense for their home. A 40,000-dollar constraint was implemented and all technologies needed to be currently available on the market with the costs of purchase and installation documented.

Finally, as part of the oral presentation and written report students were asked to consider the societal impact their home made in terms of environmental, global and social considerations. They were asked to think about the resources used to build the homes, technologies implemented and home energy consumption levels.

Evaluation

Students were evaluated on the PHPP design worksheets, oral presentation and written report. Overall the design needed to reflect a thoughtful and creative approach.

Energy Modeling

The energy modeling was primarily evaluated through the oral presentation. During the oral presentation the students provided a summary of their software inputs and resulting annual heating and cooling loads. Software inputs needed to be logical and accurate to meet the certification requirement. The students were required to apply basic scientific principles learned in their core classes in order to make appropriate choices for inputs to the software. At the end of the presentation students were asked to explain their choices of inputs and how these choices affected their annual heating and cooling loads.

Oral Presentation

A professional and organized oral presentation needed to be presented covering all the design requirements. The oral presentation was required to show off the creativity and style of the home as well as detailed information of the mechanical systems. The description of the mechanical equipment needed to include energy usage, efficiency and cost. Students were also evaluated on their consideration of the house's impact on society in terms of energy usage and environmental impact. This included thinking about materials used in construction, embedded energy, and natural resource use. The students needed to show an ability to apply the scientific principles learned during the course of the semester to design and integrate a number of technologies to work together, thus producing an energy efficient home.

Written Report

The written report was evaluated primarily based on clear organization and communication of the primary goals of the project. The engineering and technical aspects were evaluated in the energy modeling and during the oral presentation. Students were asked to address the main points thoroughly and to show thoughtfulness and insight. The report had a three page limit, therefore students had to cover the various topics concisely.

Project goals and objectives

Goals:

1. Develop an understanding and appreciation of how the building envelope affects the heating and cooling load, thus affecting the mechanical systems.

2. Gain an understanding of how renewable technologies can be incorporated into a home.
3. Develop an ability to take the information learned in the course and apply it to a real world application.
4. Become aware of technologies readily available in the market and how much they cost.
5. Realize it is possible to build a net zero energy home.
6. Have fun with designing and envisioning a new style of home.

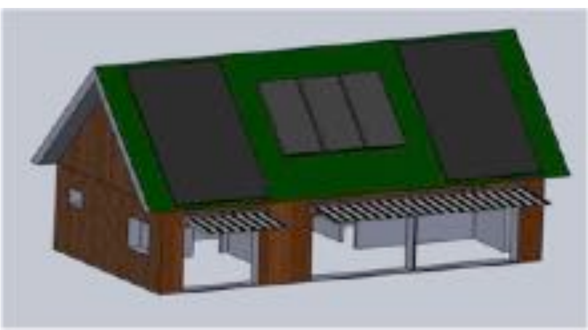
Objectives:

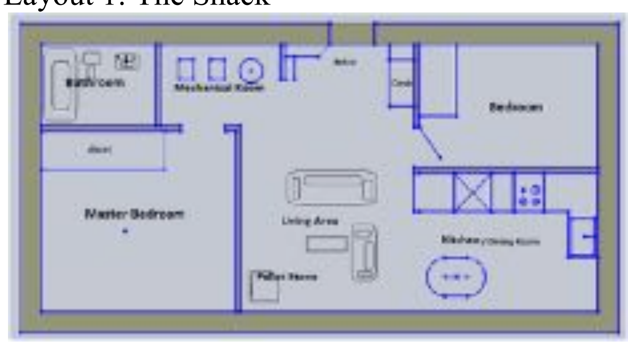
1. Be able to explain how to use the PHPP and how to chose appropriate user inputs.
2. Be able to list the pros and cons of various renewable energy technologies.
3. Be able to explain how home orientation and exterior shading balances passive solar gains between the summer and winter months.
4. Be able to perform a critical analysis of each other’s design decisions.
5. Be able to calculate payback periods of renewable energy technologies chosen for the home.

Student Designs

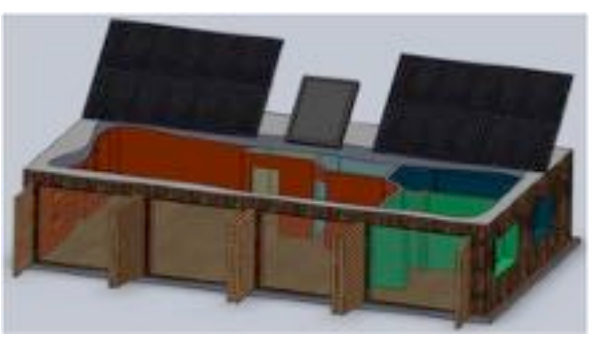
There were six groups total of which three designs were chosen to demonstrate the accomplishments and shortfalls of the project. The home design and layout is shown and discussed. Renewable energy technologies chosen are reviewed for cost and ability to meet heating and electrical demands.

Layout 1: The Shack

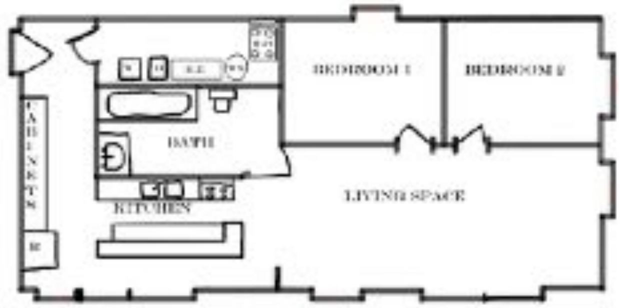




Layout 2: North Shore Home



Layout 3: Country Home



As shown in the layouts all teams mounted the main energy systems on the roof of the house. The homes are typically single story with a flat roof. The flat roof is characteristic of Passive House homes as it is more energy efficient to minimize the envelope while maximizing the living space footprint. All the homes are rectangular as a result of the project constraint on the footprint. Layout 1 does show a peaked roof to improve the aesthetic appeal of the home, however the insulated roof section of the envelope was envisioned to be flat with the peak portion to be non-insulated. External shading is seen on the all the layouts presented. The students needed to balance the winter and summer solar gains to maximize winter gains while preventing overheating in the summer. The designs and floor layouts demonstrate the creativity the students put into the project. SolidWorks models of the homes were not required as can been seen from the hand sketched example, however all the teams except the one shown built detailed models. These models and creative floor plans demonstrate the enthusiasm and fun the students had with the project. The floor layouts also show not only efficient and creative use of the space but also realize, for the students, the ability to live comfortably in only 800 square feet.

Renewable Energy Technologies

The Shack	
Renewable Technology	Cost
Solar Hot Water: flat panel	6,120
Pellet Stove	2,500
PV Panels	23,000
Total	31,620

Table 1: The Shack's renewable energy systems with cost.

North Shore Home	
Renewable Technology	Cost
Solar Hot Water: evacuated tubes	7,500
Pellet Stove	2,500
PV Panels	23,000
Total	33,000

Table 2: North Shore Home's renewable energy systems with cost.

Passive House Home	
Renewable Technology	Cost
Solar Hot Water and Space Heating	11,000
Total	11,000

Table 3: Country Home's renewable energy systems with cost.

The PHPP provided students with verification that their homes met the 4.75 kBtu/sf/year requirement as well as monthly accounting of solar gains and remaining heat demand. Figure 1 shows The Shack's monthly specific heat demand. The 'Sum Spec. Losses' shows the cooling load during the summer months. In most cases these loads are minimal for our area and can be met with natural ventilation or night cooling with the ERV. The monthly heating graph was an important output of the program. The students used it as a tool to choose the appropriate technology for meeting the heating demand and for sizing the system. They needed to be aware of not only the total yearly heating demand but also the peak demands occurring in January and February.

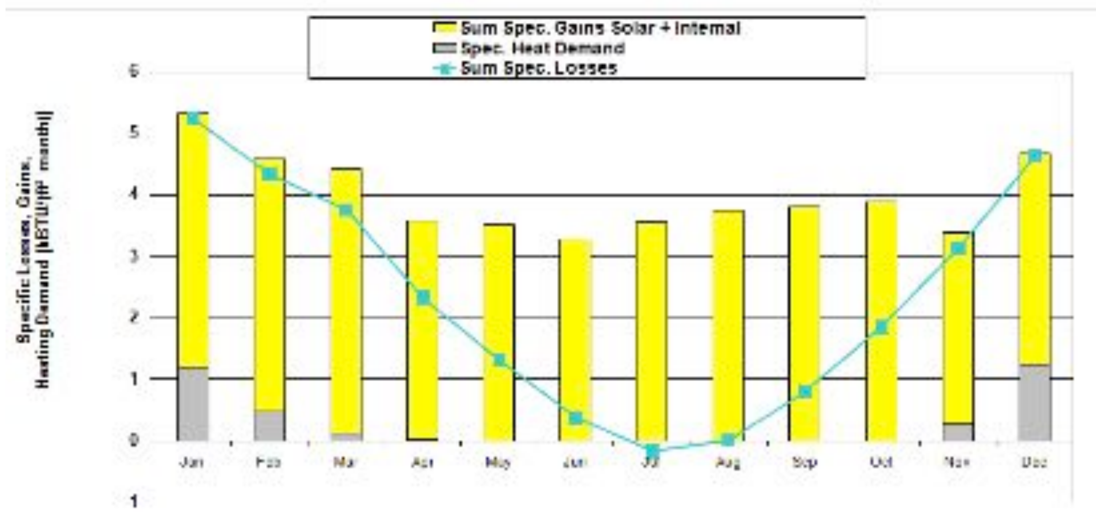


Figure 1: PHPP monthly specific heat demand.

The renewable energy technologies chosen for the homes were required to meet the heating and electrical loads. The PHPP heating calculations have very clear inputs and as can be seen in Figure 1 the data calculated and provided to the designer is easily interpreted. The electrical demand from household appliances was more ambiguous and required trusting the software to adequately estimate extent of use by the occupants of the home. According to the local architect certified in Passive House, who assisted us with the software, the built in recommendations on the appliances page has been shown from post monitoring to be accurate as long as the home is not overly loaded with, for example, TVs in every room. The students were far more comfortable with choosing and sizing the equipment required for heating then the electrical demands. In all cases except one, the students incorporated the use of PV panels. The level of detail taken to size the PV systems was consistently absent from the presentations and reports. It was not clear if local insolation data was taken into account in sizing. In the case of the Country Home the team completely neglected meeting the electrical demands.

All of the teams chose some solar heating system, mainly for domestic hot water. The Country Home team tried to meet the space heating demands as well with solar. They chose to use a 160 gallon hot water tank with a hot water coil in the ventilation system. This was a commercially available product, which provided a heat load calculator to determine the size of the system. Solar space heating alone is not feasible in Northern Minnesota without an extremely large storage system and even then is still in the research stage. The Country Home team did not work out the calculations themselves and I suspect did not consider the storage question. The majority of the other teams chose to use an electric coil in the ventilation system. Passive House recommends a coil under 3 kW for heating. To meet the additional heating requirement beyond passive solar gains and the heating coils most teams chose to incorporate a pellet stove. The Shack team even proposed using the majority of their 40 acres to grow their own biomass to supply the stove. The pellet stoves were a popular choice because they are common on the market, require minimal equipment for installation, are low cost and wood is an abundant resource in Northern Minnesota. All teams easily met the 40,000 dollar project constraint, however, it was not clear that all cost associated with the technologies were considered. Installation cost seem to be neglected.

Evidence of Meeting Goals and Educational Objectives—Lessons Learned

Overall most of the course goals as well as engineering educational objectives were met with this project. The students demonstrated an ability to apply a fundamental knowledge of heat transfer at an appropriate level to successfully use the PHPP software. They were able to integrate, design and develop a system of mechanical equipment to meet heating and electrical loads through out the year. And they learned a new engineering tool that they can utilize in their future engineering practice. The few goals and objectives that were not met were a result of not clearly communicating the requirements and expectations for the project. As this was the first time implementing this project it was presented in an open-ended fashion with a more student driven scope. The scope of the project was loosely defined as it was unclear how much time would be required for learning the PHPP and for analyzing the homes. The level of detail the students went to beyond that was not graded as heavily.

The PHPP software is a useful engineering tool that can be used by the students in their future engineering practice. The software also helped students gain an appreciation and understanding of how the building envelope affects heating and cooling loads. Students found the location, orientation and number of windows greatly affected their ability to meet the Passive House verification. Some lessons were obvious and anticipated ahead of time such as increasing the number of windows on the north, east and west sides of the building increased the heating loads. Other lessons were less intuitive such as the reduced heat loss that occurred when fewer larger windows were chosen as opposed to many small windows. Windows that were butted up next to each other also reduced heat losses as the thermal bridging was decreased. One team struggled for a number of hours to determine why their heating load was too large only to come to find the metal window framing they chose was the source of the dramatic heat losses. Students found that with an appropriately constructed building envelope with minimized surface area, small simple mechanical systems were all that was needed for meeting heat loads.

This project allowed students space to be creative and have fun designing a home they could envision themselves living in while applying the knowledge they gained throughout the semester to guide them in choosing and incorporating renewable technologies into a real world application. They had to become aware of technologies currently available on the market and determine whether they were affordable or not. This transferred the idea of renewable energy from being something that may be realized in the future to one that can be applied readily today to significantly reduce our fossil fuel energy consumption. Students came away from the project with the knowledge that a zero-energy home is possible if a home's design is reconsidered.

The project had multiple objectives, one of which was to become familiar with the PHPP and apply it to a small home. Students by no means became experts at the software package. They gained a general understanding of how it worked and it gave them a tool to apply the knowledge they gained to a real world project. They gained an appreciation for how precise an energy audit needs to be to accurately estimate heating and cooling loads in order to efficiently and appropriately size mechanical systems. One lesson learned from the implementation of this project is that the students could have gained a clearer understanding of how to use the software program if they had been required to submit worksheets from the software through out the semester rather then all at the end. Feedback could have been more regular and mistakes caught earlier.

The students demonstrated both critical thinking skills and an understanding of the benefits and drawbacks of various renewable energy technologies chosen for incorporation into their design. The societal impact portion of the project required the students to think about environmental, social and global impacts of the technologies they chose. Some examples of impacts mentioned were potential ground contamination from the glycol fluid used in the solar thermal systems and environmental issues associated with PV manufacturing. The biggest impact discussed was the reduction in CO_2 emissions by designing a Passive House.

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Appendix

ME 5325
Final Project Grading Sheet

<u>Presentation</u>

Passive House Design

- Floor Plan __________5 pts

- Shading ____________5 pts
- Windows ___________5 pts
- Ventilation Unit _________5 pts
- Domestic Hot Water __________5 pts
- Winter Heating ______________5 pts
- Summer Cooling _____________5 pts

Renewable Energy Technologies

- Technology ____________________10 pts
- Logistics _______________________5 pts
- Cost ___________________________5 pts

Societal Impact ______________________________10 pts

Written Report

Grammar and Sentence Structure _______________________10 pts

Addressed Issues thoroughly___________________________20 pts

Thoughtfulness and Insight ____________________________10 pts