AC 2009-1405: FIRST-YEAR DESIGN EXPERIENCE: ASSEMBLING THE "BIG PICTURE" THROUGH INNOVATIVE PRODUCT DESIGN

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Abstract

As part of the freshmen engineering curriculum at Louisiana Tech University, students develop novel solutions to problems that "bug" them. During the spring quarter, students are asked to spend several weeks compiling bug lists – noting products or situations that they think could be improved. The students form teams and decide on which of their bugs they want to address. A creative problem solving approach is demonstrated to the students who generate and evaluate concepts for their solution. The teams then construct increasingly refined prototypes of their new product idea. Serving as the culmination of the experience, a Freshman Design Exposition is held in which the general public, other students, and judges view and provide feedback to the students' inventions. During the following academic year, the best projects are asked to enter their designs in an Idea Pitch competition which leads to the Top Dawg business plan competition where their ideas can be more formally explored.

This paper will discuss our process for Freshman Design, how it fits into the rest of our freshman curriculum, and how this project addresses the NAE's Engineer of 2020 report. Specifics include: developing the bug list, incorporating the IDEO design process, appreciation of different personality types, brainstorming, engineering decision making, design journals, and prototyping. Additionally, qualitative and quantitative data from the first two Freshman Design Expositions will be presented along with data on the effectiveness of the multidisciplinary nature of the student teams.

Background and Context

In engineering education, a consensus is forming that passive, lecture-based instruction should be replaced or supplemented by active, integrated, project-based learning.[1] In the United States, the movement toward project-based freshman engineering curricula began in the 1990s due in large part to the National Science Foundation Engineering Education Coalitions.[2-5] This movement towards hands-on freshman engineering programs with a significant design component continues today at universities across the United States.[6-8] A vast body of literature on the subject clearly shows the benefits of incorporating project-based instruction with design early and often.

There is no one-size-fits-all freshman engineering design experience. These experiences range from nothing at all, to product dissections, to team-based competitions, to open-ended "product" design, and a host of other approaches. Several papers have attempted to describe and categorize freshmen engineering design experiences in the United States.[2, 9] It is not the intention of this paper to describe the multitudes of programs and their various merits and difficulties. This paper aims to describe an approach to an open-ended product design at the freshman level.

At Louisiana Tech University, we began our own engineering curriculum reform in 1995. We created an Integrated Engineering Curriculum (IEC) in an attempt to provide a hands-on, active-learning environment for our freshmen and sophomore engineering students and with support from NSF fully implemented this new curriculum in 1997.[10] The program was successful in increasing retention and graduation rates in our engineering disciplines. Recently, we updated the IEC in order to address several factors described by the National Academy of Engineering's report: The Engineer of 2020.[11] The newly implemented curriculum relies on a concept entitled *Living With the Lab* (LWTL).

The Living with the Lab Concept

In the traditional laboratory and shop settings, faculty members or technical staff must ensure that the required equipment is ready and that supplies are on hand so that project activities can be performed and/or data can be collected. While it's possible for energetic faculty members to guide students through creative design projects and laboratory experiences in a classroom or laboratory setting, sustaining this effort over a long period of time and with a large number of students is difficult and is sometimes not possible. Our curriculum diffuses this potential problem by transferring ownership of the equipment from the university to the student.

Assignment of microcontroller platforms (in the form of easy to use BOE-Bot kits - www.parallax.com) to students or student groups makes it possible for the "laboratory" or "design platform" to travel with the students to the places where they spend their time – to their dorm rooms and apartments or to the local coffee shop. Tufts University reports that students appreciate the freedom to work anywhere on their projects; further, they are able to solve the majority of their hardware problems either on their own or with a few tips.[12] When students control and maintain their own hardware, significant increases in experiential learning are possible; students are "living with the lab". The end result is more hands-on student activity without the excessive investment of faculty time.

This Living With the Lab curriculum has been in full implementation at the Louisiana Tech since Fall 2007, with pilot programs extending back to 2004. Again, NSF funding partially supported the creation and implementation of this new curriculum. The LWTL curriculum is based on seven threads derived from the National Academy of Engineer's "The Engineer of 2020" report published in May of 2004. For more information about the Living With the Lab curriculum (including previous publications, syllabi, course schedules, notes, and homework assignments) visit www.LivingWithTheLab.com.

Living With the Lab Courses

Our original Integrated Engineering Curriculum established connections between freshman and sophomore mathematics, science, and engineering courses. Students were required to take courses in blocks. This block scheduling effectively established learning communities of approximately 40 students in each of the six to seven blocks. This block schedule has been retained and enhanced in the new Living WITH the Lab curriculum.

The freshman engineering portion of Living With the Lab consists of a sequence of three courses: ENGR 120, 121, and 122. Students are grouped into cohorts of 40 students in an engineering, math and science courses. Each of the LWTL engineering courses is a two (semester-credit) hour course that meets 20 times during the quarter for one hour and fifty minutes per class. The courses are held in two newly constructed classrooms that are specifically designed for an active, group-based learning environment. Each team of four students is assigned a work table and a work station. The workstations provide access to precision fabrication equipment and a small selection of hand tools for in-class use. Additionally, students are required to purchase various small tools for their own use (multimeters, screwdrivers, calipers, . . .). LWTL course sections are typically serve 40 students (or 20 students in an honors section). A picture of the 1,800 square-foot 40 student classroom can be seen in Figure 1.

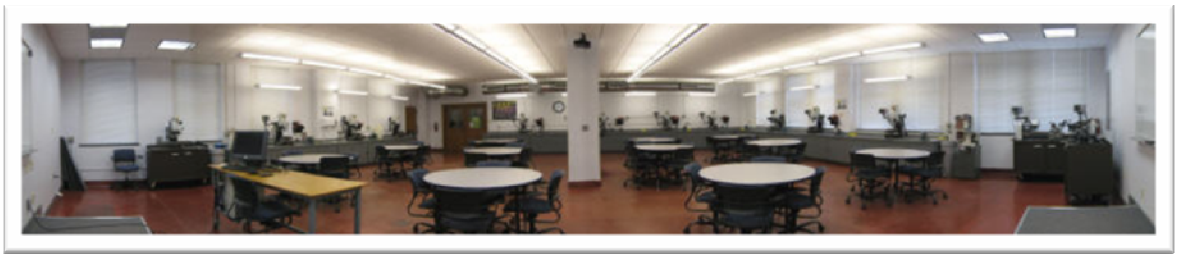

Figure 1. Panoramic view of freshman engineering classroom.

ENGR 120 - The first LWTL course introduces the new engineering students to a variety of topics and tools including (but certainly not limited to) circuits, conservation of energy, computer aided solid modeling, Microsoft Excel, computer programming, milling, and soldering. These introductions are made through small projects such as building a centrifugal pump. In order to enroll in this course, students have either scored a 26 on the math section of the ACT, completed a college algebra (or higher) math course, or otherwise proven that they are ready for our first engineering calculus course.

ENGR 121 - The second course in the LWTL sequence expands on the skills and knowledge gained previously by incorporating a systems level thinking approach. Students are challenged to build a control system that will effectively control the temperature and salinity of a small volume of water. In this course, the students expand their skill set to include topics such as photolithography, conservation of mass, and more in-depth computer logic. Students must complete ENGR 120, and MATH 240 (our first engineering calculus course) with a “C” or better in order to enroll in ENGR 121.

ENGR 122 - The third course in this sequence is the focus of this paper. There are typically three sections of 40 students each and three honors sections of 20 students each. Along with the design topics, students learn basic statics and engineering economics. The students are also enrolled in the third engineering Calculus course and the first Physics course. As part of the design aspect of this course, students are allowed to demonstrate their mastery of their new skills through an open ended design project. Students are given the task of identifying a problem that "bugs" them. By the end of the quarter, the students have imagined concepts, built prototypes, and constructed a product that offers a solution to this problem. This project serves to tie the seven threads of the Living With the Lab curriculum allowing the students to effectively assemble the “Big Picture.”

Design in Freshman Engineering

Initiate the Problem: The first phase of most design processes is to identify the problem. In our previous curriculum, student teams were all assigned the same problem (design a rope climbing machine, build a small airplane that will fly 75ft, . . .). This competition based approach worked well, but did not always allow the students to take full ownership of the project as they were not given a choice on the problem to solve. In the new Living With the Lab curriculum, the students generate lists of problems that they would like to try to solve and their project evolves from these lists.

The first two courses in the Living With the Lab curriculum have allowed the students to begin learning to work in a team environment through the variety of group projects included in the course work. A more formal approach to effective teaming is taken during this third course. Students are introduced to the "Ten Faces of Innovation" by Tom Kelley.[13] This book describes ten attributes, or faces, that team members may exhibit. The intention is to encourage students to recognize their own strengths and weaknesses and to appreciate the contributions of the team members. As part of their homework, the students are instructed to:

> *Review the Ten faces of Innovation presentation from the last class. Considering your personality and skills, which of the "Ten Faces" do you think best describes you? Why?*

This assignment is completed and turned in during the next class period and is designed to start the students thinking about the role(s) where they feel they can contribute in a team environment. Official team roles are not assigned, but effective team management techniques are discussed.

Project Selection: At the end of the first three weeks of the course, each team of four students have developed an extensive list of "bugs", approximately 28 total bugs per team. The teams then choose one of their bugs (or a variant thereof) to explore further. The teams write a memo to the instructor describing the bug, but are encouraged to remain open to the actual solution to their bug. It is pointed out that one of the typical issues preventing creative solutions is the tendency for students to come into a situation already knowing the "best" solution. Students are encouraged to really dig deep into the problem that they are attempting to alleviate before they form too many ideas about the solution. This prodding also follows the model described by IDEO's Kelley in the book, *The Art of Innovation*.[14]

Organizing Ideas: The next step in the process is to create a mind map of the bug that was selected by the group. During class, the students are taught about the purpose of mind maps in organizing their thoughts. Material from Gelb's *How to Think Like Leonardo da Vinci* is presented concerning the construction and use of mind maps.[15] For homework, students write their thoughts about the bug on Post-It notes. The students then use a large sheet of paper to arrange their Post-It thoughts into categories in the form of a mind map. This technique is used to encourage open discussion between the team members on the scope of the team's bug.

To give the students an idea of what a creative problem solution looks like in action, the IDEO "Shopping Cart" video is shown.[16] This 20 minute video was produced by ABC as part of their

Nightline program in 1999. The video follows the development of a new shopping cart at the product design firm IDEO. This video is shown as an example of people with a board set of skills and backgrounds working together to solve a problem. The video also does a great job of demonstrating several phases of the design process. After completing the mind map as a previous assignment, the student teams have a better grasp of the scope of the problem they are attempting to solve. The next phase of the project is for students to begin brainstorming potential ideas. At this point, the students have seen the IDEO video and have been introduced to the "Seven Secrets of Brainstorming" from Kelley's "The Art of Innovation." The next homework assignment instructs the students to put the IDEO methodology into practice.

An example of one of the homework assignments in this series is shown below:

1. *In class you spent time on step 1 of the IDEO design process – Understand the Problem. Please document your classroom discussion and complete any part of the discussion that was cut short due to lack of time. You should address the client, market, technology and constraints.*

2. *Complete step 2 of the IDEO design process – Observe People in Real Life Situations. You should discuss why the "bug" you chose bugged you, your experience with other people experiencing the problem, and how the people you observed coped or fixed the bug.*

3. *Step 3 of the IDEO process was to visualize new-to-the-world solutions.*
   a. Include a cell phone picture (or other electronic illustration) of the mind map you developed in class.
   b. List all of your ideas for solving the problem (we need a lot of ideas). This should be a numbered list. If the brainstorming process was cut short in class, continue brainstorming until you start to run out of ideas. Remember to think laterally.

4. *Begin to narrow your focus to the most promising ideas. Have team member vote on their top four ideas (it can be more or less than four – you decide).*

5. *Based on the most popular ideas from problem 4, develop three design concepts that are a combination of the most-liked ideas from the brainstorming session. For each concept, write a couple of sentences or draw a sketch to illustrate your idea. Include scans or photos of any sketches with your homework. As you begin to develop your design concepts, it is appropriate to consider the resources at your disposal to implement the project (Boe-Bot, most of the sensors on the Parallax web site, foam board, riveting and sheet metal structures and brackets, the milling machines in BH 129, resources outside of class . . .). Remember that it is OK and go back and brainstorm some more as the design concepts begin to gel (add any new ideas to your list from 3b).*

Decision Making: At this point, the teams have selected a problem to address and have posited several ideas that may effectively solve the problem. The students have also been asked to narrow their list of ideas to the three the most promising. The next phase of the design process is for the students to use design constraints and performance measures to evaluate the potential of each concept. In class, students are shown the Pugh Method for decision making.[17] A Pugh chart is a simple method for comparing the relative potential for success of several concepts. As part of their homework assignment, students create a Pugh chart for their three most promising concepts and select the concept that they will focus on for the remainder of the quarter. In order to complete the assignment, students are asked to:

> *Use the Pugh method to evaluate the three design concepts. To do this, develop a set of criteria describing the needs and wants of the customer (for a whiteboard marker, these criteria could be visibility, longevity, emissions, and erase-ability). Determine a numerical score for each of the three concepts.*

Another part of the decision making process presented in the LWTL courses is to create mockups of their concept in order to better evaluate their ideas. Part of the creative methodology presented to the students is to create simple prototypes early and often so that potential pitfalls can be found and minimized. Earlier in the quarter, students are given an assignment to create a three dimensional shape from foamcore board. This assignment is complemented by online material demonstrating proper methods for working with foamcore. Additionally, in class, the students complete a quick project that incorporates metal punching, riveting, shearing, and bending. This instruction coupled with the foamcore experience, and the variety of other skills taught in the Living With the Lab curriculum allow the students an array of skills at their disposal when building their prototypes. The next part of the design phase for the students is to build their first prototype of their concept:

> *Build a simple prototype of your product – try to make a 3D prototype that depicts the form and function. It can be made of paper folded and taped together, foam core, or anything else that is quick and easy. Remember, "prototype early to succeed faster." Take a picture of this prototype to include in your electronic journal, and bring the prototype to show off in class.*

Throughout the remainder of the quarter, the students will create three prototypes, and a final product. The first prototype is mentioned above and is used to begin to define the form of the concept, but not really the function. The second prototype refines the form, and includes functional components. The third prototype further refines the form, and includes working inputs and outputs. The fourth iteration of the prototype is the final product that will be presented as the Freshman Design Expo. Much of the work on these prototypes occurs outside of the class room, but class time is set aside for the students to use machinery to which the students would not typically have access.

Some of the specific machinery that teams may elect to use in the development of their prototype include a FDM rapid prototyping machine, waterjet machining system, mills, lathes, and large format metal shears, and brakes. Many of these machines are in our "Prototyping Lab." Students also have access to a traditional machine shop during normal school hours, 8:30 AM to 4:30 PM. Figure 2 is a picture of the prototyping lab. A student "Help Desk" is also operational from 6:00 PM to 9:00 PM Sunday through Thursday nights.

Figure 2. View of the Prototyping Lab at Louisiana Tech University.

Another component of the product development is that each design must incorporate some type of "smart" technology. While it may seem unnecessary to include electronics into every design, this decision was made in an attempt to push the students to create solutions on the systems level. Of course, these types of solutions are not ideal for every problem, but we believe that it is important for the students to have this experience. This decision does create at least one difficulty though. Some of the "smart" devices that the students use in their solutions can be expensive. In order to help the students create the best possible solutions, we have purchased a large supply of a variety of electronics including GPS modules, RFID tags and readers, accelerometers, CMU cameras, temperature probes, and many more items. These items have been packaged to work with the Parallax BOE-Bot used in the LWTL curriculum. As the students develop their ideas, they are allowed to check out these electronics for use in their projects if they do not want to purchase the items themselves. This does require a considerable amount of record keeping and management in order to assure that the parts are distributed and returned in a viable manner. Contracts are signed by the team members stating which parts are on loan and the students agree to replace the parts if lost or damaged.

Communicate Results: As part of the ENGR 122 course, the students present their products at a Freshman Design Expo at the end of the quarter. This show is typically held in the student center and is open to anyone interested in viewing the students' work. Expos are held during each quarter, with the largest Expo held during the Spring quarter. Approximately 35 teams showcase their designs during the Spring, 15 in the Fall, and 10 in the Winter. Teams of judges review the work and a variety of awards are distributed.

Students are not required to turn in a formal report for this project but they are required to keep a design journal. This assignment is designed to get the students familiar with the concept of recording their progress. Later in their college careers, many of these students will have multiple opportunities to work on projects where protection of intellectual property will be an issue and keeping a design journal (or lab notebook) is an important part of that process.

> *Your team is to keep an electronic design journal that tracks the development of your product from start to finish. The electronic version of your design journal is to be turned in near the end of the quarter, with paper copies of the individual sections turned in as we go along. For example, the "problem definition" memo that you wrote for homework 8 will be the first entry in your design journal. So, please keep your journal files so you can use them later.*

Examples of student projects from previous Expos can be seen in Figure 3.

Figure 3. Top Left - RF coaster tells waiter to refill drink, Top Right – IR pants for object avoidance, Bottom Left – Smart Pot maintains constant temperature, Bottom Right – Clean Toilet for sanitary bathrooms.

Analysis to Date

We have been collecting data from a variety of sources in order to determine the effectiveness of the Living With the Lab curriculum at meeting our desired outcomes for this course. The outcomes that relate to the topic of this paper, a First-Year Design Experience are listed in Table 1. Additional outcomes for the course can be found at www.LivingWithTheLab.com.

Table 1. Learning outcomes related to a First-year design experience.

explain the roles of the ten "Faces of Innovation" as discussed in "The Ten Faces of Innovation" by Tom Kelley
create a Mind Map to organize ideas around a central topic
list the five steps in the IDEO design methodology
list the "Seven Secrets for Better Brainstorming" as described in "The Art of Innovation" by Tom Kelley
apply the Pugh method to evaluate concept ideas
conceive, design, fabricate and test a functional prototype of an innovative product that utilizes one or more sensors, actuators or other output devices, and the BASIC Stamp II microcontroller
specify, locate and purchase supplies and parts for an innovative product
generate a 3D model of an innovative product using Solid Edge
work collaboratively with one or more other students to develop an innovative product
develop a work plan to manage your time and resources to successfully produce a prototype of an innovative product
present the results of assignments and projects using written and oral communication

Data sources primarily include end-of-quarter surveys, and focus groups. The surveys are designed to include ratings on student confidence in a variety of areas, as well as frequency of performance of specific tasks. Data was collected to represent our previous curriculum to use as a comparison of the current curriculum. Items of interest for this paper show that students in the new curriculum have **confidence** means that are significantly higher for some course objectives as shown in Table 2; the confidence numbers in the table are based on a Likert scale ranging from 1 to 6.

Table 2. ENGR 122 Specific Course Outcome Means - Confidence.

Item	OLD Course Spring 06-07	NEW Course Spring 07-08
Work collaboratively with one or more other students.	5.49	5.36
Generate 3D models of engineering components and assemblies using SolidWorks.	4.55	4.94
Locate specifications and prices for the supplies, parts and systems used in course projects from manufacturers and on-line retailers.	5.23	5.14
Purchase supplies and parts for an innovative product.	5.23	5.05
Use creative techniques to overcome at least one project difficulty.	4.92	5.03
When I set a goal, I keep going after it no matter what the obstacles.	5.15	5.20
I enjoy developing technical tools that improve the quality of life for people.	4.70	5.36
I intend to develop new products/processes during my career as an engineer.	5.14	5.23
I prefer improving products/processes that already exist instead of developing something new.	4.74	4.18
Explain the roles of the ten "Faces of Innovation" as discussed in "The Ten Faces of Innovation" by Tom Kelley.	2.50	4.47
Create a Mind Map to organize ideas around a central topic.	3.26	4.99
Apply the Pugh method to evaluate concept ideas.	2.62	4.38
Conceive a functional prototype of an innovative product that utilizes one or more sensors, actuators or other output devices, and the BASIC Stamp II microcontroller.	2.80	5.00
Design a functional prototype of an innovative product that utilizes one or more sensors, actuators or other output devices, and the BASIC Stamp II microcontroller.	2.82	4.85
Fabricate a functional prototype of an innovative product that utilizes one or more sensors, actuators, or other output devices, and the BASIC Stamp II microcontroller.	2.80	4.96
Test a functional prototype of an innovative product that utilizes one or more sensors, actuators, or other output devices, and the BASIC Stamp II microcontroller.	2.83	5.02
Develop a work plan to manage your time and resources to successfully produce a prototype of an innovative product.	4.31	4.79

Additionally, the data show course outcome means for **frequency of performance** in ENGR 122 are significantly higher than the old curriculum for some course objectives as shown in Table 3; the performance numbers in the table are based on a Likert scale ranging from 1 to 7.

Table 3. ENGR 122 Specific Course Outcome Means - Performance.

Item	OLD Course Spring 06-07	NEW Course Spring 07-08
Work collaboratively with one or more other students.	5.94	5.75
Generate 3D models of engineering components and assemblies using SolidWorks.	3.89	4.38
Locate specifications and prices for the supplies, parts and systems used in course projects from manufacturers and on-line retailers.	4.18	5.02
Purchase supplies and parts for an innovative product.	4.23	4.42
Use creative techniques to overcome at least one project difficulty.	4.58	5.25
When I set a goal, I keep going after it no matter what the obstacles.	5.35	5.80
I enjoy developing technical tools that improve the quality of life for people.	4.23	5.05
I intend to develop new products/processes during my career as an engineer.	4.64	5.46
I prefer improving products/processes that already exist instead of developing something new.	4.44	5.14
Explain the roles of the ten “Faces of Innovation” as discussed in “The Ten Faces of Innovation” by Tom Kelley.	2.42	3.87
Create a Mind Map to organize ideas around a central topic.	2.40	4.03
Apply the Pugh method to evaluate concept ideas.	2.11	3.57
Conceive a functional prototype of an innovative product that utilizes one or more sensors, actuators or other output devices, and the BASIC Stamp II microcontroller.	2.65	4.89
Design a functional prototype of an innovative product that utilizes one or more sensors, actuators or other output devices, and the BASIC Stamp II microcontroller.	2.57	4.72
Fabricate a functional prototype of an innovative product that utilizes one or more sensors, actuators, or other output devices, and the BASIC Stamp II microcontroller.	2.55	4.75
Test a functional prototype of an innovative product that utilizes one or more sensors, actuators, or other output devices, and the BASIC Stamp II microcontroller.	2.55	5.10
Develop a work plan to manage your time and resources to successfully produce a prototype of an innovative product.	3.78	4.86

Another measure of design experience can be gathered from a comparison between the reported "Hands-On" activities between 06-07 and 07-08. The students in the "Living with the Lab" reported significantly higher use in every measured category. Students were asked to report the number of times they performed a given activity in ENGR 122. Students in the old curriculum reported a total of 27 hands-on activities, while students in the new curriculum reported 108 activities as shown in Table 4. The Living With the Lab approach produced four times as much hands-on learning that the previous ENGR 122 course.

Table 4. "Hands-On" Application Means for the New and Old Freshman Design Courses.

	OLD Course Spring 06-07	**NEW Course Spring 07-08**
Soldering	2.17	4.99
Layout	2.24	11.53
Assembly	3.10	11.27
Bending	4.77	6.08
Sawing	2.05	5.92
Drilling	4.29	9.66
Milling	0.09	3.46
Using a scale	3.59	14.17
Using a lathe	0.06	1.22
Rapid Prototyping	0.71	1.92
Cutting internal or external threads	0.55	1.17
Using a dial caliper	0.17	4.79
Using a multimeter	2.28	5.28
Implement circuits on a breadboard	0.62	14.48
Writing PBASIC programs	0.02	11.79
Totals Hands-On:	**26.7**	**107.7**

The project's external evaluator commented that:

> *"The design expo for ENGR 122 (the third course in the Living With the Lab sequence) was held Wednesday, May 7, 2008 from 4:00 -8:00 PM in the student center. There were 32 projects on display. A list of the projects is contained in Attachment E. Each project was assigned a table. Students from the project team displayed posters and gave explanations of their projects. The variety of projects was impressive. Among the 32 projects there were 26 distinct ideas. Students interviewed at the Expo demonstrated the ability to explain their projects clearly.*

Students also demonstrated pride in their prototypes and what they had learned. Students reported that the design project was difficult and rewarding."

As stated above, the first Freshman Design Expo contained 32 projects. Some of these projects have been entered into our Top Dawg business plan competition, where the students will further develop their concepts and begin to build a more comprehensive business idea around their concept. Student teams qualifying for the Top Dawg business plan are awarded space in our business incubator where they have access to professional assistance while developing their plans. The business plan results for this year will not be available until April 2009.

Conclusions/Future: Future plans for our freshman design experience focus on expanding the Living With the Lab curriculum as well as increasing the sustainability of the program. We believe that these two major goals can be largely accomplished through our online efforts. Currently, the student notes, and assignments are online. We hope to add additional online course modules that include multimedia video segments of common topics. Examples of such modules for this course include videos on creating foamcore mockups, creating a mind map, and concept sketching. Also, online homework assignments are being developed in which students will receive instant feedback on their work.

Expansion of the curriculum will also benefit from the online material. It will be possible for other universities and schools to access the instructional materials and use them as they see fit. Additionally, summer workshops are being offered in which faculty are trained in the curriculum. Another avenue for expansion comes through our K-12 outreach programs. Material from the Living With the Lab curriculum is used with several area high schools as part of a summer camp. During the 2008-09 academic year, the Living With the Lab curriculum is being expanded into three sophomore level courses: statics and strength of material, circuits, and thermodynamics.

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