Building a Process for Establishing an Interdisciplinary Design and Manufacturing Freshman Course

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Abstract

College freshmen, though they may be registered in the engineering programs, do not always know what discipline best suits their interests. Regardless of their future majors, current technological advancements and global competitions have created a necessary industrial atmosphere of interdisciplinary design and manufacturing in the product development cycle. An introductory course combining mechanical design, electronic control and manufacturing processes provides a totality in the perspective of engineering for the future. At the same time, the students' views of engineering are broadened by the exposure to the different disciplines. As a result of the multi-discipline engineering exposure, they are in a better position to select a future career.

In this paper, the developmental process for establishing such a course is described. The process starts from the very top of the managerial pole. Potential departmental barriers are discussed and possible ways of quenching faculty and departmental traditional cultures are introduced. The structure for the lecture and laboratory sessions, the timing, the logistics of shuffling students from one area to the next are ironed out. Common times for lecture and labs are established. Students also work in teams to perform projects. Students are evaluated in the separate disciplinary areas as well as on a final integrated project where they are asked to combine aspects of mechanical design with electronic control and manufacturing processes. The assessment process will also be described. Fun objects are used in the laboratories, such as; battery operated mechanically animated pig, electronically controlled hexapod ("6-legged insect"), thermoformed Mickey Mouse, and machined pencil holder. Students' comments included their excitement about learning the various aspects of engineering as well as being able to do hands-on designing, controlling and fabricating real products.

Introduction & Background

Current Engineering Freshmen already know about computers, internet, communication, satellites, cars, planes, missiles, weapons and much more. Given the exposure and the choices, it is very difficult for them to decide what discipline best suits their interests. They need to put their hands, literally, on devices from different fields. Regardless of their future majors, current technological advancements and global competitions have created a necessary industrial atmosphere of interdisciplinary design and manufacturing in the product development cycle. An introductory course combining mechanical design, electronic control and manufacturing processes provides a broader perspective of engineering for the future. At the same time, the students' views of engineering are broadened by the exposure and hands-on experience of the different processes. They are in a better position to select a future career.

Most universities have an introduction to engineering freshman course that covers broad views of mechanical, electrical and general engineering. Most universities concentrate on a freshman design course with emphasis on mechanical design, [Sheppart, et al., 2002][7] [University of Tennessee webpage http://tnengineer.engr.utk.edu/] [Matsuishi, et. al., 2002][3] and little involvement with electrical design. Few have electrical engineering freshman design classes [Patangia, 2002][4]. Integration in freshman courses involves mathematics, with statics, dynamics and mechanical design and problem solving [Felder, 1996][1] [Wood, et. al., 2001][11] or humanities and engineering [Sinclair, et al., 1995][8] or upper class engineering students with freshmen non-engineers [Goff, 2001][2]. No reference was found to interdisciplinary freshman courses involving concurrent exposure to manufacturing processes. Although one reference involved a upper level manufacturing class fabricating designs from a previous semester's mechanical engineering design class [Scheller,2001][6]. Such attempts involving design in mechanical, electrical and computer engineering are found at senior levels [Stone, et al., 2002][9] [Driver, et. al., 2002][Pearson, 1999][5]. The GMI heritage of Kettering University emphasizes hands-on experience to reinforce the students' learning process. All students hold co-operative positions in reputable companies throughout their academic career. In 2001, Kettering embarked on a curriculum reform. A decision was made to create an Interdisciplinary Design and Manufacturing Engineering course (MFGG-135). The GOAL of this freshman course is to bring awareness of different types of engineering as a career, to introduce all available engineering degrees at Kettering and to provide an integrated taste of design and manufacturing. The OBJECTIVES are to create a structure of lectures and labs that will provide integrative opportunities for covering design course content that spans mechanical design, electronics/electrical design and manufacturing and to develop the students' teamwork, and written / oral communication skills.

The inception and course description for manufacturing, mechanical and electronic design components are described in a previous paper [Riffe et al., 2002][10]. The essence is briefly summarized here. For manufacturing, fundamental material properties, methods of testing these properties and material processing methods are presented in lecture and in lab. Many "fun" products are made in the labs for keepsakes. In mechanical design, reverse engineering is used to study a functional product, namely an animated, battery operated plush animal. Animals are dissected, parts are drawn, moving mechanisms are studied and modeled in the computer with a 2-D Work Model Simulation software. Pictures of the animated animals, "Miss Piggy" and "St. Bernard" are shown in Figures 1-2.

For electronics design, students study electronic control of a "RoboBug", a mobile insect that operates on battery powered servo motors which are controlled by logic that the students program. Students learn elementary circuit board design, simulation, and layout. They are then taught how to solder, assemble, test and calibrate the RoboBug PWM Servo Driver circuit boards. Students program the RoboBug. A certain logic for the RoboBug gait must be achieved for stability. Students use a schematic capture program (Multisim) to draw an LM556 PWM circuit (similar to the RoboBug PWM servo driver circuit), use its simulation capabilities to simulate the timer circuit operation and use a computer layout program (Ultiboard) to layout a printed circuit board that could be used to fabricate the PWM circuit. Figures 3-4 show the components of the RoboBug.

Figure 1: Animated Animals "St. Bernard", "Miss Piggy"

Figure 2: Motion Mechanisms Shown in Dissected Animal

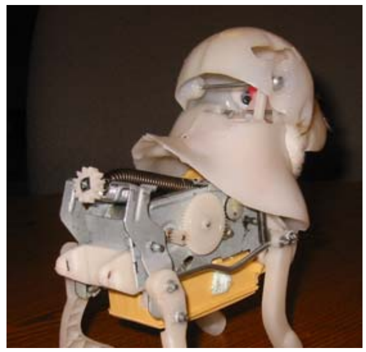
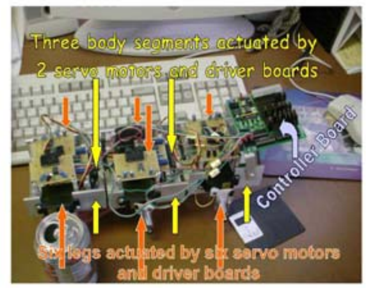


Figure 3: RoboBug showing 6 Walking Legs & Motors



In manufacturing, projects in welding, tensile testing, hardness testing, casting, machining, injection molding, and thermoforming are performed by students. They learn the sequence of operations, planning and fabricating procedures. They learn the supporting models, theory and calculations in lecture. Some of the projects are shown in Figures 5-7.

The final design paper-project is to propose an improved design of a mechanical joint, OR an improved manufacturing process / material selection, OR an improved control system for either the "Robobug" or Animated Animal AND explain how each engineering discipline would contribute to the redesign concept.

Figure 4: RoboBug Leg Positions

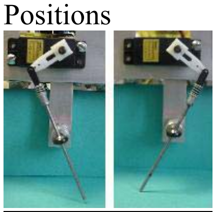


Figure 5: Lost Foam Casting & Green Sand Casting (Bulldog is the school symbol)

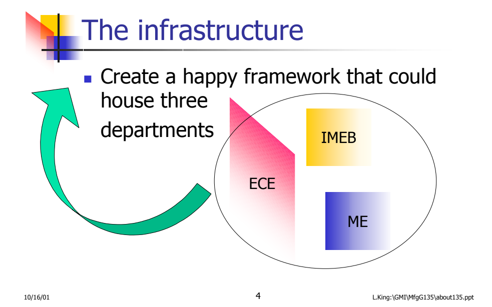
Figure 6: Machining – Pencil Holder

Figure 7: Thermo-forming – Mickey Mouse

Building an Infrastructure

A necessary ingredient for interdepartmental collaboration is to build an infrastructure as shown in Figure 8. In addition, bridges have to be built with management and university support service groups.

Figure 8: Infrastructure



Buy-in Starting from Upper Management and Beyond

Much like the corporate world, any successful project must have buy-in from top down. The Provost supported the course from its initial stage of development. He facilitated the cooperation of department heads whosubsequently solicited the collaboration of key faculty members with one person (the principal author) taking the lead. The Provost agreed to finance the initial developments. Later, course maintenance came from department budgets.

The infrastructure spans not only the academic departments but also administration segments such as student affairs, scheduling, registrar's offices. Many logistics procedures were established with these departments. Help from the Information Technology group is also needed when class material and grades were placed in Blackboard, an interactive learning support software.

Overcoming Cultural Obstacles

Turf protection, proprietary information, fear of take-over, skepticism about sharing teaching credits are often some of the sentiments among people in different departments. These are natural feelings. After 2 months of discussion, a proposal was brought forth. After 2 more months of debate, the initial skepticism of crossing departmental boundaries was overcome. The course began to gel by March 2001. It was launched in July 2001. Weekly meetings helped build bonds among all parties involved, especially the professors. The level of trust and mutual support grew. Information sharing became a common denominator. Enthusiasm among the professors also grew, each contributing ideas for projects in the different disciplines. Someone always tried to pull ideas into an integrated final project. Collaborative efforts have been phenomenal among the three departments, ranging from department heads, program directors, professors and technicians.

Structure of the Course

For the 4-credit hour course, the designed structure is one 2-hour lecture, one 2-hour manufacturing lab and one 2-hour electrical design lab alternated at midterm with one 2-hour mechanical design lab. See Figures 12 and 13. Note that in Figure 13, depending on the instructor, "Soft engineering" could be incorporated into the first week. "Integration" was discussed in the final project development. Manufacturing Processes lectures were extended.

Figure 9: Class Structure

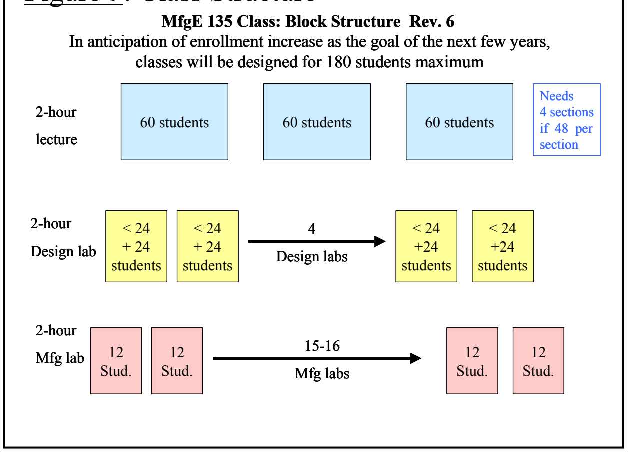
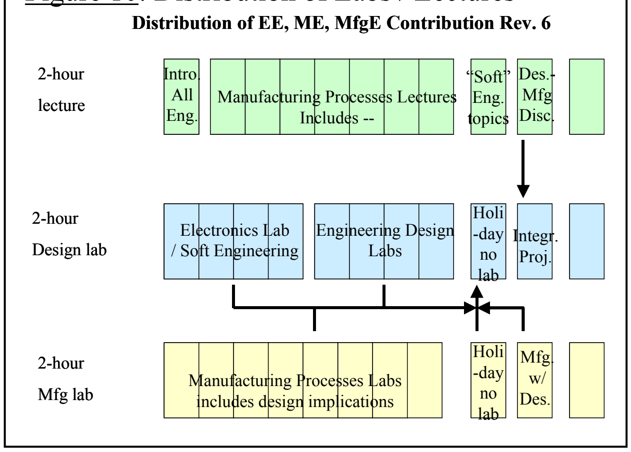


Figure 10: Distribution of Labs / Lectures



Labs

In addition to the weekly manufacturing processes lectures and manufacturing processes labs, each student has 4 weeks of electrical design lab and then 4 weeks of mechanical design lab, or vice versa. Each lab includes a short lecture introducing necessary theory, practice and methodologies. For details of the different labs, refer to Riffe et al., 2002[10]. Students work in teams of 2 or 3. Each team will perform laboratory experiments, collect data, draw conclusions, and give oral presentations of results.

Final Project

The final project is a written proposal for improvements and re-design of a mechanism or control system or material selection for either the "RoboBug" or Animated Animal. Each team of 2 or 3 students is to optimize and justify the new system. They have to explain how their modifications result in a better, safer, cheaper, faster, or more interesting product. They are to document the modifications clearly, using written descriptions, figures, sketches, and/or graphs, including any 2D Working Model simulation files. Students need to describe the finished product and indicate clearly the manufacturing process involved. They need to also describe and illustrate the mechanical mechanisms used, and the electrical mechanisms involved. Students are taught how to find references and they are to reference any material and sources used in preparing the final project.

Scheduling Nightmares

Scheduling the 160-180 students into the class structure defined above was cause for nightmares. Each term, there are typically three separate lecture sections each supporting 75-100 students that must be scheduled to minimize conflicts with the design labs and the manufacturing processes labs.

For the design labs, due to the inability of the scheduling software to split students of one lab into 2 rooms, all 48 students are scheduled into one lab room that generally holds 24 students. They are then split by the instructors into two groups, one group stays in the mechanical design lab, the other is led by the instructor to the electrical design lab. The logistics of all Freshmen finding the correct room the first week of class on time is complicated. The difficulty is compounded by the fact that half of the students leave for another room after 15 minutes. Students who arrive late may wander in the hallways. The Students Affairs Office will be requested to emphasize the coverage of the geography of the huge building.

For the manufacturing processes labs, the available equipment limits the laboratory sections to 12 students. This means that students cannot be block scheduled into the design lab sections and into a corresponding manufacturing processes lab.

With the large number of students, the sharing of ECE and ME labs, PCB milling machines, computer hardware and software with higher level classes created scheduling confusions also. Traditionally, MfgE had always taught a manufacturing processes course to all engineering students. ME and ECE departments have not handled it before. Resources were juggled within the departments and after one year, these problems were ironed out.

Budget

The startup proposed budget was $20,000. Careful spending and recycling permitted under-budget (~$10,000) development in the first year. The mechanical engineering (ME) spent ~$2,000 bulk-purchasing the animals (cost of ~$15 each plus batteries). For the electrical engineering (EE) RoboBug, six instead of eight Bugs were fabricated in-house. Parts and material, batteries, and circuit boards cost $3,000. Instead of giving away the toys and the bugs, due to the costs, a decision was made to maintain and recycle term after term. Broken animals and Bug parts will be replaced. The manufacturing (MfgE) consumables were mainly in different materials required in the various processes laboratories ($2,000). In addition, a fixed cost of $2,500 was necessary to setup the design laboratories. Since all the technicians have full-time responsibilities, some overtime was required. The yearly maintenance and replacement material costs are estimated to be $2,000 for ME, $2,500 for ECE and $2,000 for MfgE. Technicians overtime cost still stands.

Assessment and Improvement

At the onset of designing the course, after setting the goals and objectives, ABET assessment criteria (a) through (k) were mapped to the course contents. The highlighted areas are covered at an elementary level.

(a) An ability to apply knowledge of mathematics, science, and engineering (ME, ECE, MfgE labs)
(b) An ability to design and conduct experiments, as well as to analyze and interpret data (during labs)
(c) An ability to design a system, component, or process to meet desired needs (final project)
(d) An ability to function on multi-disciplinary teams (during labs and final project)
(e) An ability to identify, formulate, and solve engineering problems (lectures, some in labs)
(f) An understanding of professional and ethical responsibility (lecture coverage)
(g) An ability to communicate effectively (leadership) (lab collaboration and presentation)
(h) The broad education necessary to understand the impact of engineering solutions in a global and societal context
(i) A recognition of the need for, and an ability to engage in life-long learning
(j) A knowledge of contemporary issues (lecture coverage)
(k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

After three terms, a course binder was assembled to reflect the course syllabus, content, lecture notes, lab instructions, assessment methods, results and improvements made from term to term. A section on how this course links manufacturing / industrial with mechanical and electrical/ computer engineering; how interdisciplinary material feed forward to the education system and how they relate to the program outcomes of ECE, EE, IE, ME, MfgE was added. This binder serves as a documentation folder for ABET accreditation visits.

The initial offering of the course was not without its difficulties and this section will attempt to address some of them and ways to improve the situation. In assessment, there is often a long list and a short (more imminent) list of areas for improvement. This paper discusses the major ones in the short list. They are categorized as (1) lecture, (2) labs, (3) final project, (4) course structure and textbook, and (5) score and record keeping.

1. Lecture

Duration**:** one 2-hour lecture per week for Freshman poses a knowledge retention problem and reinforcement deficiency. Freshmen generally are not self-paced and study habits are different from juniors and seniors. They need more frequent classroom guidance. This was discussed in a proposal to GE Fund Learning Excellence Initiative, April 1999 by Northeastern University, Boston. [http://gemasterteachers.neu.edu/overview/overview.pdf]. The test scores were not satisfactory. An off-hour review session before the tests was initiated. Average attendance was 60%. Scores improved but were not sufficient. A request was made to split the lecture into two 1-hour lectures. It took effect in July 2002. Test scores improved further.

Homework: For homework on topics with numerical calculations, like tensile testing and machining, timing is an issue. When class met only once a week there was not enough time for feedback to the students. The improved schedule of two 1-hour lectures per week gave that provision.

Quizzes: quizzes were for extra credit under the philosophy that "if your can earn the points, you can have the points". They help pace the students. The scores also improved under the new lecture schedule.

Tests: Three tests and the final exam adequately covered the material but did not put too large a retention strain on the students. With the change in lecture schedule, tests were abandoned in favor of weekly longer quizzes to further help pace the students.

2. Laboratories

Manufacturing processes labs

The manufacturing processes laboratory (ManPro) experiences have been honed over the past 10 years in the previously revised course, MFGE-101 Manufacturing Processes. The majority of these laboratory exercises transferred from the old course to the new MFGG-135 course.

Each student receives a laboratory manual, which provides the necessary background knowledge required to successfully perform the laboratory exercise. This manual permits the laboratories to move in a sequence slightly ahead of the lectures during a portion of the term in which there is more lecture coverage than laboratory coverage for a single topic. The students have commented that although the laboratory manual seems too detailed in some sections, overall it does prepare them well for the laboratory exercise and the laboratory quizzes.

However, improvements in the laboratory experiences are made on a continuing basis as new ideas evolve from the faculty, the technicians or the students. Last year, a new Kettering Bulldog medallion pattern replaced some old Christmas ornament patterns as a portion of the green sand casting exercise. The new Bulldog medallion are so popular that castings must be rationed to the students.

The student performance in ManPro labs is evaluated based upon short quizzes, brief laboratory evaluation sheets and participation as a team member in each laboratory exercise. The retention of knowledge gained from the previous laboratory exercise has proven to be high when the students actually participate in the activity and when the evaluation of the knowledge is one week after the experience. When the evaluation quiz is given two or three weeks after the laboratory exercise, the level of knowledge retained drops significantly.

Mechanical design labs

The re-engineering of animated animal has been used in a junior ME design classes. This course now covers the introductory portion of the design class. Lab handouts and material are well established. The problems were student destruction of mechanisms to the point where they did not have a toy to analyze. Battery consumption was high since students did not conserve energy. Reminders were given and the situation is somewhat stabilized. The dissection of the animals to expose and display internal mechanisms is a time consuming job for the technicians. They are now starting the process several weeks ahead of the term in replacing the broken animals.

Electrical design labs

These labs are entirely new to ECE department and thus they are experiencing growing pains.

RoboBugs are high maintenance items. The initial design was not robust enough to withstand student abuse. They needed to be rebuilt. Servo motors need to be more durable. Two extra fully-operable RoboBugs will be built for final motion control application.

Students logic program errors cause 2 legs to be driven in different directions thereby causing stress on the motors / gears. One alternative solution is to use metal gears ($90) instead of the plastic ones ($10). The feasibility of substituting all metal gears on the servo motors mechanisms is to be studied. A senior research project has been proposed to evaluate the load on the drive linkage mechanism for the legs and to develop a more reliable drive linkage mechanism.

Bug feet are slipping due to its stick configuration. They need to have swivel feet with non-slip surfaces. This is a planned final project assignment for the students to improve the RoboBug feet.

Soldering and board preparation was very time consuming for the students. The PCB milling machine was introduced and it reduced the process leadtime. Eighty-five percent of the students were enthusiastic about the implementation.

Evaluation of the ECE lab portion of the course had been subjective. In Fall 2002, a point scoring system was introduced based on students' demonstrations and their worksheets generated from the Multi_SIM and Ultiboard computer software programs.

3. Final project

Some of the final reports showed a significant lack of understanding, depth of thought and clarity of explanations. A more comprehensive list of requirements was drafted for a new Project Assignment sheet. The topics for discussion (and grading) are: optimization of new design, justification, description, documentation including drawings and simulation, and publications /references. Student scores improved considerably.

4. Course structure and textbook

There was an asynchrony between lectures and manufacturing processes labs. Lecture topics are now better aligned with labs

Lecture Powerpoint slides were posted on Blackboard for better access by students

To discourage absenteeism, students missing 2 labs will fail the course

The Kalpakjian $125 textbook (Manufacturing Engineering and Technology 4th ed.) was cost prohibitive since less than 50% of the material is used. Overhead slides were printed for the students. Upon request from the students, 22 manufacturing processes textbooks were placed on reserve in the library. One possible solution is to have a partial printing by the publisher of selected sections for half the cost.

As a side note: Freshmen study habits are generally not yet adapted to college level learning. The plan is to work with Student Affairs office to rethink their explanation of how to develop good study habits which is presented during the term long Freshman Orientation course.

5. Score and record keeping

The first two terms presented nightmares to professors grading the final project reports. Reports had to be screened and sorted by ME / ECE / MfgE improvements and re-design, distributed to the appropriate professors, graded and scores pooled together from up to 6 professors from 3 departments. These grades have to be combined with the lab grades and delivered to the course lecture professor for the total grade. To provide a fair grading system, a common set of criteria were established across the departments. This has been in the works and will continue to evolve. A course account was established in Blackboard. Lab grades and final project grades are entered into this one source and all instructors have at least reading access to the records.

For assessment purposes student Working Model 2D files need to be saved. A CD burner is necessary due to the size of the modeling files.

Blackboard is also set up to enable the students to evaluate the performance of their group. A class survey was handed to the students, but survey return was insignificant. It is now on Blackboard. The results from Summer 2002 are summarized in Table 1. It shows that the set of objectives were satisfied. Majority of the students agree or strongly agree that the labs gave them the understanding, engineering tools of different engineering disciplines, teamwork and technical communication skills.

Table 1: Survey of Students on the Interdisciplinary Labs, Summer 2002

The Interdisciplinary labs ... / Ave. %	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
provided me with a better understanding of the different engineering disciplines	56	40	4	0	0
given me skills needed when working with a group on a given assignment.	33	56	10	2	0
improved my oral and written communication, and presentation skills.	14	52	29	6	0
provided me with engineering tools that will be beneficial in my work assignment and future	46	50	2	2	0

Results

A freshman course was successfully implemented where students learn the different disciplines of engineering, experience first hand what some of the functions are for a mechanical engineer, electrical / computer engineer and industrial / manufacturing engineer. They have also worked in an interdisciplinary as well as an integrated environment on account of the final project. Students are now able to discern what areas of engineering best suit their interests. They also have a good feeling and are able to grasp concepts of integrated engineering, which is what industry direly needs. The following is a summary of comments from students and professors.

Comments from students: · controls are exciting to program · "fun, fun, fun course" · good exposure to different engineering disciplines · eye-opener on how different engineering areas are related · like the things we make in manufacturing · fun working with the animated animals. They liked the manufacturing portion of the class since they were able to use the instruments and equipment of manufacturing that they had never used or seen before. There was strong indication that the lab sessions increased the learning from the lecture.

Comments from instructors: · enjoyable teaching · first time freshman are exposed to ECE · students catch on fast and are very creative · problems with retention in one 2-hour lecture per week · no textbooks but notes are sufficient · students were very receptive to the lab and the approach taken · students were not intimidated by the tools they were using · students readily took the tasks and completed them with some very good results · the PowerPoint presentation and the Working Model 2D simulations became very impressive · students seemed to function in their groups, both during the 4 weeks of lab time, and in forming new groups for the final project.

Conclusion

Despite uneasiness, fear, skepticism in collaboration among departments, by setting up an infrastructure that supports the endeavor, creating a course structure that accommodates interdisciplinary engineering topics and integrated concepts, and building a process that fosters information sharing, it is entirely possible to create an Interdisciplinary Design and Manufacturing course for Freshmen. After 15 months of classes, the group is still functioning harmoniously, still sharing pros and cons for continuous improvement of the course. The future is bright. It is the authors' hopes and aspirations that other universities will try to create a similar course. Given the right mind-set, IT WORKS!!

Future

MFGG-135 will be continuously offered. It will go through continuous improvement. The core group of professors will help provide the glue to hold it together. Effective communication with next generation professors will be required. Those teaching the classes now have been very involved with setting up the course. Even with that said, the core group is still determining new methods and items to be included in the grade, especially for the final project. Do the existing criteria become the standard that is passed along, or do we negotiate when new faculty start teaching the course? As technology advances, the course standards may shift. New criteria reflect improvement. The course should then evolve with current issues and with time.

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