Using Course Projects to Infuse Innovation throughout the Undergraduate Experience in the Engineering and Engineering Technology Curriculum

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Engineering and Engineering Technology students need to learn how to innovate and embrace new technologies as they develop and progress through their careers. Accomplishing this challenge requires the undergraduate degree programs to provide the first opportunities for innovation technological problems to gain experience and confidence before they reach the Capstone course. This paper describes the learning experiences in innovation using undergraduate courses in Robotics and Automation, Finite Element Analysis, and Parametric Modeling and Rapid Prototyping. The courses are composed of Mechanical Engineering (ME) and Mechanical Engineering Technology (MET) students. The paper relates the successful attempts the students have had in developing and using innovation through the creation of open-ended projects in the three courses. The undergraduate students in each course are self-directed and have to use innovation to develop a project of their own design within the course restraints. This breaks the cycle of students just doing the same preset experiments that others have done before them. Although doing preset experiments can reinforce the theoretical concepts given in classroom, it does little to develop skills in innovation, which will be the key to success in the global economy. The courses used in ME and MET programs provide an excellent framework for the students to demonstrate their ability to innovate using new technology to solve a complex engineering problem. The project is also supervised by instructors as students take their first steps in actually doing innovation. The confidence and process used to solve these technical problems will provide a basis upon which they can formulate new strategies to incorporate new technologies throughout their career. Using this new approach will help our students gain confidence in reaching out to use new technologies and innovation early in their career.

Introduction

New paradigms are required for undergraduate teaching in Mechanical Engineering and Mechanical Engineering Technology that are "student centered" and bring relevance to the classroom[1]. The global world we now all live in requires us to provide new innovators to create new products at a very rapid pace compared to past generations. In forming these new directions, we need to reengineer the laboratory experience. We need to rethink traditional methods to become more flexible and challenging to the individual student. If we wish to encourage innovation, a new method of delivery that is different from the traditional laboratory instruction needs to be developed.[2, 3, 9, 10] Allowing the student to use higher order learning which includes problem development, experimental planning and most important implementation all though the use of active learning styles will help reinforce the theory given in lecture and should lead the student to be a more engaged.[1, 2, 3, 4, 5] The creation and use of undergraduate research as a laboratory experience can affect career decisions leading to graduate school and relieve the monotonous aspects of learning while instilling a sense of accomplishment.[6, 7, 8, 10]

When a student is required to formulate the experiment himself/herself from a set of open-ended parameters innovation happens. In the context of the course "open-ended" was defined as using the existing tools, either hardware or software, assigned to create and demonstrate to the rest of the class an experiment that demonstrates the course capabilities. There is not a set of specific instructions to follow that lead to a predicted result as with many laboratory courses. Rather each student or student team must first determine what they would like to accomplish utilizing the existing resources. The first opportunity for this in our curriculum is in our 3D Parametric Modeling course where the students must develop a model for a complex part using the skills they have developed during the course. The next major opportunity is in the Robotics and Automation class where they first determine the project goal, then determine the type/number of sensors, the type of feeding system, and finally the end-of arm tooling needed to accomplish the project they have devised.

Similar methodologies are also used in Finite Element Analysis. The coursework involves teaching fundamental mathematical theories to build the concept, then solving a wide variety of engineering problems dealing with statics, dynamics, fluid mechanics, and heat transfer. Students enrolled in this class are also required to conduct a project solvable by the student version of the FEA tool ANSYS within a very short time. The project must also have adequate engineering complexity and convey interesting knowledge or technical concepts to the entire class.

Accomplishing this unique design requires each team to innovate to solve a unique problem that has never been done before. Learning how to innovate is one of the most important aspects of education that will stay with a student and serve him/her well no matter what new technologies he/she will encounter in the future. Technologies will “come and go” and many of the technologies we are currently teaching to our students will change drastically in the future. New technologies not even thought of will be created and used by the future engineers during their career. The ability to explore and use innovation, not just memorize and recite is the engine that will propel students to a promising future by allowing them to adapt to an ever faster evolving world.

Examples from the Courses

Students that select majors in Mechanical Engineering, Mechanical Engineering Technology, Manufacturing Technology, Design Technology, or pursuing a minor in Mechanical Engineering take an introductory course in 3-D Parametric Modeling. This course involves teaching students the basics of parametric design using the SolidWorks modeling software. The course is taught utilizing a combination of lecture, design laboratory, and a tutorial-based text that encourages students to learn how to access additional capabilities of the modeling software. As a final project in the course students must select a mechanical device and create the parts and assemblies for this device. Students are given some latitude in the selection of their project so that they can find something along their particular lines of interest. Projects have resulted in students creating models of turbochargers for their automobile, a mechanical cam device for mountain climbing, and even household items such as a hanging chandelier.

Students must get their projects individually approved so that the instructor can make sure that they are not attempting a project that will be too difficult for them or take them more time than they will be able to complete during the course. The Level of complexity is reviewed with the student and then it is up to the student to decide the best way of creating their model using the design software. Because students are excited about their projects they are willing to try tools and methods outside of those that are covered in the class. The following figures illustrate some examples of student projects from the course.

The Climbing Cam is a device used in mountain climbing. Since the actual device is designed to move and articulate, the student that selected this project had to learn on his own about tolerances for shaft and holes. This project was later created in plastic using a Dimension 1200 Rapid Prototyper. The finished part moved as it should have and validated the student's learning.

Figure 1 Climbing Cam device

The next example is in an electric guitar pickup where the student focused his learning on the electronics of how the device functioned and also on the size and standards used in making guitar parts. His design incorporated adjustable pole pieces and would fit most standard electric guitar shapes.

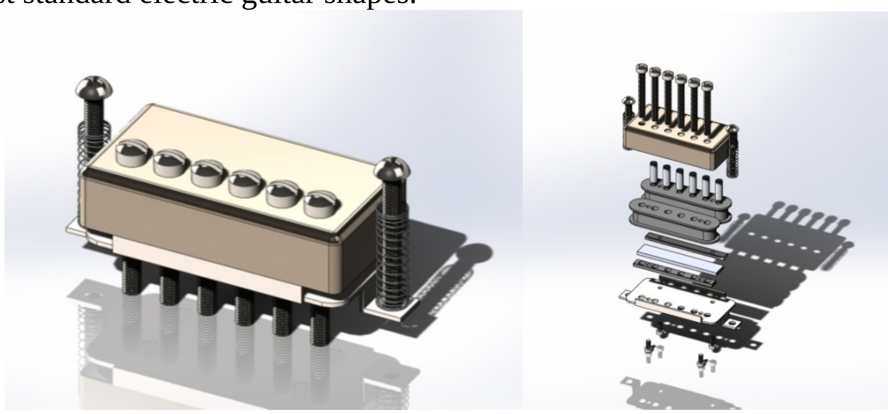

Figure 2 Electric guitar pickup, exploded view of on the right.

Figure 3 illustrates how students can use the design project to assist in their own interests and hobbies. This student was modifying an early Ford automobile chassis in his spare time and used the modeling software to try out a design for his front axle.

Figure 3 Front axle assembly from an early Ford

The lock-back knife shown in figure 4 was selected by one of the top students in our program. Initially the student assumed the complexity of the project would be due to the high number of parts to create the full assembly. The student learned about the difficulties of dealing with curved and lofted surfaces. He taught himself the more advanced tools in the modeling software to create these surfaces and learned how to create secure fasteners that would work on these curved edges.

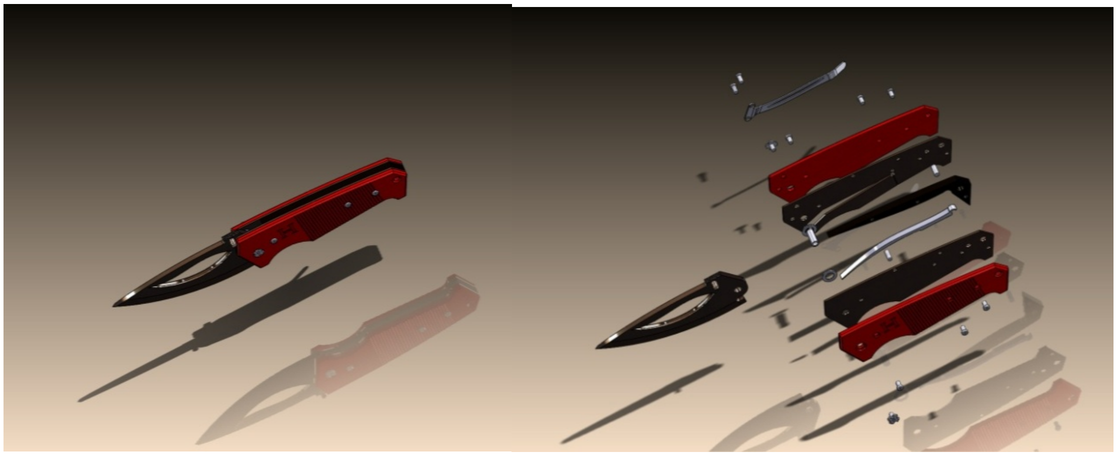

Figure 4 Lock back knife (a) assembled and (b) exploded views

In the Robotics and Automation course, the instructor gives the students very general parameters and then asks the students to formulate their own group's experiment within the confines of the parameters of the course.[1, 7] On the first day of class the instructor shows videos of past student laboratory projects for the course. This lets the students know what has been done in the past and sets a minimum expectation level on the types for laboratory projects they are expected to produce. During the first day of laboratory the students are divided up in teams of two and asked to design a robot using a Robix kit which is basically a microprocessor board, six servo's and a box of building parts as shown in figure 5.

Figure 5 The Robix Kit

This is the first of three laboratory experiments that the students will be asked to do in the confines of a 10 week quarter system class. The simple robot kit is used first so the student can learn and discover some to the unique and unexpected movements a robot can make without damaging a larger robot or themselves. They are told that they have two weeks to design, build, program and demonstrate a robot of their own design with the kit. The students have made many different projects. Some of the projects they have made include, a robot the makes tea, an animated puppy dog that walks, grilled pancakes, auto loaded air cannons, a rope climbing robot, precision throwing robot with ten targets, rock'm sock'm boxing robots, and a robot planted seeds in pots. Figure 6 illustrates some of the projects created by the first two weeks of the course.

The students must first understand the capabilities of the equipment at hand, then formulate a problem or task for the robotic equipment to perform, and finally demonstrate the project for the rest of the class. The projects are always different since the student must design the robot from a basic kit in a box of parts. The students tend to choose and design a project that is more complicated and time consuming than any the instructor would normally assign or dream of designing for a laboratory assignment. This is usually one of the first times that the student has had the opportunity to do undergraduate research of any sort on their own. The innovation experience and method of designing and building their own robot that does a task they have conceived is a valuable learning experience.

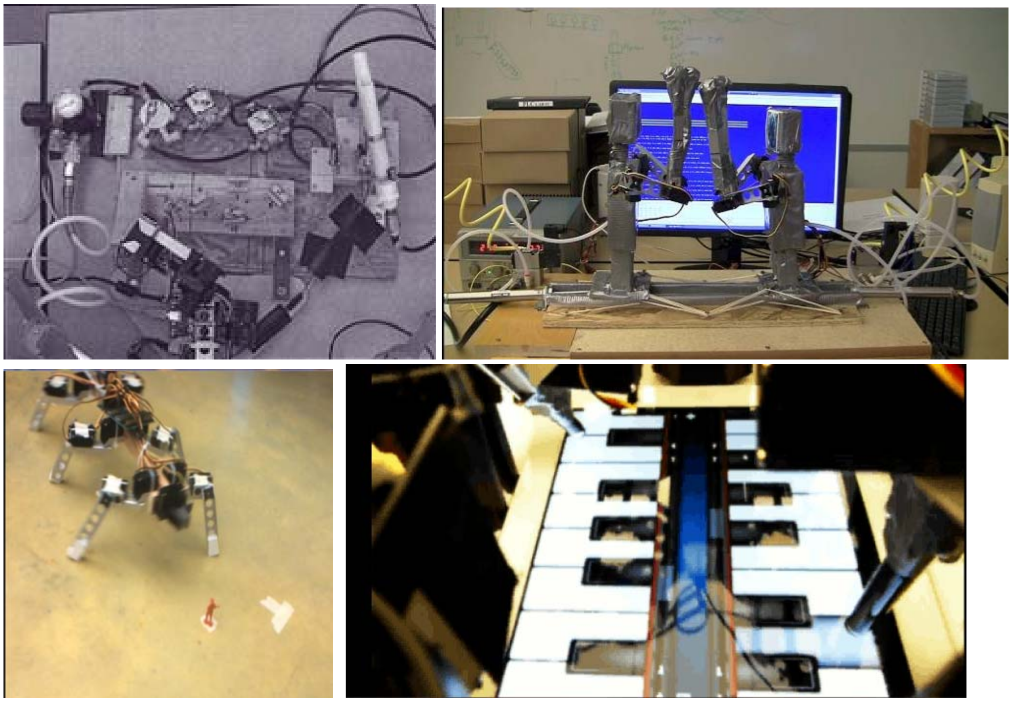

Figure 6 Examples of Robix Kit Projects. Air cannon, Rock'm Sock'm, hexapod, and piano playing robots.

The second rotation during weeks 3 – 8 of the course uses the industrial robots. The teams are reconfigured into teams of 4 students. Each team is assigned an industrial Robot. The lab currently has 8 industrial robots. Four of the industrial robots are ADEPT Cobra 600 SCARA type robots and the other four are FANUC LR MATE 200i robots as shown in figure 7. Each robot manufacture is currently using its own programing language and procedures to program its robot. The students have not been previously exposed to the programing language of each robotic manufacturer. The method forces the students to work with “new to them” unknown technology, which simulates the experience they will face in industry as new technologies are introduced into the companies for which they are working.

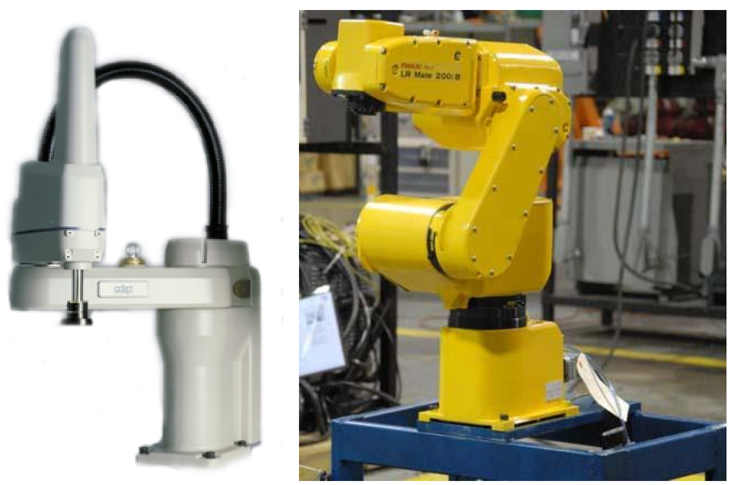

Figure 7 ADPET Cobra 600 and FANUC LR MATE 200i Robots

The students receive the robots as they would from the manufacturer without end effectors or part feeding / output conveyors. Students are instructed to simply “impress the instructor”. This simple instruction forces the student teams to research the capabilities of the robot assigned and design a project that is within its capabilities. Then the teams use innovation to design the end effector, part feeding systems and output systems to accomplish the task they envisioned. The projects require them to draw upon their experience in other courses they have taken as well as the application of the theory of the robotics and automation course they are currently taking.

The students have done extremely interesting projects including a billiards playing robot; a rod polishing robot; car painting robot; a light bulb testing, sorting and packaging robot; a recycling sorting robot and a pallet packaging robot with scissors lift. Some of the robots have included significant innovative ideas. One project used a single laser proximity sensor to characterize building blocks in 3D space to find the best match in a 3D matrix of the existing blocks in a Tetris game. Random blocks were feed through a conveyor and placed in the best possible positions in the Tetris cube.

Figure 8 Industrial Robot Projects that play billiards Robot, polish metal rods, paint model cars, and sort & package light bulbs

Our third set of examples are from our one-quarter long finite element analysis (FEA) class in the Mechanical Engineering curriculum. This course teaches computational methods to solve engineering problems using the state of art FEA software ANSYS. First, the coursework teaches fundamental mathematical theories to build the concept, analyzing simple structural problems using matrix algebra. Then our students solve a wide variety of engineering problems dealing with statics, dynamics, fluid mechanics, and heat transfer. As we are in quarter system, it is challenging to solve additional multidisciplinary complex engineering problems in regular *class lectures*. Therefore, students enrolled in this class are required to conduct a project solvable by student version of ANSYS within very short time. The project is usually assigned during the seventh week and needs to be completed before quarter ends.

Figure 9 represents one of the finite element projects conducted in the FEA class. This project did an acoustic analysis of the Liberty Bell, a well-known engineering structure, located in Philadelphia. Many factors surely played role in cracking the bell, but the exact causes are still unknown. This cracking could be due to the combination effects of material properties and geometry. These parameters not only affect the structural integrity of the bell, but also the sound it produces. The main focus of this project is to conduct the acoustic analysis of the Liberty Bell changing material properties and geometry. It also investigated how the acoustic performances change between the intact and cracked configurations. Modal and harmonic analyses were performed on different bell configurations using ANSYS Workbench. The numerical results were compared with corresponding analytical solutions to enhance the conceptual understanding.

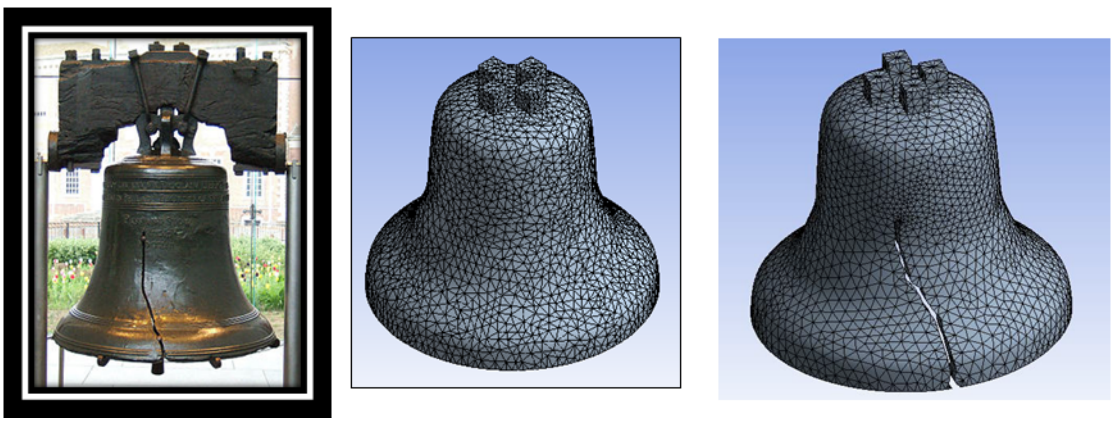

Figure 9 Acoustic Analysis of Liberty Bell: Intact and Cracked Configurations.

Similarly, Figure 10 represents the structural analysis of a commercial climbing cam used by rock climbers to arrest a fall. The cams are placed into cracks in the rock, and the lobes are allowed to expand as to lock it into the crack. Numerical analyses were conducted to investigate the deformation and stresses under several boundary conditions and loadings that occur in real life situations. Additional numerical analyses were conducted to optimize the shape without compromising the strength.

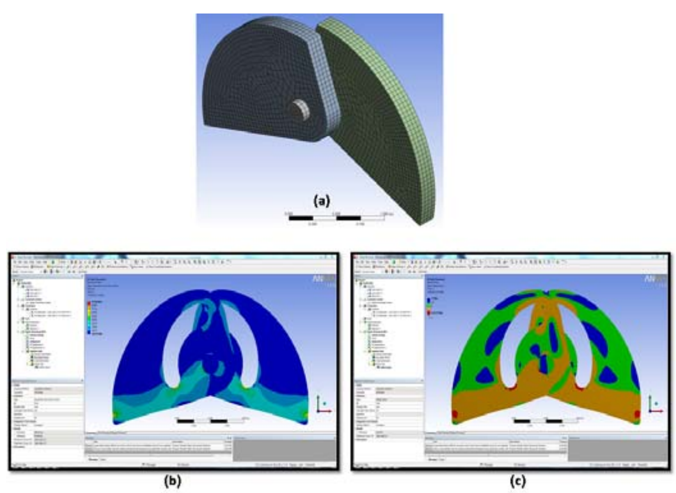

Figure 10 Structural analysis of commercial climbing cam. (a) Finite element model, (b) Deformation analysis, (c) Stress analysis.

In all three courses, the students are told the projects will be graded like an Olympic diving competition. Half of the performance is on difficulty and the other half of the performance grade is on execution. This prevents the students from selecting a project that does not have enough rigor. A simple project no matter how well executed will not result in a good grade since the project would receive a very low difficultly grade.

This grading methodology also prevents the students from selecting a project that was too difficult and therefore not accomplish the proposed project and still think he/she has done a great job. The grading would give him/her a good grade for difficulty but a very low grade for execution. The instructor approves all projects before the student team is allowed to start the project. This helps the students select an appropriate project that has enough of a challenge without dooming the student to a project that is not reasonable to be accomplished in the time frame of the course.

Results and Conclusion

Students have really responded to the new method of open-ended laboratory experiences. They are very willing to put in whatever time is required to complete their project. Students find they often need far more than the scheduled class time to complete the laboratory assignments for the projects that they have self-selected. They demanded to have more time in the labs and the labs is outfitted with electronic locks so the students can have nearly 24 hour access to the labs. This alone is in stark contrast to many traditional methods of doing laboratories. Most traditional labs have trouble getting the student to spend the full scheduled lab time. We believe this is because they are bored doing the same tired experiment that others have done before for years. They are not exploring, not innovating. They are simply droning on doing the laboratory instruction page by page, waiting for the end of the period, and often not really learning the principle being shown in the lab. With that methodology it is a wonder that any of the graduates go on to be innovators after they graduate. The old method of laboratory experiences does not teach, encourage or allow them to practice innovation. Rather we are training them by example to be drones that will do just what they are instructed to do. The new method used in these courses requires them to innovate and explore. They have to research a project and the uses of the new technology being introduced. To accomplish the self-selected and self-directed project they are faced with one challenge after another to be solved. Problems they discover and then develop solutions. This is the beginning and flowering of innovation within themselves. The process of looking at or even developing a new technology is what our work force needs. We need to be producing innovators and problem solvers for problems that have not even been envisioned today. Students have been developing new strategies to solve the problem while learning the principles and learning objectives of the course.

The student perception and instructors evaluation of meeting the course educational objects in Robotics and Automation course are very good as shown in figure 11 for the last four years. All years used the new laboratory method described in this paper. Students were surveyed at the end of the course on how well they met the various educational objectives. Scoring was from a low of 1.0, no or very little understanding, 2.0 average understanding, 3.0 very good understanding, to a high of 4.0 for excellent understanding of the objective. The graph shows that the students have consistently felt they accomplished the educational objectives.

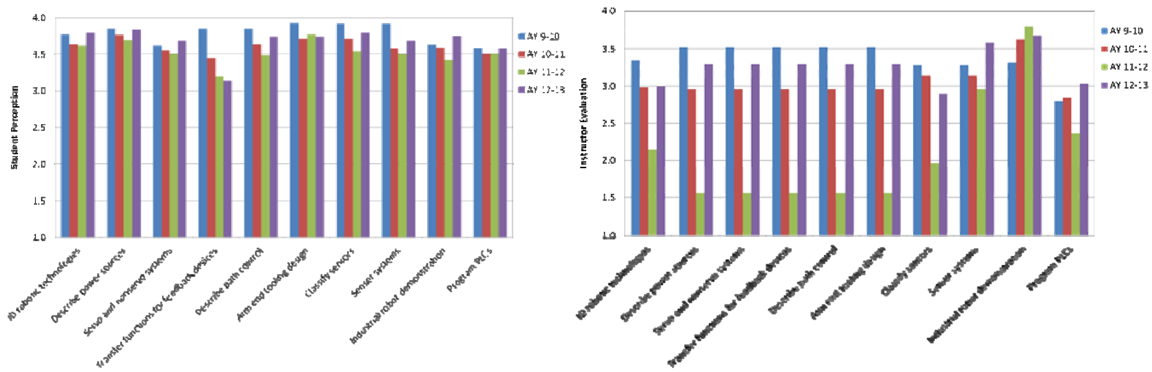

Figure 11 Student and Instructor Evaluations of educational objectives of the Robotics Course

The instructor evaluations match for the most part with the student perception except for academic year 2011-2012. The drop in the instructor evaluation of some of the objectives in that year were analyzed by the instructor and attributed to both an increase expectation of the instructor and the lack of tools/ helpful guides for students to successfully meet the increase expectations. The instructor has since make more guides available and revised expectations to better match was can be reasonably expected to be accomplished within a 10 week long quarter course.

Similarly, the instructor and students perceptions of meeting the course educational objectives in FEA course is very good, as shown in figure 12 for the last three years. Students were surveyed at the end of the course on how well they met the various educational objectives. Scoring scale was the same as used in Robotics and Automation class. The graph shows that the students have consistently felt they accomplished the educational objectives.

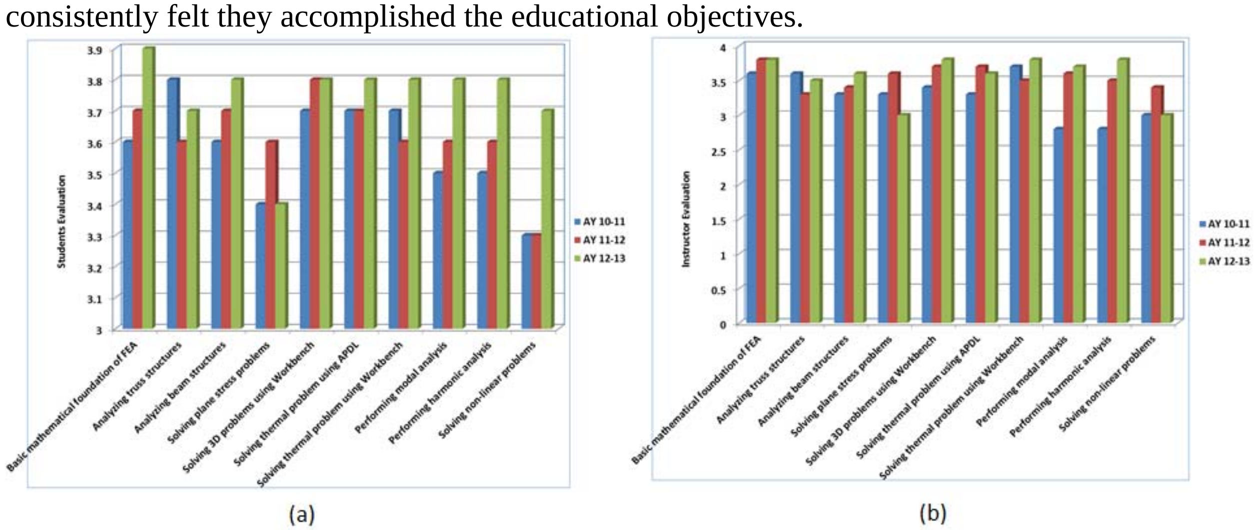

Figure 12 Evaluations of educational objectives in FEA class. (a) Instructor evaluation; (b) Students evaluation.

This new method of teaching has serious repercussions for the instructor as well. The instructor takes on a new roll in the lab as a mentor and enabler. Since the labs are not preplanned exercises, the instructor has a few other new challenges as well. He becomes a resource and has to coach the students to the right solution without giving the solution outright to them. He often feels like he is playing multiple chess games at the same time. The difference is he is not trying to win but help each team to win. He is to help them explore options through feedback on both process and product design. This feedback helps them “flesh out” their designs and explore alternate solutions. He must also guide them to solutions if he feels they are “getting stuck in a rut and spinning their wheels”. They need to problem solve and innovate but not cross the fine line to frustration.

Projects and reports are different and require more time to grade. All the above results in a wide array of questions and inquires by the students. Not all students are happy with this new methodology of teaching as well. Some prefer to just do the “spoon fed” instructions and are not comfortable with having to solve problems of what and how to do the next step. These prefer to do the experiment by the numbers and observe the result. They are being moved out of their comfort range and this can be traumatic. We believe however, that this is the exact type of student that needs this experience to learn to grow, explore and hopefully discover new solutions. It is hoped that this student will learn by success that he/she can indeed be successful and thereby more comfortable with innovation. Then when they are faced with the need to innovate in their career they will be less apprehensive about it and know that yes they can succeed. We need to provide those first tentative steps here in the relatively safe environment of the university and not on their first job where the tentativeness to try innovation can have serious career repercussions.

The other end of the spectrum is the “ let me at it” student that has been waiting his/her entire time at the University to be let loose. They want to explore and let their mind run free and look at new solutions and new ways of doing something. For them this course is a joy and a joy for the instructor to observe and give gentle guidance. We believe that a team composed of both of the above types of students improves the educational experience of both types of students. The “spoon feeder” learns to grow and the “let me at it” student learns to help motivate team members that may not be a motivated as they are. In industry we need to learn to work with all types and how to motivate team members to provide what you need form them.

Thoughts on the future

The concepts and method used for these courses will work for many undergraduate engineering courses taught with laboratory components. The authors agree that not all lab courses can use this method but all laboratory courses should be examined to see if this approach would be advantageous and appropriate. One thing the instructors have concluded is that the good thing can be carried too far. There is a need for good guides to be developed as well as instructional resources for the students to use. Throwing the student into the river to have “them sink or swim” has some use but there needs to be “life lines” for them to grab or they become too frustrated. The instructor needs to understand that this is the first time for many that they are required to “dig it out” on their own and need more help than was first thought. To this end more guides and tutorials are being developed to help students learn the technology. Past laboratory reports are being made available to the students to serve as a guide and samples of how to develop robotic programs/syntax, sensor circuit wiring, methods used for part feeding and end of arm tool design. Digital videos of past projects have also been made available to the students to view and use as a resource in developing their own projects. The development of the above instructional resources will hopefully allow more in depth and complicated projects as students spend less time learning the basics.

The authors feel using the type of “open ended” laboratory experiences described in this paper is an excellent way to prepare students for their senior capstone course which typically is an “open end” design problem often from industry for them to solve. Using the above method to infuse innovation into the undergraduate experience will help prepare them for the challenges they will face in their careers as technology constantly changes. It is the authors hope that you may find a course or courses in you institution to try this new methodology as described above.

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