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# Expanding the Objectives of the Laboratory Experience*

KAREN E. SCHMAHL
*Manufacturing Engineering Department, Miami University, Oxford, OH 45056, USA.*
*E-mail: schmahke@muohio.edu*

*This paper describes a framework for an approach to the engineering learning laboratory program that includes objectives emphasizing customer interfaces and the iterative nature of the engineering design process. The approach is designed to help students' transition from standalone labs and laboratory-based design projects to a capstone experience. In this approach the students are customers of each other and must improve their product, a laboratory exercise, based on other student's feedback. The four phases to the project are research of a topic, development of a laboratory exercise, continuous improvement and final report/evaluation. The phases are explained in a format that could be applied to other engineering laboratories and a case is presented to illustrate application in a specific course.*

## INTRODUCTION

ENGINEERING EDUCATION must go beyond teaching students to apply the technical aspects of engineering. To be effective, engineers need to have improved communication skills [1–3] and be better able to view projects with an overall perspective [4, 5]. The perspectives of engineers need to be broadened so that prior to application of knowledge, the engineers can better identify with customers' needs. Further, they need to recognize that the engineering design process is an iterative process which is not completed until the customers' needs have been satisfied [2]. Such needs were highlighted in feedback from the Miami University, School of Applied Science's Industry Advisory Council. This input, from representatives of industries that hire graduates of the Manufacturing Engineering program, was taken into consideration in designing a new university learning laboratory experience.

Traditional hands-on learning laboratories with engineering classes in the first and second years of study introduce students to a new tool or concept in the laboratory each week. An example of this would be use of a new machine or process each week in a series of labs developed to co-ordinate with a manufacturing processes course. Generally two goals are met with this type of lab. The first goal is often for reinforcement of classroom concepts using a structured, cookbook-type approach [6]. The second goal is generally for students to gain a minimum level of competence with some tool or software in one to two weeks allotted to the topic area.

In later year courses, as greater levels of engineering design are incorporated, a project component is often added to the laboratory experience. The most common way to incorporate design in a class is with design projects [6]. Typically, students are placed into teams and use an engineering approach to solve a given problem. In a laboratory course, these projects require creative solutions to meet a customer need utilizing equipment and concepts learned in the course. Broader objectives associated with these types of projects are improving interpersonal skills as a member of a team, and developing written and verbal skills to communicate their results [6]. While students in hands-on learning laboratories will generally practice written communication skills in the form of laboratory reports, the project format often adds a verbal communication component with a formal presentation required upon completion of the project.

Another type of engineering design project experience found in the curriculum, in the final year, is referred to as the capstone course. This experience addresses the application of the senior students' knowledge to perform a major open-ended design project. The capstone projects in Manufacturing Engineering at Miami University encompass all the fundamental elements of the design process as defined by the Accreditation Board for Engineering and Technology (ABET): establishment of objectives, synthesis, analysis, evaluation, construction, presentation and reporting [7]. The students must interact with a real customer in defining the problem and objectives. Upon acceptance of their proposed solution, the students must again work closely with the customer in implementation. This year-long design project experience is similar to those at many ABET accredited universities in the United States [8–12].

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In this capstone course it is expected that our students have the communication and customer interface skills, along with the problem solving and technical knowledge, needed for 'near professional' execution of their project. What has been observed, however, is that the unknowns and uncertainty inherent in a major design project can be overwhelming to students. The students have a tendency to jump right to 'solutions' without taking the time to work with their customers in properly defining the problem and the objectives of a project or in researching the problem and possible alternatives. Furthermore, as is not uncommon [13], students often became frustrated at the iterative process required for good design. Improvements often had to be incorporated to satisfy the customer after the student 'designers' thought they were completed with a project phase.

After reflecting on our lab objectives and experiences of the students in the capstone course, the feedback from the Industry Advisory Council regarding people skills and customer perspectives could more readily be understood. We were only providing our students with a single opportunity to interact with a customer. We did not emphasize enough, early in the curriculum, the importance of the role of the customer and the iterative/continuous improvement aspects of the design process. It was decided that the objectives of a selected lab at a lower level should be expanded to better prepare the students for the senior project and, ultimately, employment in industry.

## OBJECTIVES IN REDESIGNING THE LABORATORY PROGRAM

In designing a new laboratory approach, the goal was to accomplish all the objectives of the current laboratory as well as to incorporate customer interfaces and continuous improvement aspects. A new approach would, ideally, allow the students to interface with a customer to set objectives and then, after development of a 'product', receive customer feedback to improve the product. To do so, students would have to master the tools or techniques associated with their product. This would give the students more in-depth knowledge and a greater sense of accomplishment than could be achieved with a minimum competence on a variety of tools. Ideally, the students would not only be the developers of a product, but would also gain understanding of the customer role by being a customer as well. The students would not only practice communication skills but would improve upon them. Finally, for learning to be most meaningful, the students should not only feel that they were trying to please the instructor (make a good grade) but should feel a responsibility to themselves and their classmates for the effectiveness of the learning experience. Table 1 summarizes the objectives to be met with the proposed approach, called the Lab Development Project. The approach includes the goals of the traditional laboratory and project approaches.

An engineering laboratory with such expanded objectives would complement a curriculum which includes the standalone and design project laboratories and culminates in capstone course. Students would benefit from the opportunity to improve customer interface and communication skills within a controlled environment prior to having a 'real' customer in the capstone. Dealing with customers also requires a level of maturity that may not yet be found in first and second year students. A laboratory format was therefore designed and implemented in a course in the third year of the four-year program.

## LABORATORY FORMAT

To achieve multiple objectives emphasizing customer interfaces and continuous improvement, an approach, called the Lab Development Project, was developed. In the Lab Development Project, students work as a team to develop a hands-on learning opportunity for other students in the class. Each team researches an assigned topic or tool and develops a laboratory exercise. Feedback

Table 1. Laboratory objectives

| Lab Activity | Objectives |
|---|---|
| Standalone labs | • Reinforce theories/concepts from the classroom;<br>• Gain a minimum level of competence with a variety of tools;<br>• Practice written communication. |
| (which are followed by a) typical design project | • Use a problem-solving methodology/engineering approach to a problem;<br>• Be creative in developing solutions to a problem;<br>• Improve effectiveness of contributions as a member of a team;<br>• Practice presentation skills. |
| (which are incorporated in the) Lab Development Project | • Learn the value and importance of customer interactions;<br>• Participate in a continuous improvement process;<br>• Learn to use a specific tool very well;<br>• Practice and improve both oral and written communications;<br>• Be responsible to each other for the effectiveness of learning. |

from the team's primary customer (other students who perform the lab) will allow the developing team to improve upon their product (the lab handout/experience) prior to project completion.

By developing the lab exercise to be performed by other members of the class, the students are the customers as well as the producers. In the role of the producer, they must become the experts in their assigned technology. As customers, the students as a class establish the objectives of the project by brainstorming 'What makes a good lab?' As producers they become creative in designing their labs to meet the class's established criteria while providing a minimum level of competence on the tool and reinforcing class theory. As customers again, they not only perform the other developed labs but must provide constructive feedback to the developing team. In a continuous improvement process, the developing team must improve upon their lab after each time it is performed. The feedback helps the students to improve not only the design of the exercise but also emphasizes written communication skills relative to the clarity of lab instructions. The structure of Lab Development Project also emphasizes the engineering approach to the problem and embraces the concepts of engineering design.

To perform the project, the course is divided into four phases:

I. Topic research
II. Lab development
III. Continuous improvement cycle
IV. Final report and evaluation.

The phases, associated deliverables and approximate time frames required are summarized in Table 2. Each of these phases is illustrated in the case study.

## CASE STUDY

The format as described above, with its four distinct phases, evolved as the general concepts were applied in a manufacturing engineering course entitled Quality Planning and Control (EGR 334). The third-year course provides a study of the principles and techniques of precision linear measurement, statistical analysis of the measurements, total quality management concepts and applications of quality principles in the manufacturing environment.

The Laboratory Development Project has been used for three semesters in the EGR 334 laboratory. There were fifteen to twenty students per lab section with an average of two per semester. Each semester there was only one lecture section but all aspects of this project were contained within the laboratory periods.

Prior to implementation of the Laboratory Development Project, the two-hour laboratory periods each week were generally dedicated to application of a single measurement tool and/or quality analysis technique. Thirteen weeks of laboratory periods were available during the sixteen-week semester. The Laboratory Development Project was structured to fit into eleven weeks, starting the third week of the semester. The first two laboratory periods were used for two standalone labs covering topics not incorporated in the Lab Development Project. This allowed the instructor to lay a good foundation in theory of statistical quality control before the students would be required to apply it in their project. A more detailed discussion of how the laboratory development project fits within the framework of the course can be found in Schmahl [14].

Each of the phases of the Lab Development Project, as applied in the EGR 334 laboratory are described below. A discussion of how well the project accomplished the objectives follows.

*I. Topic research.* At the start of the first phase, students in a lab section were placed into four teams of three to five students based on their stated preference for project topics. Four quality tools were offered; the optical comparator, electronic

Table 2. Phases of the lab development project approach to an engineering laboratory

| Phase | Description | Deliverables | Duration |
|---|---|---|---|
| I. Topic Research | Teams research assigned tools/topics and become proficient at its application. A short paper is prepared and presentation made to the class on the topic. | • In-class presentation<br>• Short paper/class handout | 3 weeks |
| II. Lab Development | The class, as the customers, determines the objectives to be met by the product to be developed. Each team then develops a laboratory exercise (the product) for their tool. The lab exercise should meet class objectives and be designed to provide a minimum level of competency with the tool as well as to reinforce theories/concepts learned in class. | • Initial lab handout | 3 weeks |
| III. Continuous Improvement | Students perform each other's labs. Opportunities are then provided for improving the developed lab exercises based upon feedback from performing teams. | • Interim lab versions | 3 weeks |
| IV. Final Report and Evaluation | A final version of the lab exercise is submitted in a report which summarizes the continuous improvement experience. The lab is performed and evaluated one more time. | • Final lab version<br>• Lab development report | 2 weeks |

calipers with a software wedge, an image analysis system and linear measurement hand tools (micrometers, height gages, etc.).

Each team then prepared a fifteen-minute presentation for the class to give background and basic information about the tool assigned. The presentation material and a summary of team research were included in a short paper which was provided to the class as a handout. The following were suggestions of topics, provided to the students by the instructor, which could be included:

- History/background of equipment
- Applications/use in industry
- Description/parts
- Operating principles
- Variations of instrument
- Capabilities and limitations
- Advantages and disadvantages
- Possible errors in using
- Maintenance and care
- Safety precautions
- Equipment demonstrations.

The first semester that the project was introduced to the class, the students were allowed to select their team members and were assigned a topic. This led to the inevitable complaints that some teams got 'better' equipment than others. The method of team selection was changed the second and third semesters. Each piece of equipment was described and, immediately, the students were required to state their order of preference for each tool. The class was then given a break while the instructor sorted out the teams. In both the semesters where this was done, all students were able to be assigned either their first or second choice of equipment. There were still occasional complaints, this time about non-productive team members, but overall the students seemed to think this was more 'fair'.

Also the first semester, the research element was not separated as its own phase, but was combined with the development of the first draft of the lab. It was discovered that, as with the capstone course, the students tended to jump into development of the lab without adequate research of the topic. Defining this as a distinct phase in the subsequent semesters, enabled students to focus on learning the tools and consequently be better prepared for developing the laboratory exercise.

*II. Lab development.* The initial stage of lab development required determination of objectives for the exercise. The requirements from the instructor's perspective were that students must gain a minimum competency with the tool and that the developed exercise must reinforce, correctly, the classroom theory. The students were also told that the laboratory exercises should be designed in such a manner that a lab assistant would not be necessary and a lab report for each exercise would be required.

The real customers of the exercise were, however, the other students in the class who would be gaining knowledge from performing the exercise. Therefore, the students in the class brainstormed 'What makes a good lab?' and then, from that list, selected objectives that should be met by all labs. Popular objectives selected by the students included:

1. New knowledge or experience gained
2. Practical application or real-world connection
3. Direct tie or reinforcement of concepts learned in class
4. Meaningful, not busy work
5. Fun, enjoyable experience
6. Clear directions with explanations
7. Reasonable work required for time allowed.

With these objectives and the knowledge gained in the research phase, the teams developed a lab exercise for their assigned topic. During this time the instructor acted as a consultant to the students on an as-requested basis. Three weeks were allotted to this phase with the deliverable being a lab handout and any associated components or fixturing needed to perform the lab.

*III. Continuous improvement.* During this phase the students would perform each other's labs and provide feedback to the developing team. Each lab was performed twice during this phase.

The first time a lab was performed, the developing team was permitted to observe the performing team. The idea was that by observing, the developing team could assess where in their instructions the performing team was having difficulties and, if necessary, help the performing team through unanticipated problems. At the end of the lab period, the performing and developing teams met to discuss how well the lab met the objectives and what could be done to improve it. While the labs were being performed, the instructor also reviewed the handout and also offered suggestions for improving the lab.

With two teams observing and two performing, it took two lab periods for all four labs to be performed the initial time. The lab handout then had to be revised prior to the next group performing the lab. The third lab period of this phase had all four teams performing labs. Improvement feedback for this iteration was in written form to be submitted along with the lab reports one week later.

This stage of the project proved to be most difficult for the students. Students were placed into the position of having to critique their peers and they were not comfortable with the situation. After the first semester the project was performed, two steps were taken to alleviate the situation. In working with the Communications Department at Miami University, a short lecture and brief exercises in constructive criticism were developed for the class. This additional session, taught right before this phase, seemed to make students more comfortable with the critiquing process. The second step taken was to provide more structure to the feedback. Forms were developed listing the selected objectives and allowing the students to circle 'Needs improvement', 'Good' or 'Excellent'. The students were then asked to comment on every objective. If the student circled 'Needs improvement' or 'Good', they were asked to give specific suggestions on how to move to the next level.

It was in this stage of the project that students seemed to learn the most relative to the design process and to customer interactions. They discovered that their work was not perfect the first time and what they thought were good instructions were often misunderstood or not read. They found that, given the circumstances, they were often unable to meet many of their customer demands (it is not easy to create a 'fun' lab). They found that they could not assume that students remembered anything from previous classes. They found that their customers were inconsistent in their feedback—one person thinking that the instructions were not complete enough and another saying that they should be allowed to think more for themselves, not be led by the hand through every step. It was an awakening for many of the students because this was the first time they had to interface with customers and make judgments, beyond application of their engineering knowledge, to produce a product.

*IV. Final report and evaluation.* The final report required the students not only to submit their final version of the lab, but to review the 'judgment' calls made throughout the project regarding the feedback from their peers. Each team submitted a notebook containing all versions of the lab handout and documenting the changes between versions. Just as importantly, they were required to document instances where they did not make the changes that the customers suggested—the judgment calls. Documenting the process that the team went through to get to the final project was considered as important as the final physical product of the lab handout.

An additional component to the final report was an evaluation of the students' contribution to the project and effectiveness as a team member. Each team was required to keep a log throughout the project which documented meetings of the team, including assignments made and completed by each team member. Along with this log, the team had to agree on a distribution of 'effort' towards the project by allocating 100% among the members. In addition, individuals evaluated each other relative to 'Contributes fair share', 'Reliable', and 'Positive, professional attitude' by ratings of excellent, good, needs improvement or unsatisfactory. The individual forms were submitted to the instructor aside from the overall report.

The grading of the project put equal weighting on the 'quality' of the final product as judged by the group that performed the final lab and the instructor, and on the improvements made and documented throughout the project cycle. The project counted as 25% of the total course grade. The students also received a homework grade on the reports submitted on the labs performed and on the feedback submitted to the developing team, again equally weighted. (The actions taken by the instructor based on the team member performance information varied with team circumstances.) The grading was structured to emphasize the objectives of the Lab Development Project which focused on the process as well as the product.

*Results of the lab development project*

How well did this approach meet the multiple objectives? The case shows that multiple objectives were accomplished. The structure of the project facilitated the use of an engineering approach to a problem and made the students responsible for each other's learning. From their final product, the laboratory handouts, it was evident that the developing teams had learned to use their assigned tool very well and were creative in its application. In performing others' labs, the lab experience did reinforce class theory and students gained a minimum competency with several tools.

The more difficult objectives to evaluate were relative to improving effectiveness of contributions as a member of a team, learning the value and importance of customer interactions, improving communication skills and in the effects of participating in the continuous improvement process. In their final reports the students were asked to discuss how well the process of developing the lab worked and what they learned from the project. The project was successful in achieving these objectives as is reflected in these student comments:

- Our team started out segmenting the responsibilities and doing the work individually. After our first criticism, we realized that this method was ineffective in creating a good lab. It is necessary to have a cohesive group in order to have a cohesive lab. We learned quickly the value of the group over the individual because of the errors in each section that could have been improved before the lab was performed.
- If it were not for the continuous improvement, we would not have met our customers' needs. Each revision we did was better than the previous one.
- The opportunity to make and correct mistakes and continually improve our efforts worked extremely well. In particular, it was very helpful to get constructive feedback directly for the lab participants (our customers).
- By taking the frustration we encountered during the first trial, we were able to recognize the importance of producing a product with the customer and not simply for the customer.
- With the help of feedback we were able to see

what was working, such as the diagrams and pictures in the lab, as well as the things that weren't satisfactory, such as the clarity of the directions and the interaction between the work descriptions and the diagrams.

- This lab taught us the means to hear customer demand and also to create possibilities to meet those demands. We found that labs should be educational and meaningful rather than a means to an end.
- We came into it thinking that the production of a lab was easy and not much work was needed to complete it, but we soon found out this is not true. Conveying your thoughts to others is not a simple task. It takes a lot of revisions and rethinking. This is what the development process of this lab was meant to do. The user feedback was vital in knowing what areas of our lab needed work.

## CONCLUDING REMARKS

The framework presented for an alternative approach to an engineering laboratory enables incorporation of numerous objectives to help the students' transition from standalone labs and laboratory-based design projects to the capstone project. The Lab Development Project is structured in such a way that students first research a tool, then design an exercise for other students to perform and finally they must improve upon the design of the laboratory exercise/handout in a continuous improvement cycle. Objectives go beyond reinforcing classroom theories and gaining a minimum level of competence with a laboratory tool as in a traditional laboratory or using a problem-solving/engineering approach to solve a given problem as a part of a team as in a laboratory project. Most importantly, the Lab Development Project allows the student to learn the value of customer interactions and to learn by being a part of a continuous improvement cycle; both will be important elements in execution of the capstone project and in design situations they will encounter in the workplace.

The Lab Development Project approach is best applied in situations where students are mature enough to deal with customers and where they can gain experience prior to a final year capstone experience. Laboratories which contain a series of exercises on different types of equipment, or with varied theories applied would be candidate for modification to the Lab Development Approach or a tailored version thereof.

An example of a tailored version of the Lab Development Approach can be illustrated with a manufacturing processes class. In this laboratory, the students have too many processes to learn to dedicate a great portion of the semester to the complete Lab Development Project. An abbreviated version could work as follows: Students learn about the various processes (mill, lathe, welding, etc.) in class, by-passing Phase I. Student teams could be given a lab exercise to start with on an assigned piece of machinery, then asked to incorporate an additional aspect. Phase II could be shortened with only one additional lab period added. Phase III, the continuous improvement cycle, and IV, the reflective aspect, would remain unchanged. Students would still be performing and learning a new technique each week during the improvement cycle as they would under a standalone lab format. Not all of the equipment/processes need be included in the project, standalone labs could still be used in the remainder of the semester. A side benefit of such an arrangement in the processes class would come if the lab had a design project at the end of the semester. The teams for the design project could be selected such that one 'expert' from each type of process was included. In this manner, the collective knowledge of the team would be greater than if each person came with the same knowledge base gained from a series of standalone labs.

Using the Lab Development Project approach to an engineering laboratory to complement conventional laboratory approaches can provide students an opportunity to learn and practice important concepts regarding the role of the customer and continuous improvement in the engineering design process. Consequently, the students will be better prepared to execute their final year capstone projects and ultimately meet industry needs.

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**Karen Schmahl** is an assistant professor in the Department of Manufacturing Engineering at Miami University, Oxford OH. Dr Schmahl's primary research interest is in the assessment of advanced manufacturing technology and systems implementation on production operations and costs. Her industrial experience includes positions held in manufacturing engineering and production operations for General Electric Aircraft Engine, E-Systems and Rockwell International. Dr Schmahl holds professional engineering registration in the State of Ohio. She received a Ph.D. in industrial engineering from the University of Cincinnati and Bachelors and Masters degrees in industrial engineering from Texas A&M University.