Collaborative need identification and definition of machine design class projects

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Abstract**—***This Innovative Practice Full Paper presents a collaborative effort by two faculty members of different disciplines into creating machine design class projects. Machine design classes involve the coverage of theoretical aspects of design and failure theories and culminates with students working on a design project following the standard design process: Identification of need, definition of problem, synthesis, analysis and optimization, evaluation, and finally presentation. The design project topics are usually proposed by the instructor and/or are solicited from external parties. Very often, instructors run out of design project topics and the external parties might not be willing to put a budget aside for machine design project. It is very rare to see faculties of different engineering discipline collaborate in creating design project topics. In this paper, we will present the collaborative efforts of two faculty members, a civil engineering professor (a principal investigator of a materials laboratory) and a mechanical engineering professor (the instructor of a machine design class and user of the materials laboratory) in identifying a need and defining a machine design projects. The need was collaboratively identified in such a way that the products will be useful in Materials laboratory exercise and in conducting research. Accordingly, the need for several testing apparatuses was identified and competitive products were built that saved the university a significant amount of money. Some of the apparatuses have went through several iterations, each time a better alternative design was developed and built. Students have benefitted from these iterative and innovative processes. Some of the products and their benefits will be discussed and conclusions will be presented in this paper.*

Keywords**—***machine design, class project, collaboration, need identification, materials lab*

I. INTRODUCTION

West Texas A&M University (WTAMU) is one of eleven universities comprising the Texas A&M System, enrolling approximately 10,000 undergraduate and postgraduate students. In cooperation with local and regional stakeholders, WTAMU established undergraduate programs in mechanical (2003), civil (2010), environmental (2012), and electrical engineering (2017). These programs were joined with existing engineering technology, computer science, and mathematics programs to form what is now the School of Engineering, Computer Science, and Mathematics (ECSM). In just fifteen years, ECSM has expanded to over 700 students, of which over 600 are engineering and engineering technology majors. Growth has been rapid but the school still maintains a very hands-on and personable approach to instruction with faculty instructing all lectures and laboratory courses.

With the rapid growth in student enrollment, lab equipment needs have grown dramatically. All civil and mechanical engineering and engineering technology students must take at least one material science course with a lab component, necessitating procurement and/or fabrication of customary lab activities and test apparatuses.

To fulfil some of the needs of the labs, a new partnership between the required mechanical engineering Machine Design course and the materials lab was instituted where some test apparatuses would be designed and built for the lab.

II. LITERATURE REVIEW

Several institutions have utilized a machine design course to make equipment for instructional purposes. Mosleh and Thom [1] report on the use of problem-based learning (PBL) techniques in their machine design course to build small scale tension testers to test metallic wire to failure. Atiqullah [2] used the course students to build a high temperature creep test apparatus. Atiqullah [3] also had students build a Charpy impact testing apparatus for polymer materials. Student-built torsion testers are also popular. Che [4] had students built a very low cost tester for steel bolts while Gupta and Kosciol [5] added a student-built tropometer for small angle measurements in the linear elastic range to an older Tinius Olsen 10,000-lb torsion testing machine.

The creation of low-cost laboratory equipment may encompass the collaboration of two or more instructors and/or institutions. Ball et al. [6] has reported a productive collaborative effort between the faculties of two institutions in machine design, fabrication and testing of a CNC Plasma Machine. Another collaborative effort between two instructors: one teaching Thermodynamics and the other teaching Mechanical Design and Synthesis, is reported by Constans and Gabler [7]. In their collaborative project, both instructors seek for common educational ground in their respective course presentations and hence assigned their students to design and build an air compressor as a project conducted simultaneously in their Thermodynamics and Mechanical Design Courses.

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Romero et al. [8] has also presented a unique experience of collaboration among students and teachers in order to develop multidisciplinary projects.

III. MACHINE DESIGN COURSE

The course is structured to meet specific learning objectives defined in the syllabus and consistent with ABET Outcome 3 objectives. The course is designed in such a way that students will start with a two-week simple group design project that will have several design requirements such as size, weight, cost, use of three or more simple machines, and a task that the machine will achieve. This design project does not require the students to do detailed analysis except determining the overall mechanical advantage that could be attained by using the simple machines implemented in their solution. Nevertheless, students will be introduced with the subject of designing to solve a defined problem while fulfilling the specified constraints. Meanwhile, a two week review on the basic concepts of Mechanics of Materials in the analysis of stress and strain (deformation) is presented. This reinforces previously learnt material so that the newer concepts of Failure Theories due to Static and Dynamic loads will be well understood. The final group design project is then assigned at the end of the fourth week while students are learning the new concepts of Mechanical Engineering design and Failure theories. The theories they have learnt will strictly be implemented in the design of component of the proposed solution. The design process (Figure 1) starts with need identification followed by problem definition, synthesis, analysis, optimization, building a prototype and testing and culminates by writing a comprehensive report and presentation. The summary of the design process is presented in the figure below.

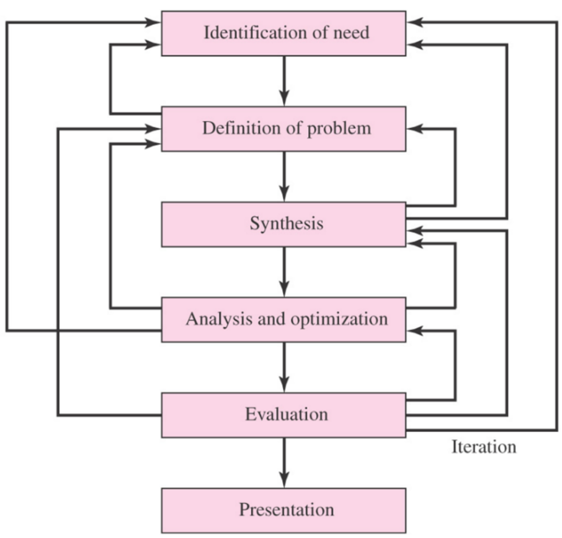

Figure 1. The Design Process [9]

For the last four semesters, the need identification was performed by the collaborative effort of two faculty members, a civil engineering professor (a principal investigator of a materials laboratory) and a mechanical engineering professor (the instructor of a machine design class and user of the materials laboratory). The need was collaboratively identified in such a way that the products will be useful in Materials laboratory exercises, conducting research, and saving money as compared to buying commercial-grade products. Accordingly, the need for several testing equipment was identified and were assigned to groups of four students. After the projects have been assigned, students performed the problem definition in consultation with both faculty members. Alternative solutions were presented by each member of the design groups and were compared using Pugh (Design) Matrix after relevant criteria were set by the group. Detailed analysis of every components were performed using static and fatigue (as needed) failure criteria and optimized using available finite element commercial software. In addition, power supply units, transmission components were sized and selected. Students have finally prepared a bill of quantity based on optimized dimensions and capacities and has built their products in the institutions workshop or in local shops of their preference. Testing and evaluations were performed and necessary modification were implemented when needed. Finally, the students have written a comprehensive project report and have presented their product in an open venue using a specific evaluation rubric where faculty members, students and other invited guests were present.

Students are continuously given guidance and advice by the course instructor during and outside of class time. In addition, students are guided with the help of a project planner or Gantt chart (Table 2) for timely progress on achieving the milestones of the machine design projects. On the ninth week of the project, overall progress is presented by the team and feedback is given by instructor. In the meantime, the faculty members who collaborated in this project were meeting periodically to ensure that students stay on track with the project.

The course is designed to achieve the following learning objectives:

- Apply the concepts of stress, strain and strength to analyze system components, and select appropriate materials based on design requirements.
- Include deflection, stiffness and strain energy methods in the analysis of components and the design of machines.
- Apply statistical considerations to machine design analysis.
- Incorporate failure theories for static and dynamic loading designs.
- Analyze a physical design problem, develop procedures for investigating the problem, and effectively perform a thorough engineering design.
- Use commercial software packages to analyze machine designs, and communicate design details.

To assess the achievement of each learning objective, instructor discusses progress with the group and conducts a one-on-one discussion with team members. In addition, to insure the contribution of each student to the design process, students are evaluated by their peers, the customer, and their instructor. Individual evaluations were used as factors to assign grades to each member. Since this was communicated at the beginning of the course, students has responsibly executed assigned task and cared much for the success of the project, with few exceptions.

Some of these machine design products are presented as case studies in the next chapter.

IV. Case Studies

As described earlier in section III, based on the collaboratively identified needs, several test apparatuses have been designed, built, and tested by the machine design course students for the use in the materials lab. Some devices required more than one iteration to yield a device that was acceptable for use. All devices were built by students under the continuous guidance of the collaborating faculty members. The following sections describes the design and construction of some of these machines for use in the materials lab.

A. Creep Tester

A miniature tensile creep tester was built Spring 2014 and put into service in Fall 2014. The creep tester (Figure 2) replaces an earlier tester built in 2012 that was not as safe to operate and had some inherent error built in because it was a level arm format instead of a true direct tension device.

B. Impact Tester

A miniature Charpy Impact Tester has been in use in the materials lab since the first engineering students enrolled in 2003. However, this device is not capable of testing full sized Charpy Impact test specimens. A full-sized impact tester was built (Figure 3) and delivered for use in the Fall 2018 class.

Figure 2. Creep Tester

Figure 3. Impact Tester (Charpy)

C. Torsion Tester

Figure 4. Torsion Testing Machine

The torsion-testing project spanned three iterations. The first iteration was a self-contained device that had a load cell that had a capacity of approximately 6 lb-ft, severely limiting its use to very small metallic wire-sized specimens. A major difficulty was the machining of these specimens as well as the angular measurements in the linear elastic range. The second iteration of the device used some parts from the first machine but with a far larger torque capacity. This device was combined with a fatigue tester. However, the compromised design had major difficulties reconciling the needs of a torsion tester with the fatigue tester. The third iteration of the torsion tester (Figure 4) was completed at the end of the Fall 2017 semester and will be used in Fall 2018.

D. Fatigue Tester

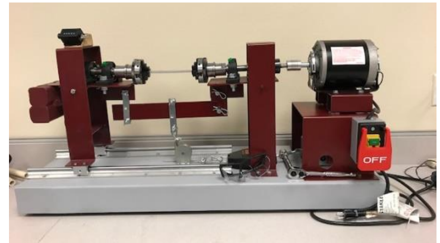

Figure 5. Fatigue Testing Machine

The fatigue tester went through two iterations to arrive at a workable testing device (Figure 5). As described with the torsion tester, the first iteration of this device was a compromised design that did not work well. The second iteration will be used in Fall 2018 in the materials lab for instructional purposes.

E. Gang Stirrer

A gang stirrer (Figure 6) was built in Fall 2016 for use with the civil/environmental introductory lab course. The gang stirrer can accommodate up to six 500 mL glass beakers at any one time. This device has an adjustable dial to change the rate of stirring for the solutions in the beaker(s).

F. Concrete Vibration Compactor

A concrete vibration compactor (Figure 7) was built in Fall 2017 for use with the fabrication of concrete cylinder and beam specimens in the civil engineering material science course. The device ensures that concrete specimens are properly compacted, similar to what is done for full sized concrete elements in buildings, bridges, foundations, and other civil engineering structures.

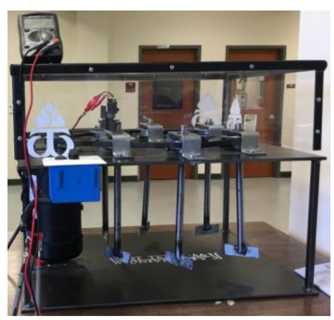

Figure 6. Gang Stirrer

Figure 7. Concrete Vibration Compaction Machine

V. Results

In the last three semesters (Fall 2016, Spring 2017, Fall 2017) five testing machines have been finalized and are presented in Table 1. Three of these products have went through two iterations and the final products presented are tested to function very well. This product have saved the university a total of approximately $16,000.00. In addition, according to the modified Bloom's Taxonomy used to indicate the students' level of learning, students' involvement in "creating/designing" the collaboratively developed design projects contributed to the development of their higher order thinking skills as well as in achieving the 'a' through 'k' of ABET's General Criterion 3.

Table 1. Finished Machine Design Project

Item #	Design Project Title	Project Cost	Commercial Equivalent Price
1.	Gang Stirrer Machine	$1177.56	$3910.00
2.	Charpy/Izod Impact Testing Machine	$1033.17	$2000.00
3.	Torsion Testing Machine	$529.90	$5000.00
4.	Concrete Vibration Compaction Machine	$724.61	$2986.85
5.	Fatigue Testing Machine	$699.10	$6000.00
Total		**$4,164.34**	**$19,896.85**
Saving		**$ 15,732.51**	

After the designed apparatus were built, each prototype was tested successfully according to the specified measurable design requirements. Students had to establish a testing methodology, follow standard lab testing procedures and compile the results in their final report. Thhey also recorded the issues encountered during testing and has critiqued their design solution based on the tests conducted and the results they collected. They have discussed the strength and weaknesses of their design candidly.

Students were officially, through semester-end course/instructor evaluation, and informally, through one-on-one discussions, were asked to give their feedback on their learning experience in Machine Design course and projects. Here are few of the comments received in the past two years:

- this course has helped enormously by gaining real world engineering experience
- great learning experience in how to effectively communicate with a group and design a marketable product
- lessons valuable in designing and assessing machine designs. This will be relevant to my future job sites and future design projects.

VI. FUTURE DIRECTIONS AND CONCLUSIONS

The partnership between the Machine Design course and Materials Lab is expected to continue. As the enrollment of the engineering programs has approximately quadrupled in the past ten years, it will be important to supply more lab equipment not only in the Materials Lab, but also in newly established Electrical and Fluid Mechanics Labs as well. By the use of the Machine Design class, students are supplied with excellent opportunities to apply their skills and to economically supply equipment for the engineering teaching laboratories.

The authors learned that communication within groups and between groups and the instructors is key. Many groups wait too long to solicit input from the client and/or feedback from the course instructor. Faculties who may wish to set up a similar course are advised to make sure that the groups meet regularly as well as with the client and course instructor to stay on task. While some groups may be more motivated and/or skilled than others, all groups need appropriate supervision to complete the required projects. Strict implementation of the milestones indicated in the project planner (Table 2) is critical.

It is anticipated that future projects will incorporate direct and indirect evaluations via quantifiable student scores and course evaluations as well as through qualitative student interviews and/or short response questionnaires. In addition, the feedback of students who will be using the machines will be collected and reported in future publications.

ACKNOWLEDGMENT

The authors wish to thank the machine design students for their hard work and dedication, the WTAMU School ECSM for gracious funding, and our engineering shop manager Mr. Jay McGaugh for assisting students to build their projects.

Table 2. Project Planner (Gantt chart)

MENG 4350 Design Project Planning

Actual Start | Actual (beyond plan | % Complete | % Complete (beyond plan | Plan Duration | % Complete

Period Highlight: 3

#	ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Project Topic (Identification of a need)	1	3																			
2	Defining Proplem (Specifications/Requirements)	4	2																			
3	Synthesis (Design Alternatives)	5	2																			
4	Selection of an Alternative (Decision Matrix)	7	1																			
5	Analysis (Preliminary Design)	7	3																			
6	Modeling and Optimization	10	3																			
7	Preparation of Bill of Quantities	12	1																			
8	Building Prototype	13	1																			
9	Testing and Modification	14	1																			
10	Report Writing	11	5																			
11	Presentation	16	1																			

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