A Project-based Learning-Centered Assessment Stream to Maximize Learning in Mechanical Engineering Design Courses

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Abstract: There is a critical need to bridge the gap that exists currently in machine design and related courses in Mechanical Engineering where there is an urgent need to correlate the theoretical knowledge learned in the course to challenging real-world applications that will help with knowledge sustainability. Towards this purpose, a project-based learning-centered assessment stream (PBLCAS) method is implemented as a pilot study in Mechanical Engineering (ME) Design course. The incorporation of PBLCAS focuses on the integration of mechanical design concepts as learned through a semester long project and tied assessment methods. The advantage of such an approach is that students learn the various fundamental aspects of the course through facets of the same project or learning experience rather than entirely different and separate projects. Usually, in a traditional learning settings, providing a big, semester long project is unlikely. Planning of projects is a separate milestone that students attempt after the course contents are covered and projects are seen as one of many other evaluation methods. However, tying most of the course evaluations such as exams, homework, exercises of the main lecture to one large, authentic project may provide the most engaging and compelling element that can maximize learning, this is also conformed through the results of the pilot study.

Background:

Problem-based learning or PBL as it is widely known was designed and formulated originally to help students 'bridge' the gap between theoretical knowledge and applied real-world applications (Guglielmino and Guglielmino 1984), (Guglielmino and Guglielmino 1991), (Litzler, Samuelson et al. 2014), (Litzler and Young 2012). PBL is operationalized by means of problems that serves a number of functions. The importance of problems is that it triggers the students' motivation to study the required content knowledge, afford the content knowledge to be studied, contextualize the content knowledge and provide a work-space for students to apply this content knowledge (Barrows and Tamblyn 1980), (Albanese and Mitchell 1993), (Barrows

1996). Although very critical, problems and its design have received less attention compared to other areas of PBL like effectiveness of PBL, group processing or skills of tutors. One of the recent models that have been developed towards designing 'problem design' is the 3C3R model (Hung 2006). The 3C3R model consists of two components, core and processing. Core components include content, context and connection that deal with the content/concept design part of a design problem. The processing components like researching, reasoning and reflecting concern with the students' learning processes and problem-solving skills. Both of these components combined help the students' towards their intended objectives and learning goals. The main challenge here is to tackle the difference between the levels of cognitive processing required for problem-solving to the cognitive abilities of the learners. The mantra in PBL is to ensure that from among a collection of problems in any given course/curriculum, each problem is designed to stimulate student learning in areas relevant to the curriculum (Hung 2011), (Hung and Loyens 2012), (Loyens, Kirschner et al. 2011).

Every instructional method has a place in education. The real question is when to use each one. It has been almost five decades since PBL instructional methodology has been conceived and implemented. It has since grown exponentially and prolifically due to its unassailable characteristics that help in induced-active learning; a much-needed tool in the present world. PBL has undergone rigorous testing and strong skepticism and criticism, but continues to endure even more strongly. Integration of project-based learning in engineering and related disciplines is not new and has been implemented quite successfully. The responsibility for learning is in a way shifted to the students and the instructor plays a mentor role. As is well known PBL enhances and encourages creativity, independent thinking and proactive self-directed learning (Newell and Simon 1972). An important new mantra in undergraduate engineering education is the entrepreneurship-curriculum approach. In the curriculum approach, technology and applied engineering education are blended with entrepreneurship for all semesters of study. Traditional junior and senior level courses in all walks of engineering learning in the undergraduate curriculum has traditionally relied on home work, quiz, assignments, exams and projects for administering the course as well as to assess student performance. Traditional method of learning has its advantages but has also some major disadvantages. The amount of knowledge retention in students is a major casue of concern amongst people in the education arena. Students have a tendency to pick-and-choose information taught to them, based on their interests and background knowledge. This might not be the best scenario for a comprehensive learning experience. In most cases, the retained part is 'applied learning' administered in course/term projects (Kotovsky, Hays et al. 1985), (Sugrue 1995), (Dolmans and Snellen-Balendong 1997). The proponents of separate projects for the same group of students can claim a more diverse learning experience based on multiple applications. But this same diverse learning experience could be brought on in a large project where the components of the same problem can be broken down into sub-systems where student working in well-rounded groups tackle problems that deal with a fundamental aspect being taught by the instructor. As an example, a major industry-based design project that deals with the redesign of a CNC plasma cutting machine encompasses major sub-projects that deal with the learning and solution of static/dynamic stresses, shaft designs of different types, design of spur and bevel gears, sprockets, springs, other fastening devices, vibration analysis etc.

Machine design is a foundation course in any ME program. The traditional objective of this course is to engage students with analysis techniques to safeguard against specific failure modes or to predict a product's life cycle based on a loading scenario. Generally, the course is taught by introduction of a topic first, then examples are presented and homework sets are assigned to allow students to practice and sharpen their problem solving skills (Liebman 1989). The current approach lacks the application of the complete engineering design process and the integration of other knowledge domains such as vibration and manufacturing. Additionally, the current course structure does not usually stimulate creativity necessary for the design process or train students on decision-making based on objective criteria. One of the common concerns of the ME department's senior students is the inability to "engineer" or practice "design." Capstone project instructors also echo this. In other words, students were not adequately prepared to work on their senior design projects, unless they had prior industrial or volunteering experiences. Students were found to be unable to develop ideation and design skills independently prior to enrolling in their required culminating experience. The inability of engineering graduates to engineer and design impedes the industrial productivity in the United States, since these students lack the skills that are in great demand by current employers (Tian 2014). This issue is rooted in the lack of preparatory courses that inculcate the design process in our students early in their educational program. The traditional focus is on the important appropriate scientific and analytical techniques with little regard to the complexity of the design process and its applications. Traditionally, machine design courses, where design in some instances is first introduced, are focused on the analysis of stresses due to applied loads, static failure theories for ductile and brittle materials, fatigue, and analysis of mechanical components, such as shafts, gears, fasteners, springs etc. (Horenstein 2005), (Dutson 1997), (Dym 2005). Notably, mechanical design textbooks are full of practical knowledge but it is presented solely from the perspective of performing a careful detailed analysis. Academic professors without considerable industrial experience promotes the basics of problem solving, in other words the 'science of analysis' (Clough 2007). Those academicians with extensive industrial experience understand the critical role design plays in the understanding of mechanical design and are able to share this experience with their students but may not possess the breadth of experience to cover all of the content equally in a full term course. As a result a large gap exists between the senior design experience and industry expectation and the knowledge attained in a typical machine design course.

The primary goal in this PBLCAS study was to administer an enhanced project learning experience for undergraduate mechanical engineering design students in their basic level design course. Such a PBL learning exercise where a traditional classroom based educational experience is laid over a PBL experience was worth investigation for a mechanical engineering design course at Wichita State University. This method where the class HW, exams, assignments and quizzes are related to a major project is like a chain that is strong and interconnected in active, induced and entrepreneurial learning.

Implementation:

Participants

Participants consisted of 15 senior engineering college students at a moderately sized research university in the Midwest U.S (Wichita State University).

The selected projects were customized based on course learning outcomes. A dynamic, customized rubric is also used to empower learners to take more responsibilities for various decisions associated with the project and learning, to involve various activities such as self-guided reading and promote group discussion and participation.

Prepare and Augment Research-Oriented Projects

Selection of a project that covers all facets of ME Design II (ME 541) was the primary exercise to successfully demonstrate a PBLCAS methodology. The intent of this activity was to make sure that a large 'opportunity funnel' exists in the course where projects that relate to ME 541 are selected by the students. Currently, ME Department has students coming from different parts of the world. These students have different background and skills, however, these resources are not fully utilized. The students were briefed about semester-long projects and expected outcomes. Students were then trained to work on the same aspect of a learning problem at the same time. For example, if the course schedule 'shafts' as the learning topic for that particular time-period, homework, in-class exercises and exams will be assigned from the portion of the project related to shaft. To guide students through the project, a rubric system developed by Yihun (Yihun, Nair et al. 2016) was used. Through the project students learned to: (a) create the design envelop based on an industry-provided required document or statement, (b) outline explicit, significant, and assessable goals; 3) make creative ideas to solve the problem; (c) perform a patent/external search to corroborate the innovative nature of their ideas, (d) use a design matrix with evaluation criteria based on the goals/expected functionality, and, (e) perform an in-depth engineering analysis. The inclusion of a rigorous writing and presentation experience with critical feedback engaged students in a continuous reflection on the elements of the complete design process throughout the entire semester. All the student groups worked on the various facets of their respective projects with project topics aligning with the learning content for that particular period. These projects were designed to solve critical problems in the society. Figure 1 shows the project preparation modules.

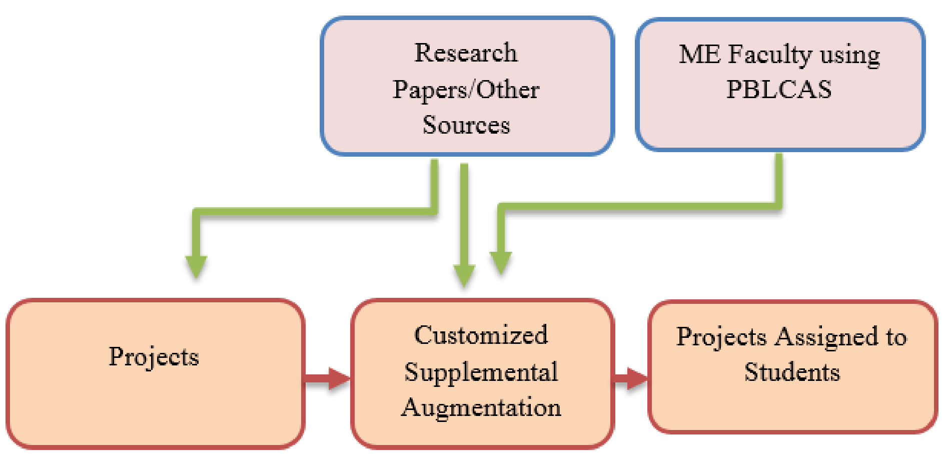

Figure 1. Preparation and Augmentation of Projects.

The projects (with additional tasks to accommodate interdisciplinary skill set) were provided to the students. CSA (customized supplemental augmentation) are also provided for those projects that lacked a particular topic that was part of the required learning for Machine Design. CSA ensured that all the projects done by various student groups were full, complete and encompassed. For example, a group that was working on a certain project did not need the services of using a belt-drive to formulate a solution. CSA of this particular group's shortcoming were to provide an enhanced problem solving technique by requiring them to find a solution to the problem by using a belt-drive, in addition to the required means of mechanical transmission. At the end of the semester, students gave an open presentation (with an invitation sent to all ME students) regarding their project, which would have potentially motivated junior and sophomore students. Figure 2 shows the general methodology of the proposed project.

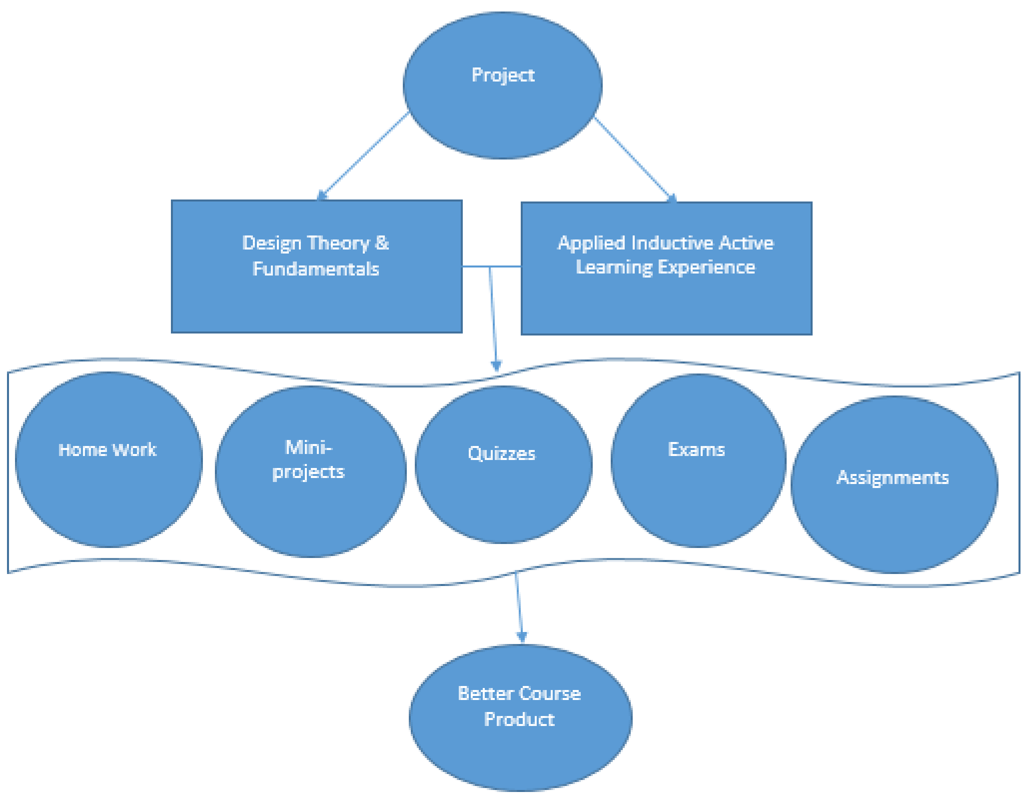

Figure 2. A PBLCAS Methodology.

As an example, a 'gear box design' project with different applications were given in the ME 541 course. The project was assigned at the start of the semester. In the course, following each lecture, the in-classroom examples, homework, quizzes and exams were provided and tied with this semester long project and the implementation was done through the following procedure.

1. The course objective and learning outcomes were clearly listed (figure 3). This helped to assess projects to comply with the course objective and make adjustments if necessary to address the learning objectives.
2. Considering the above course objectives and learning outcomes, a gear box design project was selected and provided to some students at the start of the semester with a set of data and expected tasks along with a rubric to empower learners to be responsible for various decisions associated with the project, to involve different activities such as self-guided reading and to promote group discussion and participation, as the projects were designed to accommodate ME 541 course contents that involve real machine components.
3. Other assessment methods such as classroom exercises, quizzes and exams were prepared and tied to the project to strengthen the course objective and learning outcomes.

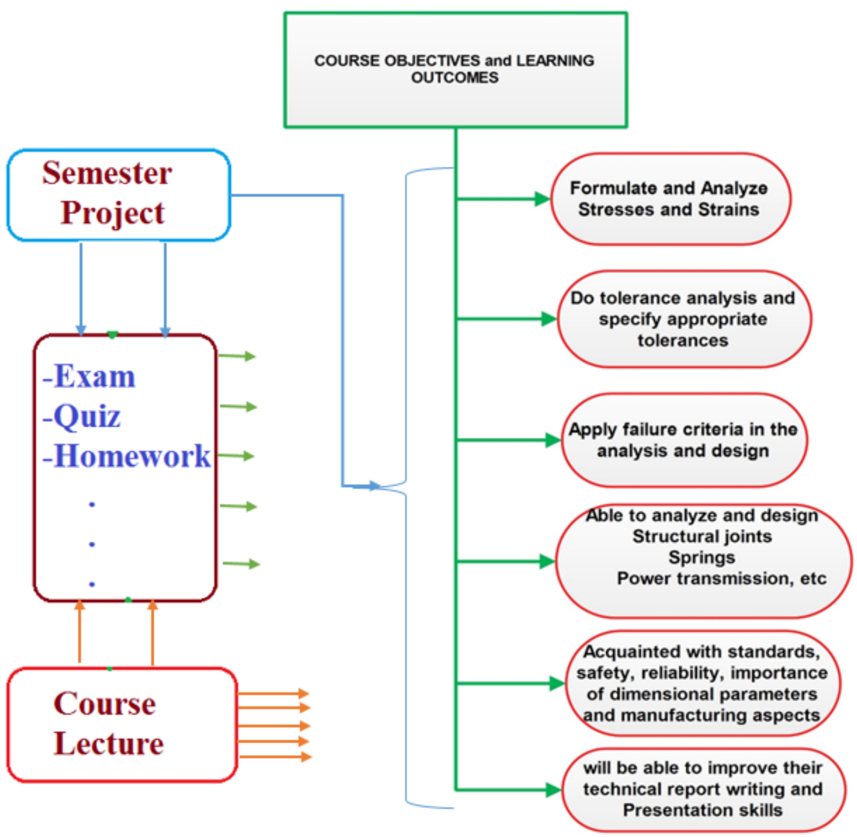

Figure 3. ME 541 Course Objectives/Learning Outcomes.

The PBL method with centralized assessment stream (CAS) helped students to grasp the content easily through practical considerations, for example, after covering stress analysis section, a homework problem is prepared as follows. "*A shaft usually carries power-transmitting components, such as gears, belt sheaves, or chain sprockets, which exert forces on the shaft in the transverse and radial directions. These transverse forces cause bending moments to be developed in the shaft, requiring analysis of the stress due to bending. Consider the intermediate/ input shaft of your gear box project, and provide the detail stress analysis due to bending.*" This way, the student had an opportunity to practice course content through their real project and get real-time feedback for their learning and project progress. The project's significance and importance lie in its emphasis on addressing both the motivational aspects to perform research-based projects and conceptual learning barriers for students in mechanical design courses. These courses demand a good understanding of mechanics and advanced mathematics that make it difficult for many students to capture concepts. Students have shown a greater interest towards this PBL method and tied assessment methods in meeting the course objectives and learning outcomes. It was found that this approach produces students who are better prepared for their senior design projects and engineering practice. Students noted an increase in their understanding of machine design concepts as an integration of all their prior preparatory training. The effectiveness of this method was evaluated through a survey. The Student Perception of Teaching Effectiveness (SPTE) result, based on 15 respondents is shown in figure 5, where response 1 means 'completely disagree' and response 5 is 'completely agree' and the rest falls in between. Majority of the students in the survey felt that semester-long projects were instrumental in meeting the course learning outcomes and paved the way for them to better appreciate course content. This motivated them to perform better and generate a sustained interest in the course towards the semester. We believe that this will also improve SDLR, motivation towards research and improved retention rate.

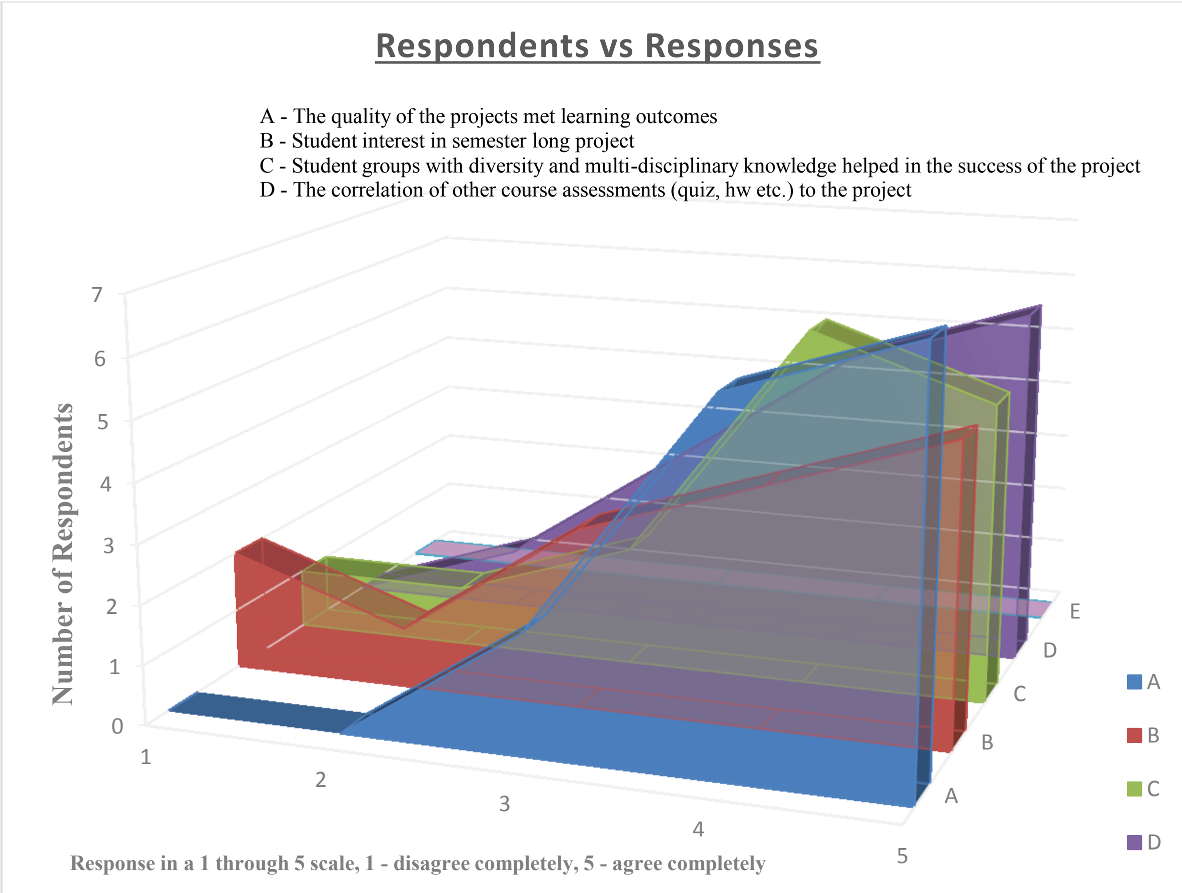

Figure 5. Student Perspective towards PBLCAS in ME 541.

In addition to the gear box project listed above, several semester long projects that are suitable for the Machine Design class are listed in table 1. These projects closely relate to material that are taught in Machine Design, and has components in it, that encompass the entire breadth of material taught in Machine Design.

Table 1. List of Semester-long Projects that are Geared towards Machine Design Class

#	**Project Title**
1	A powered Armature Coil Forming Machine
2	Paint Roller Cleaner
3	Fabrication of a Variable Drive Stand for DC Starter Generators
4	Flap System Skewed Roller In-line Brake Development
5	Cardboard Plug and Swaging Machine for Advanced Products Pipe Packaging Process

6	CNC Extrusion Trimming and Drilling Machine
7	Inverted Robotic Rail System Design and Implementation
8	Popcorn Sifting and Packaging Machine
9	Robotic Oceanic Anchoring System
10	NozePax Mass Production Machine

Conclusion:

The results of this study have given a clear indication that a more hands-on, active-induced learning, where semester-long projects are closely tied-up with course content by suitable rubrics and preparation, generate enthusiasm and the desire to learn among the students. This will promote higher knowledge-retention, self-induced learning, an even higher desire for undergraduate research and ultimately a well-prepared mechanical engineer. A more in-depth analysis is needed in order to increase our understanding of PBLCAS methodology and its implementation in ME design as well as other related courses. Future studies may incorporate measures of personality, in order to examine the existence of preference due to personality type of PBLCAS methodologies over traditional lecture based classes in ME design course. Qualitative data should be collected to determine if there is a negative perception for project-based classes among some students (based on personality types/course content). Also an educational psychology analysis where a side-by-side comparison of PBLCAS versus traditional lecture based ME design course that is taught at the same time has to be performed to generate better data towards a comprehensive educational comparison. The authors believe that such a semester-long project will work really well in classes in the junior and senior levels, especially where industry-generated projects are in question. For sophomore level classes, a semester-long industry project may not be viable as the student preparation and knowledge base may not be sufficient to substantiate and justify such a project. However, that doesn't preclude the possibility of trying out such a measure.

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