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Design-Build, Project-Based Learning in an Engineering Materials Laboratory

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Project-based learning (PBL) is an instructional method that engages students in projects for studying compelling problems. The method creates a flexible learning environment which can result in imparting thinking competencies. In this paper, the effects of incorporating design-build (DB) attributes into the PBL method in an engineering materials laboratory are presented. Traditionally, the laboratory had utilized conventional testers to measure the mechanical properties of materials such as the modules of elasticity, shear modulus, Poisson's ratio of variety of materials. In the DB-PBL approach, the student teams designed and built single-task testers to measure a specific property of materials. The assessment results indicate that students in addition to becoming problem solver, decision maker, and investigator that is typical of the PBL approach, also became innovators and gained machining skills because of the design-build attribute. Because the measurement of properties of materials are performed using the design-build testers, the students have expressed conviction on how and why their experience and gained skills were relevant. Also, the expressed learning outcomes in the laboratory were significantly improved compared with the past conventional laboratories.

Introduction

Project-based learning (PBL) is the educational method that incorporates student-centered projects for active learning and engagement in studying and solving convincing problems. William H. Kilpatrick, a pioneer of project method in education, described to the PBL strategy and its effectiveness as "*learning as wholehearted doing*" [1]. A critical enabler in the PBL and similar concepts such as discovery learning, learning-by-doing, and problem-based learning is the fact that such teaching techniques can exploit the curiosity and the sense of mastery and self-determination in students [2]. In a recent review, Thomas suggested some criteria for what a project must have to be considered an example of the PBL [3]. It was stated that PBL projects i) are central to the curriculum, ii) are focused on questions or problems that push students to encounter the central concepts, ii) involve students in a scientific inquiry, iv) are highly student-driven, and v) are realistic, not school-like. The realistic characteristic of the PBL project is especially important in engineering pedagogy where solving complex, real-world problems is the main priority. Also, the completion of the project in a determined time is important [4]. The complexity of the project necessitates group efforts and team work. There is overwhelming evidence that PBL methodologies with student centered, inquiry-based, active learning characteristics significantly help students to become self-directed learners who can apply sound higher-order thinking skills in solving real-world engineering problems [5-7].

Role of Design-Build (DB) in Learning

The design-build experience in engineering education is gaining popularity [8]. The activity can be used to train basic engineering and manufacturing skills, systems design and implementation. Also, through the process, the students gain experience in teamwork and communication. A key feature of the design-build projects is that they are being operationally verifiable and therefore can provide feedback for modification and improvements [9]. Two factors that greatly affect the success of the design-build projects in a construction setting are project team commitment and end user needs [10]. These two factors are satisfied in the educational setting because the students are assessed based on their progress in the project and the final product of the design-build project is used for testing by students.

Method and Results

In traditional Solid Mechanics Lab, commercially available tensile testing machines, torsion testers, impact testers and other machines are utilized to provide the required testing experience of the material properties that are expected in the mechanical engineering curriculum. The testing and the subsequent analysis and reporting have become routine. To stimulate the interest of the students for better engagement and learning outcomes, and to realize the power of innovative thinking an experiment of assigning design-build projects that ultimately allows students to measure the mechanical properties of metals in their own built testers has been conducted. Specifically, the following three design-build projects have been assigned to teams consisting of 3-4 students:

- Project 1: Design-build a tester for studying the axial load/displacement behavior of wire samples (modulus of elasticity, yield strength, ultimate strength, elongation at break, etc.)
- Project 2: Design-build a tester for studying the torque/twist behavior of rod samples (shear modulus, shear yield strength, etc.)
- Project 3: Design-build a tester for studying the load/deflection behavior of beam samples (modulus of elasticity, compound beams, etc.)

Each project was expected to be completed in five weeks. In the first two weeks, each team was instructed to carry out research, conceptualize, and define the specifications of their design in coordination with the instructor and the teaching assistant. After approval of the final designs by the instructor at the end of the second week, each team was assigned to start the manufacture and assembly of the tester. The students had access to a machine shop. Also, the machinist in the shop provided the required help in machining the required parts and elements that were used in the design testers. The raw materials such as wood and aluminum and steel parts were available to the teams. No additional budget was provided to the teams. As such, inclusion of elements that required additional cost was a constraint and it was discouraged.

The results of the first project are discussed in this paper. Student surveys and the measured mechanical properties of aluminum and copper samples are presented as assessment tools.

Student Surveys

The number of students who took two section of the Solid Mechanics Lab were 31 students in their Sophomore year. Approximately 22 students participated in a survey which included four-choice and descriptive questions. The questions were designed to access both the commonly known attributes of

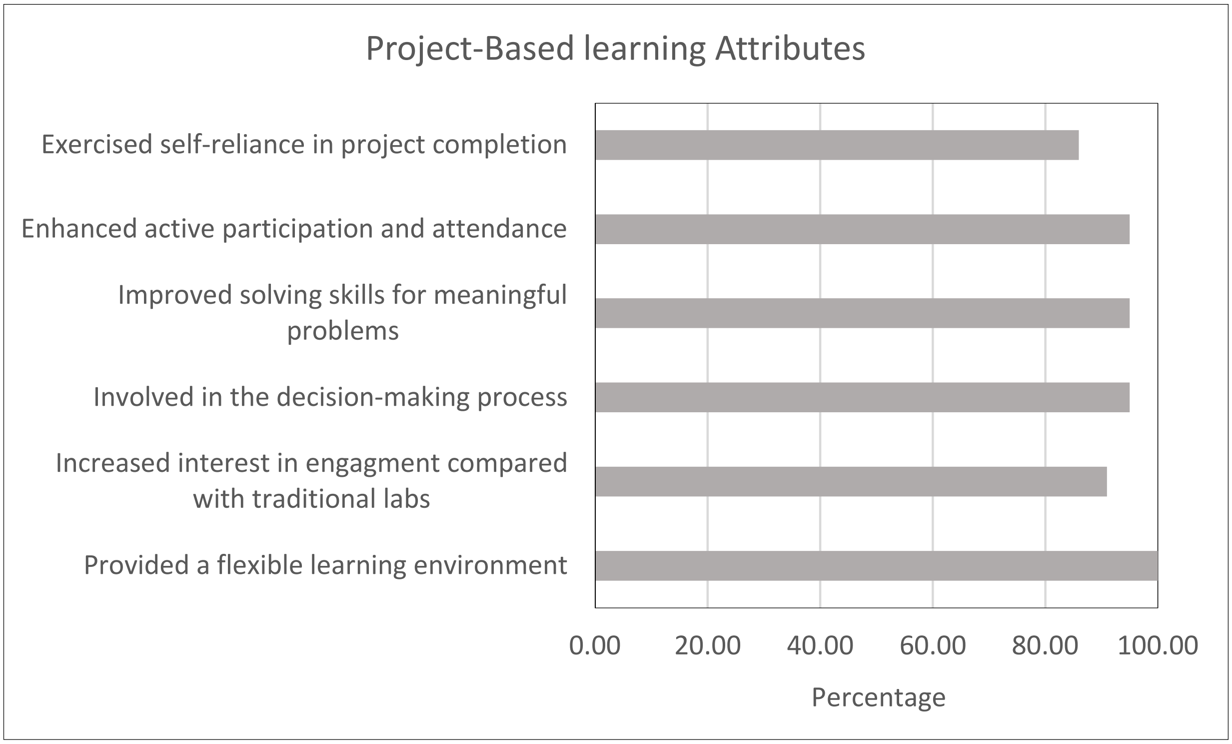


Fig. 1: PBL attributes in survey of 22 participants who strongly agreed or agreed to the questions

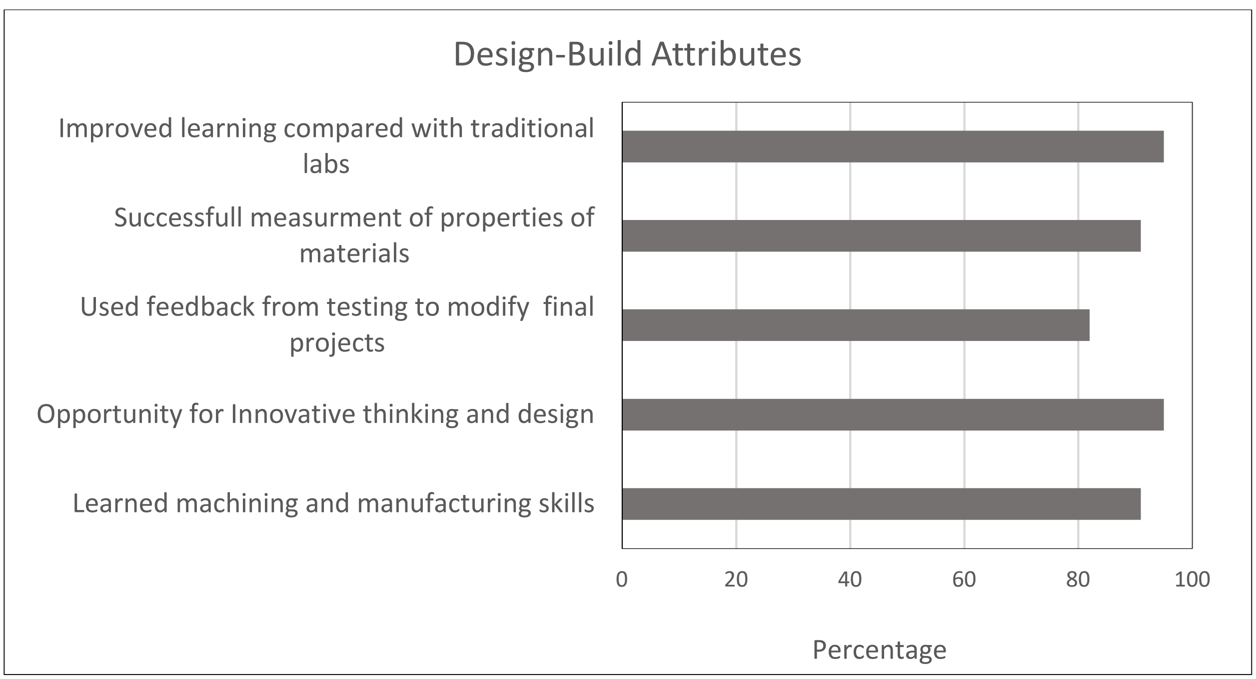


Fig. 2: DB attributes in survey of 22 participants who strongly agreed or agreed to the questions

the PBL approach, such as motivation, flexibility, Decision-making, problem solving, and anticipation and those of the design-build features such as gaining new skills, innovative design, and use of feedback from testing. Figure 1 shows the percentage of students who strongly agreed or agreed to the common project-based learning attributes. The flexible learning environment that is provided by the DB PBL is agreed upon by all participants. Figure 2 exhibits the percentage of students who strongly agreed or agreed to the design-build attributes. The learned machining skills, use of feedback from DB project for modification, and innovative design were among the attributes that the students agreed on.

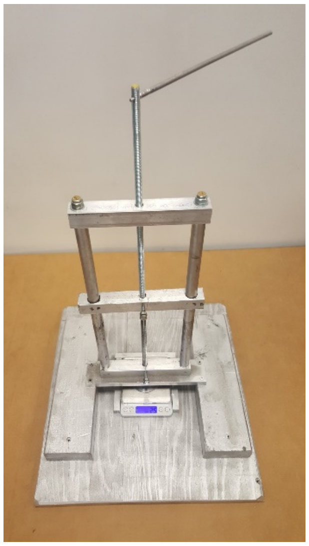
Overall, in descriptive questions, the three most referred to improved attributes by students were freedom in design and implementation, machining and manufacturing skills, and team work as shown in Table 1.

Table 1: Attributes of the DB, PBL stated in the descriptive section of the survey in order of the occurrence frequency (from top to the bottom)

	Attribute
Most liked by the students in the design-build approach	**Freedom in design and implementation** Hands-on experience Independent research Active learning
Most improved in the students by the design-build approach	**Machining and manufacturing skills** **Team work** Application of fundamentals Innovative thinking Visualization of designs

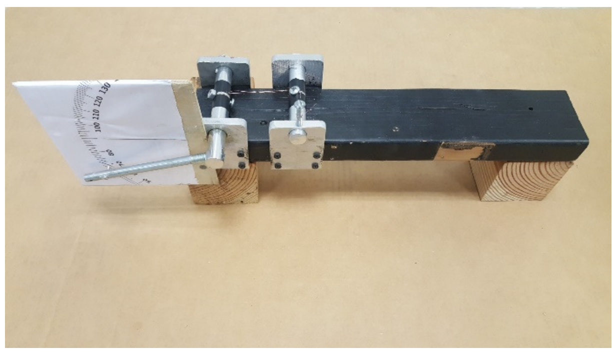
Measured Mechanical Properties

Several testers for studying the axial load/displacement behavior of wire samples are shown in Fig. 3. Two common features between them are displacement and axial load measurements. However, these features were implemented using various innovative designs.



(a)

(b)



(c)

(d)

Fig. 3: Testers using a digital balance as the load cell (a), a long wire for enhance displacement measurement (b), a rotational arm for small samples (c), and a bucket of water for small load increase increments (d)

The actual values of modulus of elasticity and tensile strength for aluminum and copper wires were obtained form he manufacturer and are listed in the tables 2-5. The most accurate modulus of elasticity measurement for aluminum has an error of approximately 16% as shown in Table 2. For copper, the least error in the measurement of modulus was approximately 57% as shown in Table 3.

Table 2: Measured modulus of elasticity of aluminum wires

Group	Measured E (psi)	Actual Value (psi)	error
G2	1.66E+07	1.00E+07	66.2%
G3	8.44E+06	1.00E+07	-15.6%
G4	2.70E+06	1.00E+07	-73.0%

Table 3: Measured modulus of elasticity of copper wires

Group	Measured E (psi)	Actual Value (psi)	error
G2	7.40E+06	1.70E+07	-56.5%
G3	2.17E+06	1.70E+07	-87.2%
G4	1.18E+06	1.70E+07	-93.1%

Table 4 and Table 5 show the measured tensile strength of aluminum and copper, respectively. The measurement of tensile strength yielded more accurate results for the aluminum wires.

Table 4: Measured tensile strength of aluminum wires

Group	Measured Tensile Strength (psi)	Actual Value (psi)	error
G1	12148.1	11000	10.4%
G3	13496.6	11000	22.7%
G5	4422.5	11000	-59.8%

Table 5: Measured tensile strength of copper wires

Group	Measured Tensile Strength (psi)	Actual Value (psi)	error
G3	38965.85	29000	34.4%
G2	36490.7	29000	25.8%
G1	5720.25	29000	-80.3%

Discussions

As the survey results indicated, the students described ***increased interest*** and ***improved overall learning*** as two important outcomes of the DB PBL, compared with the traditional laboratories. The increase of scientific curiosity and interest have been shown to be significant factors in engaging students which results in improved learning. The DB PBL can also be supplemented with the traditional lab experiences in materials science for a full range of advantages including expended knowledge. However, there are laboratories in engineering and science that the DB PRL approach may not work for. Such labs often require sophisticated instrumentations for measurements and analysis.

Throughout the DB PBL experience in Solid Mechanics Lab, the challenges of procurement of parts and materials were significant. As such advanced planning is critical. To not jeopardize the freedom of the students for a flexible leaning environment, it is a good idea to provide a budget for teams so that they can purchase certain specialized parts for adding more functionality and sophistication to their designs. Indeed, the no-additional cost constraint in Project 1 might have been a contributing factor in experiencing large errors in the measurement of the mechanical properties. The purchase of frictionless pulleys and conical chucks for handling the wire samples without creating stress concentration could have significantly added to the accuracy of the measurements. The teams have received feedback on their report, results, and specific suggestions that will be useful for their other design-build projects in the Solid Mechanics lab.

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