Design, Build, and Test Projects in an Engineering Materials Laboratory

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Abstract

A design, build, and test (DBT) approach for studying the mechanical behavior of materials in an engineering materials laboratory is shown to create a flexible learning environment which imparts thinking competencies. Traditionally, students have utilized conventional testers such as a universal testing machine for studying the stress-strain relationship and for measuring properties such as the modulus of elasticity and shear modulus. In the DBT approach, the student teams designed and built single-task devices and tested them for measuring specific mechanical properties. The surveys affirmed that student engagement, self-reliance, problem solving, and teamwork which are attributes of the project-based learning (PBL) method were improved. Additionally, innovative thinking in face of cost constraints and gaining manufacturing and assembly skills were enhanced because of the design and build activates. As the student teams advanced through the projects in the laboratory, the accuracy of measured properties compared with the nominal values notably increased.

Keywords: Design, Build, Test, Materials, Laboratory

Introduction

The design, build, and testing (DBT) method is a student-centered pedagogy which has increasingly been utilized in various learning environments[1-3]. The BDT approach is a form of project-based learning (PBL) educational method which is known to promote 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*"[4]. 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[5]. Thomas suggested that PBL projects have these characteristics; i) are central to the curriculum, ii) are focused on questions or problems that push students to encounter the central concepts, iii) involve students in a scientific inquiry, iv) are highly student-driven, and v) are realistic, not school-like. These requirements of the PBL projects are all met in the DBT approach in the engineering education. Also, the completion of the project in a determined time is important[6]. Furthermore, the complexity of the project necessitates group efforts and team work. There is evidence that PBL methodologies such as the DBT method with student centered, inquiry-based, active learning characteristics increase self-reliance in students who can apply sound higher-order thinking skills in solving real-world engineering problems [7-9].

The design-build activities in the DBT method can be utilized to train basic engineering and manufacturing skills, systems design and implementation[1]. 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[2]. 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 a traditional Solid Mechanics Lab, commercially available universal testing machines, torsion testers, impact testers and other instruments 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, and test projects that ultimately allows students to measure the mechanical properties of metals in their own built testers has been conducted. Specifically, the following two design-build projects were 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.)

Each project was expected to be completed in five weeks followed by a week of testing, demonstration, instructor feedback, and final reporting. There were three distinct phases for each project.

Problem Statement, Conceptualization, and Specifications Phase

A written problem statement for the student teams was followed by in-lab lecture to clearly identify the goals of a project, available resources such as raw materials and technician availability, constraints, the timeline, and the expected deliverables. The problem statement included the materials property to be measured and the size and shape of the test samples. Also, the theoretical background for the assigned project with reference to the textbook was reviewed. In the following two weeks, each team was expected to carry out research, conceptualize, and define the specifications of their design of a tester to measure the required property of the test samples. The teams received in-class mentoring and guidance in refining concepts and defining specifications. At the end of the two-week period, the students were required to present their design and specifications for approval by the instructor.

Build Phase

In this phase, the teams utilized the machine shop under the supervision of the shop supervisor for manufacturing the parts for their testers. The raw materials such as wood, aluminum and steel elements and other basic components such as nuts and bolts were available to the teams. No additional budget was provided to the teams. However, in some cases the teams salvaged parts such as pulleys, gears, and hinges from unusable mechanical devices. Assembling the parts into the final form of the tester was performed under the supervision of the shop supervisor and the teaching assistant for the lab.

Property Measurement and Reporting Phase

The fine turning of the testers for measuring the properties of materials such as modulus of elasticity, shear modulus, and Poisson's ratio was performed in this stage. When the team felt comfortable with the obtained results with trail samples, they tested the actual test samples for the final measurement. The analysis of the data and the calculation of desired properties based on the gathered data were presented in the team's final report.

Feedback Intermission

After the completion of the Project 1, due to the large errors in the measured properties compared with the specification values, a feedback session was convened. In the session, the shortcomings and limitation of projects were analyzed. Also, some common sources of errors in the measurement of displacement, load, and dimeter of the wire specimens in Project 1 were discussed. The adverse role of designs that may cause stress concentration which affects the load-displacement behavior of samples addressed.

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

Student Surveys

The number of students who took two sections of the Solid Mechanics Lab were 31 students in their Sophomore year. Approximately 22 and 28 students participated in surveys following Project 1 and project 2, respectively. The surveys included four-choice and descriptive questions. The questions were designed to access both the commonly known attributes of the PBL approach, such as motivation, flexibility, decision-making, problem solving, and anticipation and those of the DBT features such as gaining new skills, innovative design, and use of feedback from testing.

Figures 1 and 2 show the percentage of students who *strongly agreed* or *agreed* to the questioned attributes after the completion of Project 1 and Project 2, respectively. In both projects, 100% of participants agreed that the DBT experience provided a flexible learning environment. These figures also show that more students strongly agreed or agreed that the DBT experience had helped them in innovative thinking and decision-making process after the completion of Project 2.

In descriptive questions, the *most liked* and the *most improved* attributes by students were questioned. The results of the descriptive questions in order of the occurrence frequency are shown in Table 1.

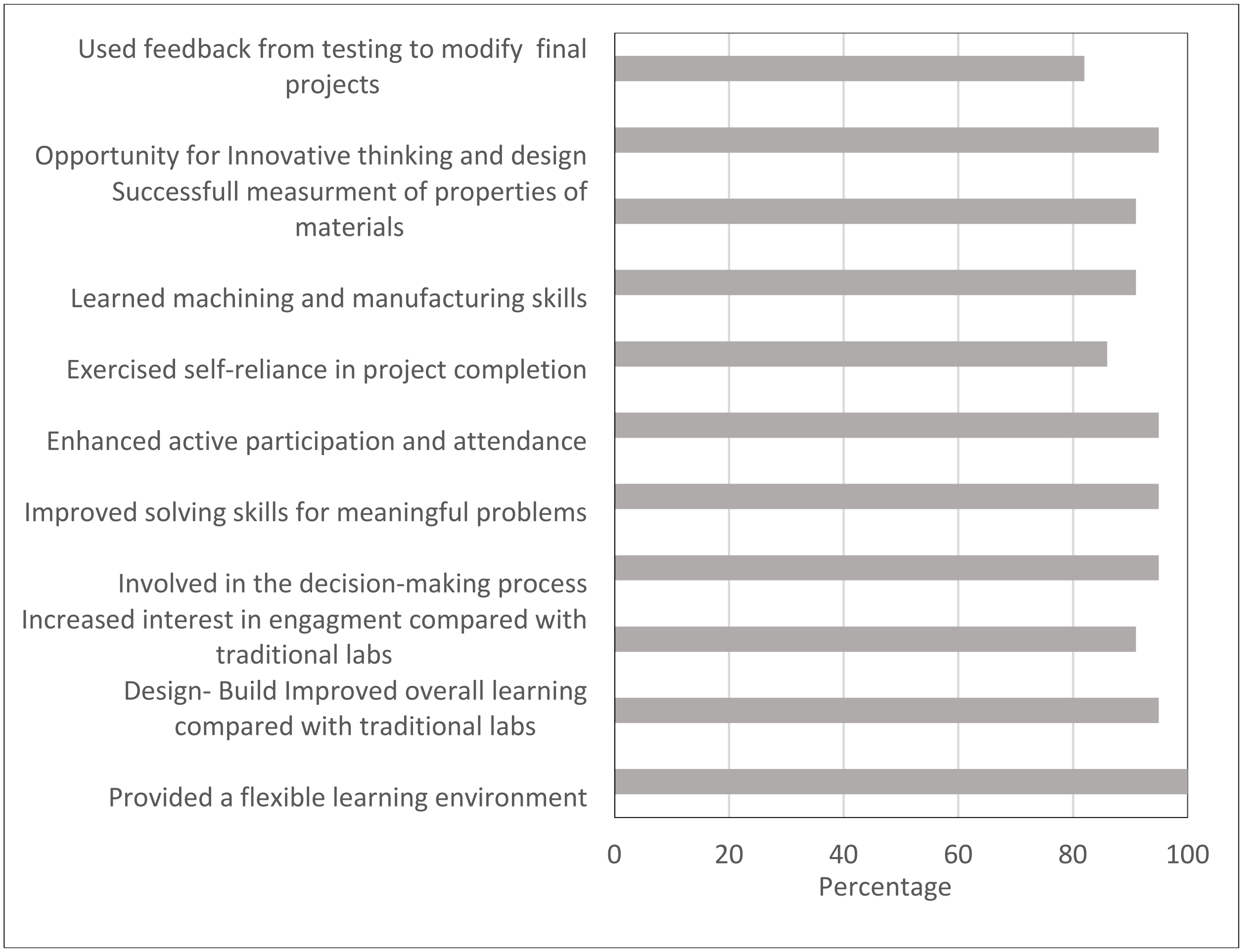


Figure 1: Attributes in survey of 22 participants who strongly agreed or agreed to the questions for Project 1 (Tensile test)

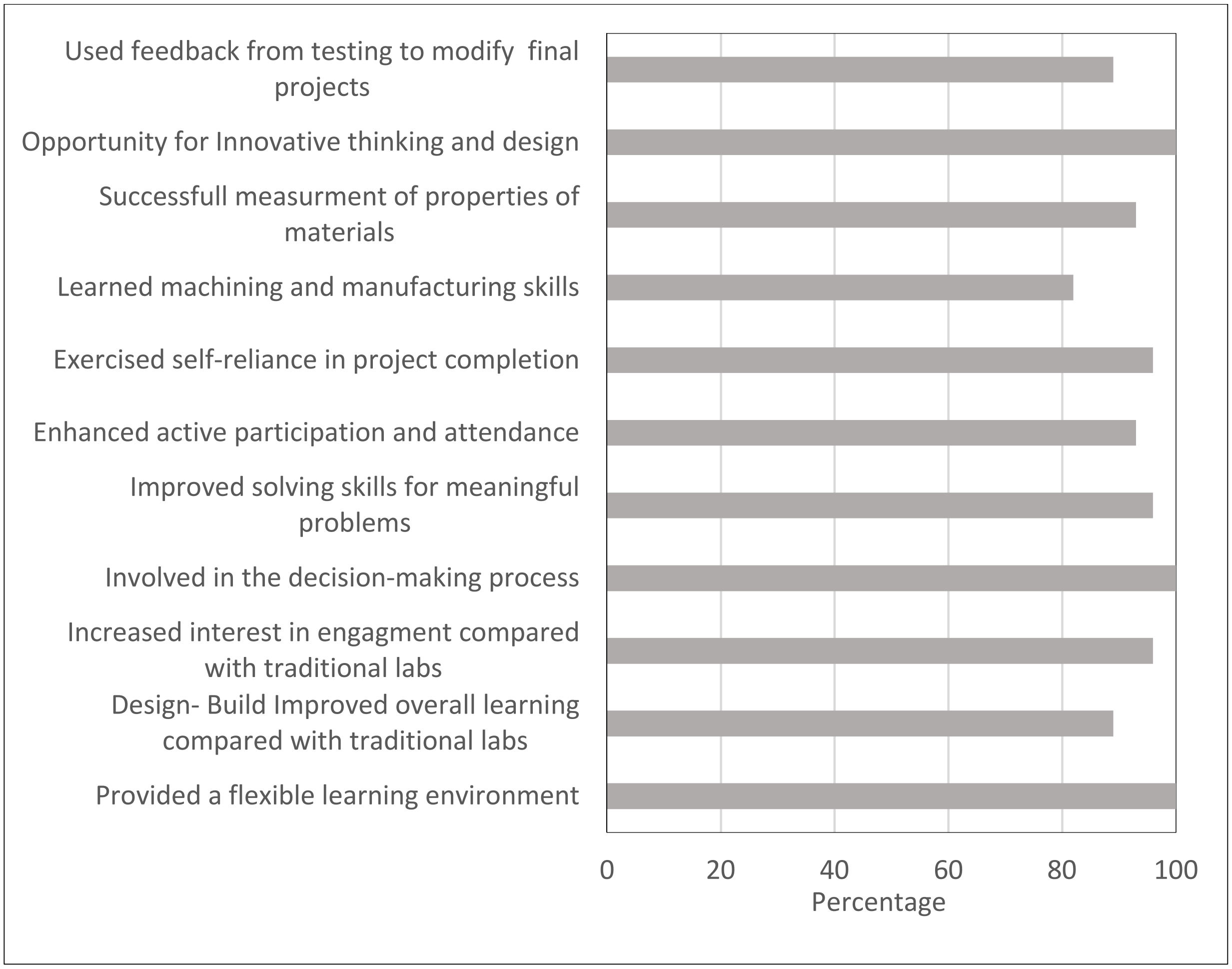


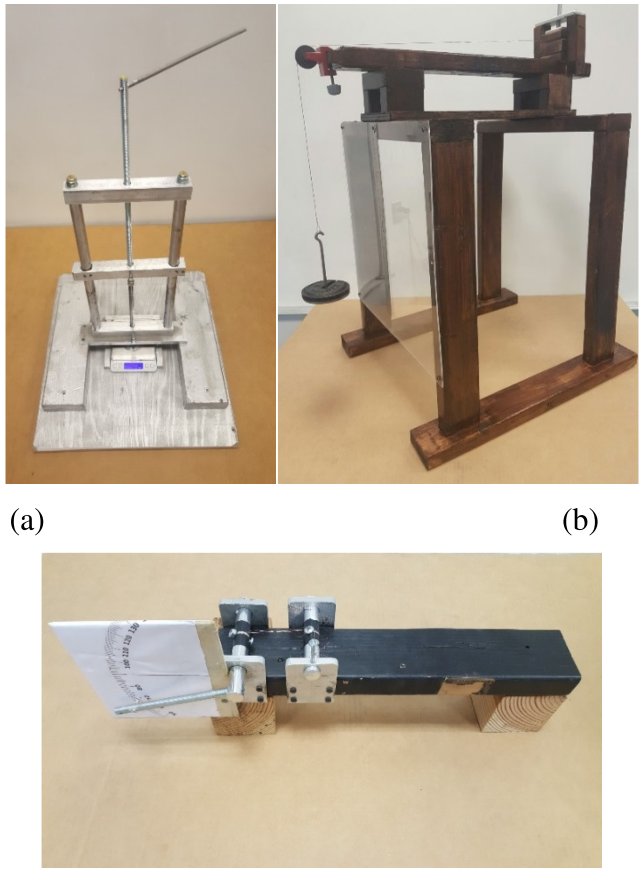
Figure 2: Attributes in survey of 28 participants who strongly agreed or agreed to the questions for Project 2 (Torsion test)

Table 1: The most liked and the most improved attributes obtained from the descriptive questions of the surveys in order of the occurrence frequency (from top to the bottom)

	Attribute
Most **liked** by the students	Freedom in design and implementation
	Hands-on experience
	Independent research
	Active learning
	Exercising of engineering knowledge
	Building something from scratch
	Creative thinking
Most **improved** in the students	Machining and manufacturing skills
	Team work and Leadership
	Application of fundamentals
	Innovative thinking
	Visualization of designs
	Breaking down of complex problems into simple components
	Improvising
	Brainstorming
	Communication
	Project management / Time management

Project 1: Tensile Test

Three developed testers for studying the axial load/displacement behavior of wire samples are shown in Fig. 3. Two common features amongst them are the means of measurement of the displacement and the axial load. However, these features were implemented using three distinct innovative designs as described in the Fig. 3.



(a) (b)

(c)

Figure 3: Testers for determining the modulus of elasticity of wire samples using a digital balance as the load cell (a), a long wire for augmented displacement measurement (b), a rotational arm for small samples (c)

The specifications value of modulus of elasticity for aluminum and copper wires were obtained from the manufacturer and are listed in the tables 2 and 3. The most accurate modulus of elasticity measurement for aluminum based on the displacement-load charts 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 wire

Group	Measured E (10^6 psi)	Specifications Value (10^6 psi)	error
G2	16.6	10	66.2%
G3	8.44	10	-15.6%
G4	2.70	10	-73.0%

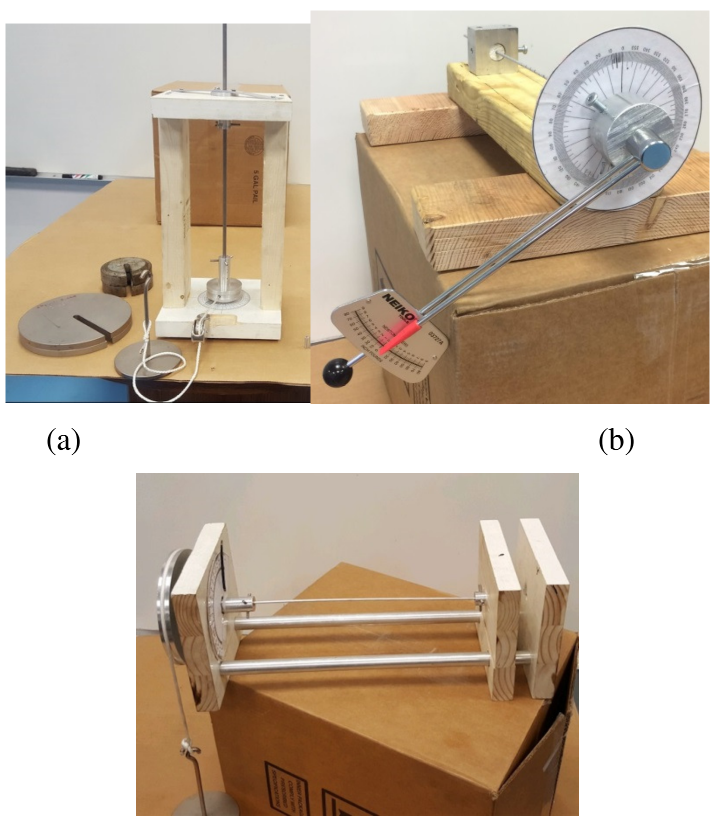
Table 3: Measured modulus of elasticity of copper wire

Group	Measured E (10^6 psi)	Specifications Value (10^6 psi)	error
G2	7.40	17	-56.5%
G3	2.17	17	-87.2%
G4	1.18	17	-93.1%

Project 2: Torsion Test

Three developed testers for studying the behavior of aluminum and steel wires subjected to torsion are shown in Fig. 4. The common feature amongst them is the measurement of the twist angle measurement. However, the measurement of the applied torque was performed either by applying a load to a rope over a pulley or using a torquemeter as shown in Fig. 4.

The experimentally calculated values of the shear modulus for aluminum and steel wires based on the measured twist angle-torque measurements are listed in the Tables 4 and 5, respectively. The specifications values of the shear modulus form the manufacturer are also provided in the Tables. The most accurate shear modulus measurement for aluminum and steel rods has an error of approximately 5% as shown in Tables 4 and 5.



(a) (b)

(c)

Figure 4: Testers for determining the shear modulus of rod samples using a rope-pully for load application in a vertical arrangement (a), a torquemeter for measuring torque in a horizontal arrangement (b), and a rope-pully for load application in a vertical arrangement with an adjustable sample length design (c).

Table 4: Measured shear modulus of aluminum rod

Group	Measured G (10^6 psi)	Specifications Value (10^6 psi)	error
G2	4.30	3.9	10.26%
G3	4.09	3.9	4.87%
G4	4.73	3.9	21.28%

Table 5: Measured shear modulus of steel rod

Group	Measured G (10^6 psi)	Specifications Value (10^6 psi)	error
G2	7.06	11	-35.82%
G3	10.4	11	-5.45%
G4	10.09	11	-8.27%

Discussions

As the survey results indicated, 100% of students affirmatively agreed that the DBT provided a flexible learning environment, involved them in the decision-making process, and provided the opportunity for innovative thinking. The surveys also point to the fact that the DBT approach resulted in an increased interest and improved overall learning compared with the traditional laboratories. The increase of scientific curiosity and interest has been shown to be significant factors in engaging students which results in improved learning. The DBT method can be supplemented with the traditional lab experiences in materials science for a full range of advantages including familiarity with modern instrumentations and data acquisition systems. However, there are laboratories in engineering and science that the DBT approach may not work. Such labs often require sophisticated instrumentations for measurements and analysis.

The feedback session after the completion of Project 1 proved to play a critical role in helping the teams in developing better designs and testers in Project 2. The minimum error in the measurement of modulus of elasticity of aluminum in Project 1 was 16%. For project 2, the minimum error in the measurement of the shear modulus in project 2 was 5%. On the other hand, the maximum error in the measurement of modulus of elasticity and shear modulus of aluminum in Project 1 and Project 2 were 73% and 21%, respectively. The feedback session identified factors that helped student teams increase the repeatability and robustness of their testers and yielded a greater measurement accuracy.

Throughout the DBT experience in the Solid Mechanics Lab, obtaining of some parts and materials proved to be challenging, as the students were tempted to utilize sophisticated subsystems and components in the design. As such, the advanced planning is critical. To further enhance the flexible leaning environment in the DBT approach, 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.

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