Leveraging Cost-Effective Custom Tensile Testing Apparatus for Improved Understanding of Stress and Strain Principles

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***Abstract*—We propose an innovative approach using affordable and easy-to-assemble test kits to enhance hands-on learning experiences in materials and manufacturing education. The paper addresses the common challenge faced by mechanical engineering departments in obtaining expensive lab equipment. By developing significantly cheaper yet effective test kits, our aim is to provide students with practical experience in experimental methodology, assembly, and problem-solving with the equipment.**

Our solution showcases the design of safe, easy-to-assemble, and reliable test kits that could be used in multiple experiments. These kits are orders of magnitude cheaper than standard equipment, costing only two to three hundred dollars compared to tens of thousands. While they may lack extra high accuracy, they still excel in achieving desired student learning outcomes. These kits rely on easy-to-make, open-source codes, and/or inexpensive off-the-shelf components. We developed and tested two kits through two design iterations: a personal universal testing machine and a personal foundry. Each kit allows students to run 2-3 experiments, providing them with the opportunity to experience assembly and full system integration for force, energy, mass, and information flows.

Student surveys were conducted to understand their self-reported response to the effectiveness of these kits in achieving learning goals. More than 60% of students consistently reported that the kit gave them command over experimental methodology, assembly of pieces, resolution of issues with the test equipment, and conducting experiments with just a manual. While initially challenging for some students, overcoming these hurdles improved their understanding of experimental methodology and tension testing equipment design. This contrasts with conventional lab experiments where students often follow set protocols without needing to understand equipment workings. The hands-on nature of the kits not only increased student engagement but also fostered a sense of ownership and investment in the learning process. Some students expressed a desire to test their own designed items, indicating deeper engagement and interest. Overall, the findings suggest that the test kits offer a unique set of learning opportunities by providing students with an unguided build, study, and report challenge.

Keywords—Stress; Strain; Tensile Test; Student Kits

I. BACKGROUND

In a more recent publication [1], the current authors presented innovative lab kits. More details on these kits are provided for two families of mechanical engineering kits: namely a personal universal testing machine and a personal foundry. These kits are meant to serve two goals: (1) introducing knowledge to the students, (2) motivation and real-world experience ones [2]. Faculty use labs and demonstrations as a vital tool in motivating students to learn. Using such kits and tools will improve the student motivation and perception of their learning experiences [3-6]. Kirkpatrick et al. [7] recommend having more industry relevant experiences as part of their 2030 ASME's vision. Traditional laboratories turn-key solutions fail in expanding students' skill set into assembly and system integration. Having inexpensive kits introduces a way of enriching the student experience by adding more learning opportunities using less structured laboratory experiences. This paper demonstrates how using one of these kits, namely the personal universal testing machine, enhances the possibility of adding to the students' learning.

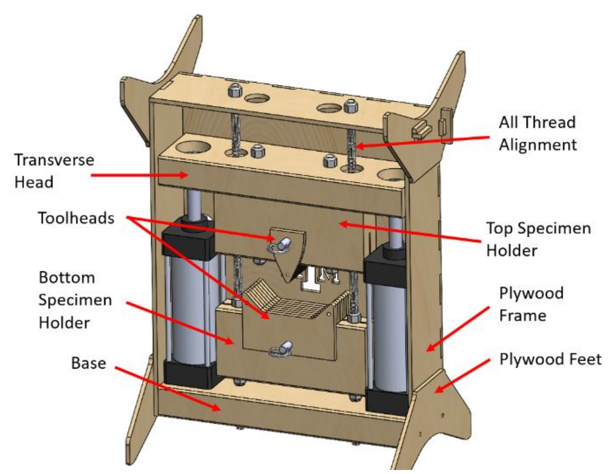


Fig. 1. Personal Unitersal Testing Machine (PUTM) kit used in this Paper.

For the current paper we have put together five personal PUTM kits. These kits were provided to students in a strength of material class. None of the students had any previous experience with tensile testing. They were tasked with assembling these kits, doing the calibrations, and testing it for three polymer types. Figure 2 shows some of the student pre and post assembled kits. The following sections provide details of the assessment methodology with the results obtained from the latest implementation. These results discuss both qualitative and quantitative aspects of the students' feedback.

Fig. 2. Implementation examples PUTM.

II. Assessement Methodology

A. Data collection

Students were asked to fill in a survey after they have completed the task of assembly, calibration and testing using the provided kits. The course introduces the theoretical background of the stress-strain curves as usually done at the beginning of strength of materials courses. The course does not have an experimental part nor a lab that is associated with it. This course serves as a prerequisite for other courses that will have a material characterization component to it including a tensile test. Table I includes the self-reflection survey questions that have been used. These questions are answered on a 1-5 scale. The questions were grouped into three categories, namely: how to conduct experiments, how to analyze the data, and how they understand the experiment. These categories are shown in Table I. Then there were 2 short questions (Table II - Q1 and Q2) asked to judge students' understanding of the experimental process. Students were also asked to describe their experiences using 3 adjectives, analyzed in section II.C.

Survey data was collected from 90 students. The collected data was analyzed in two directions: (1) qualitative and (2) quantitative. The first was done after going through the feedback from answers to questions in Table II. This was included in word clouds and modal responses utilizing a large language model (ChatGPT) tools to minimize the analysis time. Some sample comments are also introduced as representative student feedback. The second direction includes the question-by-question student feedback and category responses as grouped in Table I. The following section introduces the details of these results.

TABLE I. Self Reflection Survey questions

Self-reflection questions (Scale 1-5) **Q format: How confident are you …**		
Q No.	***Question***	***Category***
1	… to assemble mechanical systems from parts with only an end goal?	C1. Operation
2	… to resolve Assembly issues in the Tensile Testing Equipment?	
3	… on your command over how tension experiment needs to be conducted?	
4	… in calculating stress and strain from data?	C2. Data Analysis
5	… in generating the stress-strain curves for a given material?	
6	… in understanding the design in a Mechanical Testing Equipment?	C3. Understand Experiment
7	… in understanding how to read Technical Manuals?	
1: Unconfident, 2: Slightly Confident, 3: Moderately Confident 4: Really Confident, 5: Extremely Confident		

III. Results and Discussions

A. Short-answer Word Clouds

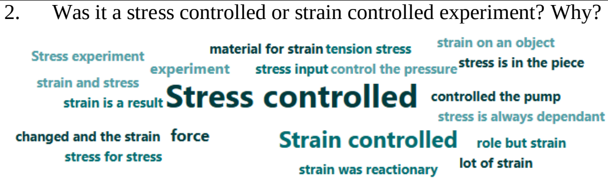
The collected answers were analyzed using a large language model (ChatGPT), the word count was a first pass to see which ones were more frequently used by the students. Table II presents the word clouds compiled for each question.

TABLE II. Deeper understanding:Word clouds short answer survey questions

Short-answer Word Clouds

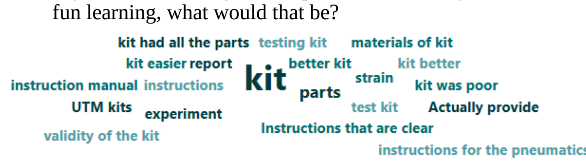
1. How is stress measured in a Tensile Experiment?

2. Was it a stress controlled or strain controlled experiment? Why?



3. In three adjectives describe your experience with the Personal Tensile Tester. (e.g. Fun, Boring, Difficult...)

4. If you want to change one aspect in this activity to make it more fun learning, what would that be?



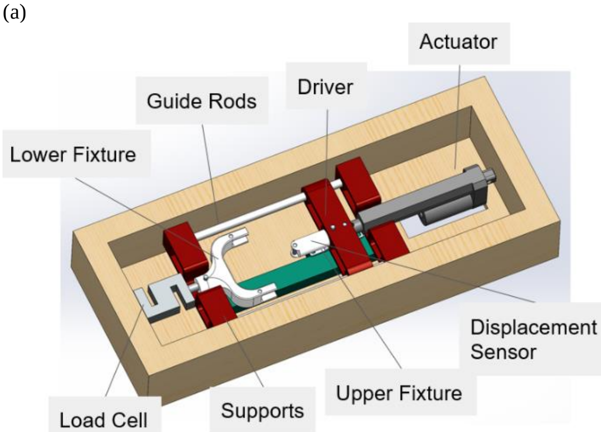
As presented in Table II- question.1 word cloud, the components of measuring the stress were clearly identified. The students had identified the force, sectional area, and the need to divide these to get the force. Students also recognized that for this setup the force is related to the pressure in the used pneumatic cylinder. This reflects the basic level of their understanding of the experiment.

The word cloud for the second question in Table II highlights both stress-controlled and strain-controlled as the most frequently used statements by students. Although the cloud shows that the largest was the stress-controlled, which is the correct answer, and upon more scrutiny this was not necessarily an obvious choice. This reflects that students were not that clear on the answer. Although this may not be a positive point, this was their first encounter with this type of testing which provided them with an awareness that would be utilized in the subsequent courses with material characterization experiments.

The third question in Table II shows the word cloud for the adjectives used by the students. This was meant to check on their engagement with the current approach. The two most used words were: Fun and difficult. Although the initial thought was that these may not necessarily be contradictory adjectives nor can they be used to gage the engagement of the lack thereof, respectively. Further manual analysis is needed to have a better feel for their engagement. More details are introduced in the following section to have a better understanding of this issue.

The answers to the fourth question in Table II showed a wide range of issues and suggestions with the kit they used. Students clearly were having issues with lower part quality and the provided instructions. One aspect that is worth mentioning is their ability to identify the lack of an obvious way to measure strain. This reflects a good handle of what needs to happen in such a lab experiment. The students had confirmed the authors ad hoc and initial feedback upon finishing the used kit design. The authors had presented another alternative [1] that would replace the kit used in this paper. The new design is shown in Fig.3.

(a)



(b)

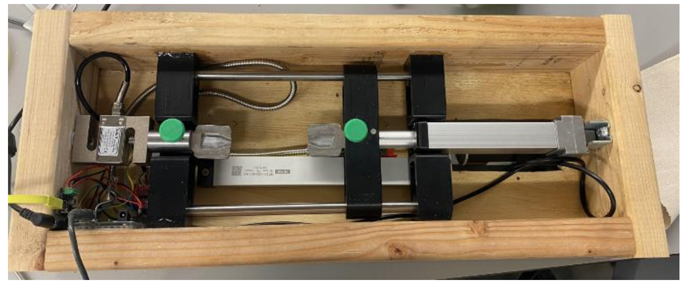


Fig. 3. Model 2 PUTM design (a) for 3-point bending setup and (b) Tensile testing [1].

B. *Quntitative Analysis of Self – Reflection Questions*

As presented in Table I, the self - reflection questions were grouped into three categories, namely: *C1. Operation*, *C2. Data Analysis*, and *C3. Understand Experiment*. Each of these categories and its sub questions represented next.

Fig. 4 depicts the answers and percentages of questions 1-3 from Table II. The sum of "*really confident*" and "*extremely confident*" levels for each question was 60% or higher. The percentage of the whole category, *C1*, boxed in the figure, was higher than 60%. This represents a good confidence level achieved by the students.

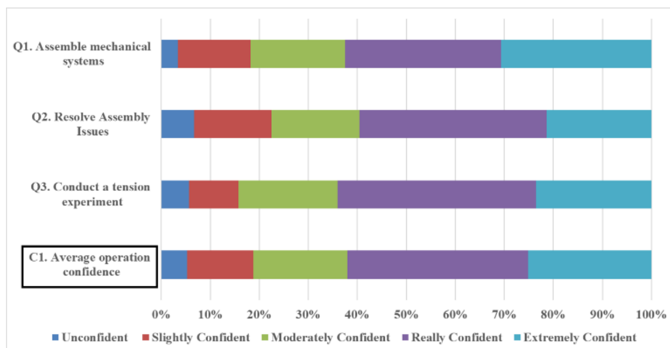


Fig. 4. Self-reported confidence levels in operation of the equipment. Average operation confidendce is average of the data within the category.

Fig. 5 shows the answers and percentages of questions 4 and 5 from Table II. The sum of "*really confident*" and "*extremely confident*" levels for each question was also 60% or higher. The percentage of the whole category, *C2,* boxed in the figure, was higher than 50%. The "*moderately confident*" level was more than 25%. The lower percentage of their confidence was reflected in the answers to question 2 in Table II. This represents a fair confidence level achieved by the students with room for improvement.

Fig. 6 shows the answers and percentages of questions 6 and 7 from Table II. The sum of "*really confident*" and "*extremely confident*" levels for each question was also 65% or higher. The percentage of the whole category, *C3,* boxed in the figure, was higher than 50%. This represents a particularly good confidence level achieved by the students.

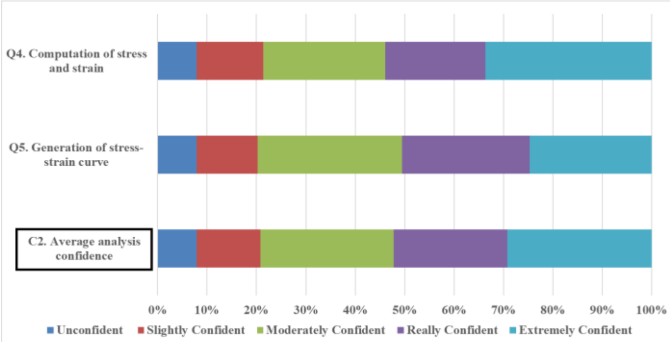


Fig. 5. Self-reported confidence levels in data analysis. Average analysis confidendce is average of the data within the category.

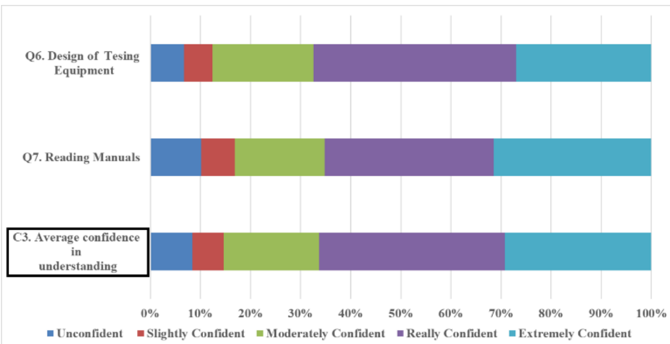


Fig. 6. Self-reported confidence levels in understanding the experimental process. Average confidendce in understanding is average of the data within the category.

Student self-reported confidence levels consistently reported that the kit gave them command over experimental methodology, assembly of pieces, resolution of issues with the test equipment, and conducting experiments. While initially challenging for some students, they managed to overcome these hurdles and improved their understanding of experimental methodology and the tension testing equipment design.

C. Sentiment Analysis of Adjectives Describing the Activity

As discussed in section II.A, students were instructed to describe their experience of the activity (Q3 in Table II) using only three adjectives with examples as, "Fun," "Difficult," and "Boring," representing categories of positive and engaging, negative but engaging, and not engaging, respectively. A sample response received was, “Fun, stressful, exciting". The purpose was to capture a broad spectrum of emotional responses from the students. We received 130 adjectives from the overall feedback from students (not all students responded with 3 adjectives). Using a large language model (ChatGPT), the students' adjectives were classified into these three predefined categories to facilitate a deeper understanding of their reactions to the activity. The detailed analysis of these responses is summarized in Table III, which also includes selected examples of the adjectives provided by the students.

When we separated the adjectives from the responses and bind them into various categories, it was observed that 36% of the overall adjectives given by the students fell into the positive and engaging category. Meanwhile, 47% of the responses were negative but engaging, and 17% were from not engaging category.

Despite the high proportion of responses deemed negative, further scrutiny revealed significant insights. We observed that 45% of the responses had at least one positive and engaging adjective. And within these, 77% contained a negative but engaging adjective as well (like the sample response). This increased the overall percentage of negative adjectives. This duality suggests that while students found aspects of the activity challenging, these challenges did not diminish their overall engagement. The activity involved assembling an inaccurate setup, which many students found confusing and difficult. This complexity appears to have had a significant pedagogical advantage. Although students encountered difficulties, they did not describe the project as boring or disengaging. In fact, the challenging nature of the task enhanced their engagement. Moreover, this difficulty contributed to a positive outcome, as many students reported an increase in confidence upon completing the activity.

TABLE III. SENTIMENT ANALYSIS OF ADJECTIVES DESCRIBING THE ACTIVITY

Sentiment of Response	Top Adjectives used	Percentage of responses
Positive and Enganging	**Fun**, interesting, engaging, insightful, cool, exciting, fine, prospering, satisfactory, intuitive, good, great, helpful, simple	36%
Negative but Engaging	**Difficult**, confusing, frustrating, faulty, annoying, horrible, rough, problematic	47%
Not engaging	**Boring**, tedious, unorganized, garbage, incomplete, discombobulating, chaotic	17%

The analysis reveals that the activity was effective in maintaining student engagement despite its challenges. The students' responses indicate that the confusing and difficult aspects of the activity did not lead to disengagement but rather encouraged perseverance and a sense of accomplishment. The task's challenging nature, coupled with the need to overcome difficulties, seems to have fostered a positive learning experience. This suggests that the activity not only engaged students but also contributed to their confidence and sense of achievement, highlighting its educational value.

IV. CONCLUSIONS

An innovative approach using affordable and easy-to-assemble test kits to enhance hands-on learning experiences in materials and manufacturing education. The cheaper yet effective test kits provided students with practical experience in experimental methodology, assembly, and problem-solving with the equipment. Student surveys were conducted to understand their self-reported response to the effectiveness of these kits in achieving learning goals. More than 60% of students consistently reported that the kit gave them command over experimental methodology, assembly of pieces, resolution of issues with the test equipment, and conducting experiments. This included overcoming hurdles improving students’ understanding of experimental methodology and tension testing equipment design. The hands-on nature of the kits not only increased student engagement but also fostered a sense of ownership and investment in the learning process. Students expressed engagement and interest even when they described it as difficult or rough. Overall, the findings suggest that the test kits offer a unique set of learning opportunities by providing students with an unguided build, study, and report challenge.

Acknowledgment

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References

[1] S. Balawi, N. Thomas, and A.R. Srinivasa, "An Inexpensive Alternative to Materials Lab Turnkey Expensive Systems: A Less is More Story!," in 2023 IEEE Frontiers in Education Conference (FIE), College Station, TX, USA, 2023 pp. 1-4. doi: 10.1109/FIE58773.2023.10343041.

[2] P. Wankat and F.S. Oreovicz, *Teaching Engineering*, New York, McGraw-Hill, 1993.

[3] S. S. Moor, and P. R. Piergiovanni (2004) "Inductive learning in process control." ASEE Annual Conference and Exposition Proceedings. Paper 563.

[4] K. Khalaf, S. Balawi, G.W. Hitt, and M.M. Siddiqi, “Engineering Design Education: Effect of Mode of Delivery”, International Journal of Engineering Pedagogy (iJEP), Volume 3, pp 46 (2013).

[5] S. Balawi, M. Al-Jarrah, “Simulations versus Hands-on Projects’ Effect on Students’ Inclinations towards Engineering and Technology Education,” 2010 INTED International Technology, Education and Development Conference (INTED2010), 8- 10 March, 2010, Valencia, Spain.

[6] K. Khalaf, S. Balawi, G. W. Hitt, and A. Radaideh, “Engineering Design Education: When, What, and How”, Advances in Engineering Education, Vol 3, issue 3(2013).

[7] A. T. Kirkpatrick, R. O. Warrington, R. N. Smith, K. A. Thole, W. J. Wepfer, and T. Perry, "Vision 2030 - Creating the Future of Mechanical Engineering Education," American Society for Engineering Education, 2011.