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Creating Statics and Solid Mechanics Lab Experiences from Open-Ended Design Briefs

Dr. Kathryn Hasz, Carthage College

Dr. Hasz is an Assistant Professor of Engineering at Carthage College. She is involved in the development of the new Engineering BA and BS programs at the college.

Work in Progress: Creating Statics and Solid Mechanics Lab Experiences from Open-Ended Design Briefs

Abstract

Laboratory classes provide students with an opportunity to take the theory learned in class and apply it to an experiment. However, many lab experiments are still divorced from what work looks like as an engineer. To encourage student engagement with engineering technical content in a realistic manner, a set of laboratories is in development for a sequence of two courses covering statics, solid mechanics, and material properties. These courses are part of a non-disciplinary engineering program and start second semester sophomore year and continue through first semester junior year. The labs are inquiry-based and meant to be completed in one to two 100-minute lab periods, providing students with multiple distinct problems to address throughout the courses.

The labs are motivated by design briefs providing a real-world problem. Students must apply the content learned in class to design an experiment to address the design brief. In addition to solving the problem, students must ensure their solution is realistic through considerations of costs, safety, and regulations. Students then write a memo, design report, or white paper as their lab assessment. They report both their technical results, individual interpretations, and recommendations based on the results.

Early labs in the sequence contain significant scaffolding for students through guiding questions, examples, and class discussions. This scaffolding is slowly removed throughout the course sequence to help students develop independence. The sequence ends with an open-ended laboratory in which students are given a mystery material and must determine the type of material and provide a potential use for it.

This work-in-progress paper describes the motivation and development process of these labs, as well as preliminary lab examples and planned assessment.

There is substantial discussion in the engineering community about the importance of including ill-structured problems into curriculum within engineering education, as these problems better represent the experiences post-graduation [1]–[7]. However, past work has found that textbook problems are rarely ill-structured in form and that students may be rarely exposed to ill-structured problems within their engineering curriculum [1], [2], [5]. One area in which ill-structured problems are easier to incorporate are within lab experiences. Student laboratory experiences are valuable to help students gain the experimental skills needed for future jobs and to see how to apply coursework topics. A well-structured problem in a lab experience is valuable for gaining technical skills. Bringing ill-structured problems into the lab environment will encourage students to think beyond the operational mechanics of the lab to connect a situation to the mechanics they are studying [2], [3].

We are building a sequence of labs within the mechanics course curriculum that emphasize critical thinking skills and address ill-defined problems that are more representative of problems encountered in the real world. These labs are a co-requirement of the lecture portion of the required Statics and Solid Mechanics and Materials Engineering courses within a non-disciplinary engineering degree. The program is in its first year at a small, primarily undergraduate institution.

Traditional labs are still important to introduce equipment and practice technical skills. The redesigned labs are used after instrumentation is introduced in an earlier lab to extend from the how of instrumentation to the why of instrumentation. They are based in the content of traditional mechanics topics and use similar or identical equipment to that used in other laboratories and experiments. Supplies were often selected to be useable in multiple labs or easily commercially available consumablesHowever, instead of traditional lab instructions with a goal and methodology, students are given a short design brief. They are also given a list of materials available to them, but they are not given a procedure or explicit instructions as to what to measure, how to measure it, or how to use data to determine a solution. Instead, they are expected to make assumptions as to what aspects of the problem need to be prioritized to best fit the design brief, determine what constraints can be assumed, find a way to perform measurements to acquire the data they need, and interpret those measurements in a meaningful way to provide a recommendation relevant to the design brief. This laboratory design also addresses ABET outcome 6, “an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.” [8]

With this instructional method, we hope that students gain independence and confidence for addressing wicked problems and learn to make assumptions and estimations relevant to real engineering work [2], [5], [6]. The problems addressed in lab are not wicked problems—they are intended to be completed within 1-2 lab periods by second- and third-year students. However, we believe they will be a valuable introduction to ill-structured problems.

Labs will be heavily scaffolded to allow students to slowly build skills. Ideally, by the end of the two-course sequence, students will be able to independently design and perform an entire lab with no scaffolding or pre-instruction beyond providing an ill-structured design brief. Their growth will be measured both through student-generated questions within the lab and by successful completion of a final, open-ended lab in the course sequence.

This work-in-progress paper lays out the general structure of the labs, provides examples, and explains the general assessment plan. The first implementation of this course design is beginning in Spring of 2024 with a cohort of mixed physics and engineering students.

Laboratory procedure

Each lab starts with a "design brief" describing a problem that may be encountered in real life that an engineer would be asked to solve. These problems can be solved using the content of the course covered in the last 1-2 weeks, but those topics are not explicitly mentioned. The design brief is short, usually 1-2 paragraphs, and studentswork in teams of 2-3 to solve the problem at hand.

After presenting this problem, students are given a short time to talk in their groups. There are initial prompt questions asking them to think through what they know from the design brief, what they need to know, and what topics the task relates to. They are prompted to sketch out the situation and draw a relevant diagram or identify a relevant equation. Students are then instructed to generate 1-2 questions that they need answered in order to proceed. They are given questions to help them get started [9]–[11] and are encouraged to write honest questions, whether they are "What do I do next?" or "How does this extend to…" Importantly, there is no expectation that students currently know the answers to the questions they ask.

After students generate their questions, the instructor brings the class back together to discuss the given prompts and develop potential next steps as a group. While students are able to ask their questions, there is no requirement that they do so to avoid development of artificial or constrained questions for fear of peer and instructor judgement [12]. Some example questions that lead to next steps will be discussed in one of the first lab sections to model how asking questions can move a project forward.

Students then are tasked with designing an experiment to measure the values they need with the equipment they are given. There are often multiple ways a student could successfully approach the problem. In early labs, the class will come together again to discuss the problem and potential solutions after another block of student planning and work time.

Between halfway and 2/3 through the 100-minute lab period, students are again asked to pause and generate 1-2 questions they currently have. They are then free to use their sources to try to answer those questions.

As this course continues into the second semester, the level of student scaffolding will be reduced. There is still prompting for the students to identify what to measure and how to measure it, as well as the suggestion to create a plan before beginning any measurements. However, there are not prompts as to what diagrams or properties to think about, nor is there relevant background information provided. Students are expected to make those connections and find the relevant information themselves. The points in which students are asked to identify their questions will remain, but there will be fewer times when the class reassembles as a whole. However, students are welcome to discuss with other groups, and the lab instructor(s) will be circulating to address any extreme misdirection.

As a deliverable, students write a short memo with their recommendation for the design brief with justification. They must include their experimental data in that justification and clearly explain any assumptions they made. Students must also turn in their documentation from the lab period with the initial brief, the prompting questions, and their plan. This ensures students work methodically to create a plan which is graded for completion. A summary of lab topics, design briefs, and required materials is given in Table 1.

Table 1: Content topics, design brief summaries, and supplies for labs within the course sequence

Content topic	Design Brief Summary	Supplies
Moments (Statics and Solid Mechanics)	A company wants to construct a drawbridge opened and closed by ropes for a children's play castle. Determine the forces the bridge ropes must withstand as children are playing on the bridge.	• Weight plates • Moment arm • Load cell • Ruler/tape measure • Protractor
Friction (Statics and Solid Mechanics)	A restaurant regularly moves wooden crates from delivery trucks up to their raised porch. Design a ramp and coating to facilitate this process.	• Ramp board • Weight plates • Load cell • Lab jack • Protractor • Base material options
Trusses (Statics and Solid Mechanics)	The Marketing and Communications office wants to stage a photoshoot on the bridge. Determine how many students can fit without risking collapse.	• Bridge on campus • Tape measures • Protractors
Axial loading (Statics and Solid Mechanics)	A client is not convinced that a model can be used to test the strength of aluminum struts for a shed. Provide evidence that the stress and yield of a material are independent of geometry.	• Bar stock of different thicknesses • Calipers • Load frame
Transverse loading (Statics and Solid Mechanics)	A company is designing rungs for a ladder from a pier into the lake. Provide a design that will be low-cost and structurally sound.	• Aluminum barstock • Load frame • Ruler/calipers
Loading (Materials)	The local playground is under construction. Recommend a material and design for the monkey bars.	• Metal barstock of aluminum, steel, etc • Load frame • Ruler/calipers
Heat treatment effects on strength (Materials)	Determine the best processing technique for steel supports of a filing cabinet	• Steel bar stock • Box furnaces • Load frame • Hardness tester
Eutectic curves (Materials)	Wisconsin sidewalks need to be de-iced in winter. Determine the best type and concentration of a set of salts to use.	• $NaCl$, $CaCl_2$, KCl, etc • Beaker • Graduated cylinders • Scales • Freezer • Thermometers
Summative lab (Materials)	A company has recovered a large amount of scrap of an unknown material. Identify the scrap and determine a use for it.	• Bar stock • Load frame • Other testing options as available

Example labs

As an example, a lab occurring in the first half of the statics and solid mechanics course focuses on friction. Students are tasked to choose a coating for a wooden ramp. They are given the height that the ramp must reach and its purpose—letting people slide wooden crates up and down from a porch quickly and easily. A desired length and width of the ramp are not provided. Lab materials consist of a load cell, a wooden ramp piece, a lab jack able to adjust the height of the ramp, protractors, weights, and base coating materials that attach via Velcro™: plastic, wood, rubber, and outdoor carpet (see figure 1a). Students are prompted to identify the forces in this scenario and draw a free body diagram. A group discussion occurs after students have the opportunity to think and then identify 1-2 questions.

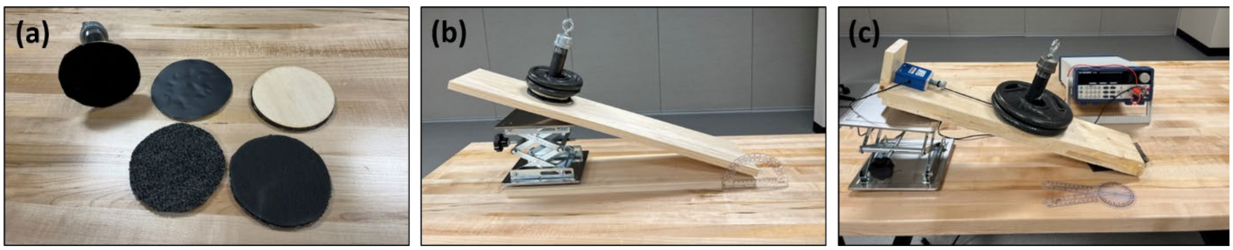

Figure 1: Potential experimental set-ups for the friction lab. (a) Base materials of plastic, wood, rubber, and outdoor carpet can be attached to the weight support with Velcro™. (b) Students can use the angle of the board and slip conditions to calculate the coefficient of friction. (c) Students can measure the force from the weights at an angle using the load cell.

Students have multiple past experiences to help them determine their testing strategy. One straightforward test of a ramp is to quantify the coefficient of friction by measuring the angle at which a box will slip (see figure 1b). Students have seen an incline plane example in their introductory physics course, so they have a prior reference point to draw on. Another option is to use the load cell to measure the force of the object along the ramp at different angles (see figure 1c). Students have used load cells in previous labs to measure vertical forces and moments. Both approaches are reasonable and can inform the student's final ramp plan. However, students must determine angles, the magnitude of forces, and how many trials to do themselves, among other aspects. Prompts after developing the measurement plan remind students that they will need to analyze their data and ask how they will account for error and other such factors.

In the second course of the sequence, Materials, a lab focuses on heat treatment of steel. Students are to decide on what heat treatment is best for steel that is to be used in the support frame for a metal filing cabinet. They are given standard low carbon steel bar stock to start and have the ability to heat, quench, and age the steel as they see fit. While the finite time spent in lab and availability of furnaces does limit the students from performing a full systematic set of experiments with a variety of ageing times, it is enough to apply some conditions as to the desired heat treatment. Once students have developed their desired samples, they have the ability to test them in tension, compression, or bending as well as investigate their hardness and microstructure (see figure 2). Students have to think through what properties matter most for the desired use of the steel and test the related mechanical properties. With a limited amount of samples, students also have to make judicious choices on what to measure and when to measure it.

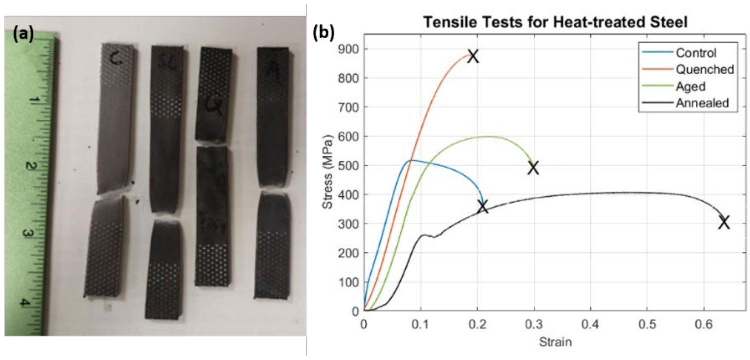

Figure 2: Students chose how to heat treat low carbon steel to change its properties and performed tensile tests. (a) Samples of different heat treatments were pulled until failure. (b) Students generated a stress-strain graph based on their experimental tests. Figures from student work.

The second course of the sequence will not have an initial regrouping in most labs. Students will still be asked to generate and record their questions at two points, but they can choose whatever resources they think are most appropriate to address the questions. Students also write a white paper to communicate their results instead of a shorter memo. The white paper provides a path to develop technical writing skills beyond those needed for a memo.

The Materials course ends with a very open-ended, ill-structured problem. Students are tasked with identifying a material and providing suggestions for its use. This is introduced in the form of a design brief from a company that can recover significant amounts of scrap of an unknown material. The students are tasked with identifying the material using the techniques they have learned in the course and providing a recommendation for reuse, repurposing, or recycling of the material. Students are expected to consider both the scientific and practical aspects of the material and its use, such as the ability to re-form or further process the material if the geometry or other aspects are to be changed. All materials used are commercially available bar stock, with a 3 ft length per group. Students have a limited amount of material, so they need to plan their measurements before beginning cutting material to test. There is no explicit guidance as to the best path or what factors to judge a material on, but the lab instructor is available to act as a reference or advisor.

Future Assessment

We are using student question generation to evaluate the efficacy of these labs in developing student independence. At regular points during the lab, students will be asked to pause and write down 1-2 questions, ranging from “What am I doing?” to “Does it make sense to assume…?” and beyond. Students will be required to write down questions but not to share them with the class. This is to encourage honest questions and minimize focus on how other students may perceive them [10], [12].

Once the course sequence is over, the student questions will be categorized based on categorization schemes already in practice for physics and engineering [9], [13]. If this method is effective, we would expect to see a transition from primarily lower order questions that are unspecific, procedural, or clarifications to higher order questions regarding the why and how of the work and more predictive inquiry.

As the first iteration of this course sequence is currently ending, there are no preliminary results to be analyzed. Future work will determine whether this is a potentially fruitful path as data is obtained.

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