“Design-Based” Instruction – Teaching Engineering Design in the Context of Practice

Shirley Fleischmann and Sanjivan Manoharan
Padnos College of Engineering and Computing
Grand Valley State University
Grand Rapids, USA
fleischs@gvsu.edu; manohars@gvsu.edu

This Research-to-Practice Full Paper discusses what “design-based” instruction is and how it can be used to place the teaching of engineering into the context of practice as required by the recent 2019-2020 accreditation criteria. This paper will describe a hands-on design and build project that has been used with great success in a junior level fluid mechanics course for more than 30 years; an iconic project that students look forward to from their freshman year. Far more than just a project, it is an approach to teaching design that permeates the entire course – building expectation, stimulating creativity, and pulling several fluid mechanics principles taught in the course into a single theme through the application of concepts and skills to a particular end product. Students design, build, and test a 1/12 scale model sailboat and use the model tests to predict full-scale prototype performance. They must work within constraints of the material provided for the hull, and as a last step, they must be able to race their models forward over a test course with the wind coming from the side. Over the years, this project has forged an approach to teaching the entire course. A five-step iterative scheme for the design process serves as a framework for design-based instruction, and while this will be illustrated for the fluids project, it can be extended to any engineering course project. Successful design also involves the use of three types of literacy that serve to place the design experience in the context of practice: conceptual literacy (knowledge of theory and concepts), mechanical literacy (knowledge of tools, machines, and components), and cultural literacy (knowledge of how to communicate and how to properly place a design into a social framework). A planning matrix that enables the instructor to plan the mix and balance of the steps of design and types of literacy will be presented in this paper. The matrix can also be used to address the 7 student outcomes in Criterion 3 of the ABET Criteria. This approach was severely tested during the COVID-19 pandemic and subsequent lockdown that required all courses to be delivered remotely; however, the framework and approach to teaching enabled the authors to distill the critical features and to adapt the project and the course approach to the online environment.

Keywords—Design based learning; Design process; Mechanical engineering

I. Introduction

For more than 30 years, the Wooden Shoe Regatta (boat) project has been wildly successful at our university. Studying its success over the years has evolved into an approach that not only permeates our practice of teaching but also satisfies the requirements of the Accreditation Board of Engineering and Technology (ABET) to teach engineering in the context of practice. From the very first day of the Fluid Mechanics class, students want to know when we will be launching the boat project and are motivated to learn what they must know before starting the project. The design-based approach discussed in this paper is a direct consequence of the search to develop an approach that better reflects current engineering practice while at the same time engaging and meeting the needs of students by drawing them into the practice of engineering.

It all began 37 years ago when one of the authors was an instructor at the United States Naval Academy. While the students had an excellent textbook complemented by a full laboratory experience with the best equipment available, the students were not engaged and not being transformed by the academic experience. There was no excitement, no sense that the knowledge gained in the fluids course was meaningful when these students anticipated a career as Naval officers where such knowledge was critical. The solution was in an experience common to all midshipmen. All entering midshipmen learn to sail in the summer before classes begin; sailing lessons are part of their introduction to a career of commanding ships at sea. Sailboats embody many of the topics covered in a junior level fluid mechanics course, and the Naval Academy was uniquely equipped to study boats with towing tank facilities and a full professional wood shop to provide models of hulls to be tested. The boat project was developed to draw the students into the excitement of practice.

The project involved each student building a 1/12-scale model sail boat and predicting full scale performance of the boat based on model tests of the hull and the sails. Each student was provided with a 2 in. x 4 in. x 10 in. wood block from which they were required to shape a single displacement hull. They would individually test their hulls in a towing tank using the same scaling laws used by the naval architects and they would test model sails in the wind tunnel. They would use the model tests to predict full scale performance in windy environments. A report containing their findings would then be submitted to be graded. Furthermore, a speed competition would be held where all students raced their boats. The competition was not graded, but it required them to balance the forces on the hull, sail, keel and rudder to sail their models over a 9-foot course using only the wind coming from the side. We also added a style competition which was judged by staff and faculty and trophies (wooden shoes) for the winners were presented. The competitions were not graded but were an opportunity celebrate their accomplishment and to put their skills to a public test. The project was well received at the Naval Academy and was successful in building excitement and motivation to learn fluid mechanics. When the author who started the project joined a new university the project was adopted there in the first year.

In addition to hands-on skills, the boat project requires mastery of fluid mechanics concepts such as: buoyancy and stability, external flows, boundary layers, flow separation, and dimensional analysis. The project provides context - a reason to learn the topics covered in more than half of the course since students will need this material in order to build a successful and hopefully winning boat. In particular, the dimensional analysis requires application and understanding of scaling laws and the limitations of empirical testing. A sailboat hull experiences two types of resistances viz.: wave-making resistance (scales with Froude Number) and viscous resistance (scales with Reynolds Number). Complete similitude requires matching of both numbers for the full-size sail boat (prototype) and small-scale one (model), and this is not achievable in water. Students are introduced to the practice followed by naval architects to account for this incomplete scaling analysis. The scaling of wind tunnel data on sails is more straightforward but again, requires insight into fluid forces and is a separate test. Students use this data for full-scale prediction of their prototype and determine possible points of sail for various wind angles. All of the topics required to complete this project are also covered in lectures, in homework problems, and in labs but the project provides the context for practice in a way that is meaningful to students.

The project takes place every summer, and this year will be the 31st year that the boat project has been conducted at our institute. For mechanical engineering students at our university, the project has become a "rite of passage" and a tradition in which they join more than 1000 alumni who have completed this project. The interest and excitement generated by this project lasts long after the class is finished. Many alumni report still having their boats and keeping them – not just as a symbol of accomplishment but also as a symbol of joining a profession. In fact, part of the race is a christening ceremony in which the models are christened as symbols of the unique potential that each student offers to the profession of engineering. Based on this long-term level of enthusiasm, we can only conclude that this project meets the needs and expectations of students on many levels. What are the features of this project that are responsible for this success and can they be extracted and applied to the whole of the engineering curriculum?

II. ENGINEERING DESIGN

Through lecture, lab, and project work, we prepare students for engineering design - a complex activity which lies at the heart of engineering practice. The ABET 2019 -2020 criteria [1] defines engineering design as "*the process of devising a system, component, or process to meet desired needs and specifications within constraints. It is an iterative, creative, decision-making process, in which the basic sciences and mathematics and engineering sciences are applied to convert resources into solutions. Engineering design involves identifying opportunities, developing requirements, performing analysis and synthesis, generating multiple solutions, evaluation solutions against requirements, considering risks, and making trade-offs, for the purpose of obtaining a high-quality solution under the given circumstances. For illustrative purposes, examples of possible constraints include accessibility, aesthetics, codes…usability.*" In retrospect, it is easy to see that the Wooden Shoe Regatta project – including the speed and style competitions – meets this definition of design quite well.

Fig. 1 shows a generic five-step model which provides some structure to think about teaching engineering design. The following steps are included: Problem Identification (Step 1), Modeling (Step 2), Solution (Step 3), Implementation (Step 4), and Presentation of Solution (Step 5). Typical homework assignments, lectures, and labs focus on steps 2 and 3. Design and build projects such as the senior capstone project might include all 5 steps, but senior project occurs at the end of the student's course of study and much of the curriculum before this point is not well balanced. So, how do we develop a balanced approach that includes all aspects of teaching design? A potential solution would be to simply focus on the three types of literacies.

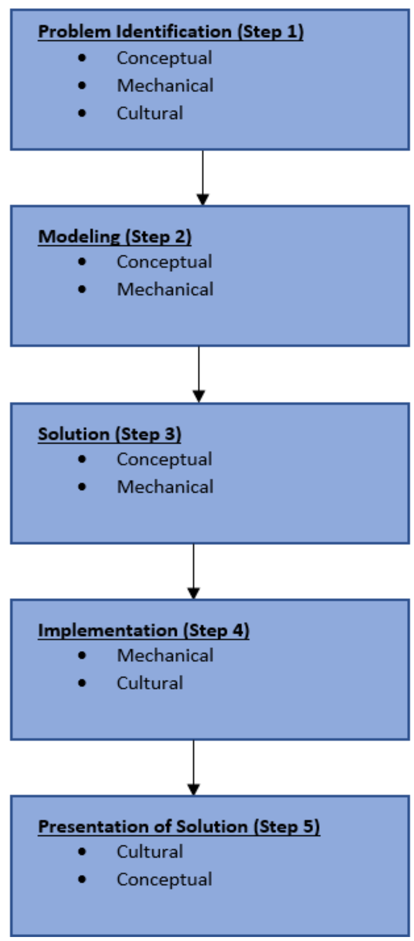

FIGURE 1: STEPS OF THE DESIGN PROCESS WITH LITERACIES AT EACH DESIGN STEP

A. Literacy as Required for Design

In addition to the steps of design, it is useful to think about literacy and in particular, three types of literacy as necessary for engineering design [2]. They are: conceptual literacy, mechanical literacy, and cultural literacy. Conceptual literacy involves the knowledge and understanding of scientific and mathematical concepts or ideas that form the basis for engineering analysis. Mechanical literacy is an understanding of tools and machines as well as a working knowledge of how to use them. Cultural literacy is an understanding of various groups within a culture and how to effectively communicate with them. Engineering design practice involves all three literacies as well as the steps of design in a balanced manner. Fig. 1 shows the steps of design as well as the types of literacy most strongly associated with each step. The usual lab submissions and homework assignments typically focus mostly on conceptual literacy. Therefore, we typically emphasize only two of the five steps in engineering design and only one of the three literacies.

Literacy is related to mental structures into which we place new knowledge. Hirsch [3] in his book discusses the mental schemata or structures related to literacy and understanding. He states: "*We know that schemata perform two essential functions that are relevant to literacy. The first is storing knowledge in retrievable form; the second is organizing knowledge in more and more efficient ways, so that it can be applied rapidly and efficiently. Without appropriate background knowledge, people cannot adequately understand written or spoken language. And unless that knowledge is organized for rapid and efficient deployment, people cannot perform reading tasks of any complexity. Although there are sizable variations in reading rates among good readers, no good reader is a very slow reader. Slowness of reading beyond a certain point makes assimilation of complex meaning impossible. The limits of short-term memory do not allow the integration of "unchunked" material, and so crucial parts of meaning are lost to memory while other parts are being painstakingly worked out*."

Instead of reading, we are talking about the complex task of design. The 3 types of literacy: conceptual, mechanical, and cultural, form the mental structure or the schemata into which our students must place new knowledge and from which they must deploy knowledge. If that structure is incomplete or weak, students will find it difficult to assimilate what they see as unrelated or "unchunked" material. In the process of painstakingly working out those deficiencies they will lose critical parts of meaning. Even worse, they may sense that their preparation is not complete and, on their own, they may not see how to complete it. If nothing in the curriculum addresses it, this can lead to uneasiness and discouragement – even fear, and students may decide to leave an engineering program because of it.

For example, how can mechanical engineering students design a pumping system if they do not know what various pump designs look like? How can they design a piping system if they do not know about valves and other plumbing components? A piping system is more than a theoretical concept; it is a practical reality in design practice. This is an example of mechanical literacy - an area in which many of our students are very weak. The typical high school preparation of college-bound students does not include in-depth shop class and most students have little experience (beyond Lego's) with building components of any kind. Many of our fluids students have no idea what the difference between a gate valve and a globe valve is, or what a sweat fitting is, yet these are the components which they must specify in a system design. While they might be able to look components up on the internet it might not occur to them to compare alternatives or to fully appreciate advantages and dis-advantages of various choices. Their level of mechanical literacy is very low, yet this is the type of information that can be easily incorporated in a very informal way into a well-designed laboratory experiment by simply requiring that students select and install the component that is to be tested. This will provide the students with the opportunity to examine the valves closely, and it also provides the instructor with an opportunity to discuss why loss factors might be different based on the valve geometry.

The effect of a well-balanced curriculum which recognizes the weaknesses of students and provides opportunities to build the necessary schemata is the same as the effect of well-balanced diet on health. Students make the new knowledge their own and are able to build on it and use it. Their class activities become essential to a transforming experience as they are drawn into the practice of engineering.

III. PROJECT WORKSHEET

Table 1 shows the project worksheet for the Wooden Shoe Regatta. This worksheet is a very helpful tool in assessing the balance in the project. The table can be easily modified for any project. The specific tasks that the student is expected to complete for each problem-solving step are listed in column 2, while column 3 lists the types of literacies required to complete the associated step along with subtasks. Using Table 1, one can determine if a project is well balanced or if it requires further modifications. For the boat project, which takes 5 weeks to complete, it is evident that balance is achieved in the steps of design and in the literacies required. It does this while also being fun and engaging for the students.

It is also important to note that it is not always necessary to have student activity fill in the entire worksheet, neither is it necessary to make every part of a project a graded or assessed activity. For example, the Wooden Shoe Regatta always involves the development of a press release. This is something that done by the instructors and submitted for student review. At the time that it is shown to them (close to the racing date), we discuss the importance of a press release when dealing with the media and when it is important to tell the story correctly. We also talk about how to work with the public relations people who are part of the staff of most companies and organizations. We also share experiences with this project in which interaction with the press has gone badly or when interaction has gone well. The students gain the benefit of an exposure to this aspect of cultural literacy within the presentation step of problem-solving. They gain it within the context of engineering practice and without involving a lot of their time or our time in grading 70+ press releases.

TABLE 1: BOAT PROJECT WORKSHEET

Steps	Tasks	Required Literacy
1	1. Identify forces/moments acting on sailboat system 2. Identify geometrical factors that might affect forces 3. Model must be stable 4. Hull to be carved from a single 2"x4"x10" block provided	**Mechanical** What does a sailboat look like? Why proportioned as it is? **Conceptual** knowledge of fluid forces, direction of action, factors affecting forces
2	1. Model test equations: a. Froude scaling for hull b. Reynolds scaling for sails 2. Decide on test velocities for realistic prototype speeds 3. Decide on hull shape and sail configuration	**Mechanical** Test equipment, operation and limitations a. How fast do sailboats sail? b. How to trip a turbulent boundary layer on model? **Conceptual** Understand test results a. skin friction drag b. Form drag c. Wave-making resistance d. Froude's hypothesis e. Definition of hull speed f. Vector analysis
3	Resolve trade-offs in hull design- example: length for speed vs. width for stability and limited material to use.	**Conceptual** Same list as for modeling plus stability principles
4	1. Shape and finish hull 2. Add mast, weights for trim adjustment if needed 3. Design and build sail 4. Add keel and rudder 5. Perform hull resistance and sail force tests on model hull, sails 6. Test model to sail on a beam reach for race (wind from side)	**Mechanical** a. Use of various power & hand tools b. Finishing techniques i.e. painting, wet sanding, etc. c. Use & calibration of lab test equipment **Conceptual** a. Inadequacies of modeling b. Error propagation c. Visualize force balances d. Effect of appendages on hull drag **Cultural** a. Work as "apprentice" with skilled craftsmen b. Time management – deadline to meet c. Getting along with technical staff
5	1. Write technical report 2. Competitions – Style & Speed: a. Not graded b. Trophies awarded 3. Publicity: a. Posters and announcements b. Invitations to special guests c. Media-press release 4. Official logo, stationary 5. Thank you to technical staff 6. Announcement of results **3-6 above instructor responsibility, also trophies*	**Cultural** a. Presentation of work to public and tech. report b. Dealing with news media c. Importance of recognition of support staff to support morale **Conceptual** Evidence in report, mastery of all concepts listed above **Mechanical** Sail, rudder adjustments to sail desired path

The worksheet is a valuable aid in documenting the design content of curriculum elements. This same overall structure can provide guidance in setting up an approach to an entire course. For example, the first step in the design process is problem identification. This involves asking the right questions. While students have a wealth of practical experience with fluids from everyday life, they are generally not adept at recognizing that certain phenomena are related to their study of fluids. For that reason, the first lab in fluid mechanics is an observation lab in which a series of 10 to 15 stations is presented to the students. In teams of 2-3, students are asked to sample at least 7 of the stations and to articulate questions as well as to advance theories about answers related to those questions. The stations are selected to pose specific questions that will be answered as the course progresses.

At one station, students are asked to drink milkshakes and water through a variety of straws while viewing their mouths as pumps and the straws as piping systems. They are then asked what factors affect the required pumping power for a given flowrate. This is a very simple and common experience but most likely the student has not viewed it as related to the study of fluids. A series of such simple experiences provides a set of questions that can be answered as the course progresses. It provides students with tactile experience in fluids that can provide a bridge to analysis or to enhance the "schemata" referenced earlier in this paper. It also raises the student's expectation that this area of study will have practical application. Because the lab is enjoyable, the students begin to expect to enjoy lab and some of the questions are posed in order to initiate or enhance that "aha" reaction when it is explained in lecture. The role of the instructor in this lab is to help the students formulate questions and to encourage them to look for answers as the course progresses. The students present their results for this lab in the form of a journal that might be appropriate for a general audience but that also serves as a reminder of the questions for which they will seek an answer. In the first lab, the students are introduced to an approach that weaves the lab experience with its tactile knowledge as well as conceptual, mechanical, and cultural literacy into the lecture experience. Along the way, expectations for learning are raised. Of course, the towing tank to be used later for the boat project is part of lab 1 and the tank in which the boat race is held is clearly visible to them.

This first lab in Fluid Mechanics does have elements of all 5 steps of problem-solving, but it is strongest in steps 1 and 5 - problem identification and presentation. Knowing this, later labs, classroom exercises, and homework can be stronger in the other steps. The types of literacy can be balanced in a similar way. This may seem to be complicated and it may seem to require a lot of extra time on the part of the instructor in setting up grading and assessment; however, it is important to recall a point made earlier in this paper. Not all activities need to be graded in order to give students the full benefit of the activity. In the fluid mechanics lab, we achieve this using board problems to fill in gaps in literacy.

B. *Board problems*

Grading requires a lot of time and requires the instructor to focus on judging performance rather than helping students with process. We use board problems in the lab starting with the first lab and continuing through Fluids to the Heat Transfer course two semesters later. These problems are not assigned in advance and they include key concepts that we know students must review. The students go to the board with just the problem statement and are asked to begin to work the problem out. No single student is put on the spot since they all go to the board at the same time and can consult with each other on the solution. The instructors walk around and discuss the problems that they have with the solution and "get them unstuck". Usually more than one student has the same problem, and once they learn how to overcome it, they can teach others thereby strengthening their concept as well. Another important aspect is that students often realize that they are not the only ones with a particular weakness. This is related to the concept of "peripheral participation" described as "the process by which newcomers become acclimated to existing communities of practice" by simply hanging around at the outskirts and listening in. Described as one of the most significant aspects of a professional environment, it is especially important in fostering inclusivity and mentoring [4]. Board problems allow for this interaction in lab. Since all of this is ungraded, we are free to simply give advice and encouragement (mentoring) and students are free to ask questions without fear of being judged. This too, reflects practice and places a focus on process rather than end result. More importantly students and faculty work together as a team on building literacy.

IV. Accreditation Board for Engineering and technology (ABET)

Design-based instruction involves carefully balancing student activity and student exposure to the 5 steps of problem solving and to the 3 types of literacy required for the practice of engineering design. The project worksheet presented in this paper is a valuable aid to quickly assess this balance. If students sense that a balanced curriculum meets their needs, they learn more and learn it with far more interest and enthusiasm. In the end, this is essential if our students are to become and also remain proficient in design. The ABET 2019-2020 criteria (required for accreditation of undergraduate engineering institutes) have also been designed to make design practice part of the entire engineering curriculum [1]. All seven student learning outcomes required by ABET are listed below along with the predominant types of literacy for each outcome within parenthesis in order of importance.

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics (conceptual, mechanical)
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors (mechanical, cultural, conceptual)
3. An ability to communicate effectively with a range of audiences (cultural, conceptual, mechanical)
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts (cultural, conceptual, mechanical)
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives (cultural, conceptual, mechanical)
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions (Conceptual, Mechanical, Cultural)
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies (Conceptual, Mechanical, Cultural)

The matrix below in Table 2 shows the same information in a more visual format. There are only 3 types of literacy, and they are clearly distinguished from each other. Therefore, any assignment can quickly be assessed for the type(s) of literacy required to complete the assignment and then mapped to student outcomes that require that type of literacy. If, for example, student outcome 7 is to be assessed which is ranked high in conceptual literacy and ranked medium in mechanical and cultural literacy, one would look for an assignment which most closely matched those rankings. We use boat project reports to assess student outcome 7. The reports are typically long and complicated, and it might be difficult to clearly identify what to look for in assessing outcome 7. The matrix along with the project worksheet could lead to a narrower focus for the purpose of assessment on how the student presents the problem identification and on the interpretation of test results – since these are tasks that require high levels of conceptual literacy and some mechanical literacy to complete.

TABLE 2: LITERACY MATRIX

Literacy/Outcome	1	2	3	4	5	6	7
Conceptual	H	M	M	M	M	H	H
Mechanical	M	H	L	M	L-M	H	M-H
Cultural	L	H	H	H	H	M	M

H = High; M=Medium; L=Low

This framework of literacy and ABET student outcomes can be used to assess an individual lab exercise or homework problem as well.

V. Lessons learned during COVID & remote instruction

In March of 2020, our state was under lockdown orders that resulted in all classes going on-line for the remainder of the winter semester and extending through the summer semester.

We teach Fluid Mechanics only in the summer. As is evident in this paper, the boat project and the lab experience are an essential part of how we teach this course. Having just lectures and not having the lab was not an acceptable choice. Just preparing videos of experiments performed in the lab and sending data to students for them to write up was also not acceptable and our labs are not set up for remote operation. Some authors have stated that learning outcomes could be enhanced using computer simulations or remote configuration of the labs [5-7]. However, these approaches do not provide the required literacies. What we decided to do was a hybrid approach in which some labs were presented entirely in the video format with data sent to analyze, but most labs had a "build and test at-home" component in parallel so that students had some form of mechanical literacy. The experiments were fun to do and could be easily completed with commonly used household materials. The experiments are described in detail in another paper soon to be published. We were able to salvage at least part of the boat project but in a different form and, of course, no boat race. This was done to ensure that student learning Outcome 7 was assessed and not omitted.

To assess the effectiveness of our approach during lockdown, we were able to collect ABET assessment data for two cohorts of students. The first cohort took Fluid Mechanics in the summer of 2019 in-person, while the second cohort took Fluid Mechanics entirely on-line in the summer of 2020. As mentioned previously, we asses ABET student outcome 7 using the boat project. For the fluids lab that went online in Summer 2020 (cohort 2), we were not able to do the board problems in the on-line format. The result of this was felt when that cohort took Heat Transfer subsequently in Winter 2021 in-person where we could do board problems in Heat Transfer lab. This is related to the "peripheral participation" noted earlier in the paper. Students were noticeably weaker in analysis for heat transfer and far less confident of their own abilities when compared to students who had the board problem experience (cohort 1). Apart from this, the boat project also had to be modified so that it could be done at home but preserve the main essence of it.

For the boat project, we were able to recast the project with a 1/35 scale hull model cut from a 2 inch wide section of a standard 2 in. x 4 in. Students were able to compare the performance of a streamlined shape to a blunt barge-like shape. Since the wood blocks were very small, students could easily get them from nearby stores or obtain them from the engineering building where a supply of wood blocks were placed for easy access. By this time, the lockdown had eased allowing for them to drive but no in-person classes were allowed. One important difference was that they were required to build their own gravity driven towing tank using a bathtub or a wallpaper tray for the tank using pennies and nickels as the driving weights. For this, and for all the home-built experiments, the authors built the equipment at home first and then prepared short videos demonstrating the equipment and the experiment. These were posted on BlackBoard. This way, we at least could invite the students into practice, but the students missed the comradery of other students that is often important to encouragement and motivation.

From the project worksheet (Table 1), we were able to preserve the tasks and literacies of steps 1, 2, and 3 of design. In step 4 (Implementation), we added the mechanical literacy required to build and use the towing tank, but lost the finishing of the hull and adding sails since many of the students did not have the shop facilities available at home. While the tasks changed somewhat, the mechanical and conceptual literacy parts were preserved for this step. However, for cultural literacy under step 4, we were only able to preserve the time management task. For Step 5, only the technical report was preserved under Tasks, and under Required Literacies, only conceptual literacy was preserved. In a regular semester, for the 1/12th model, the hull tests are done as a one-on-one activity between the student and the instructor. Due to COVID, the community-building parts were largely lost. The fun of the competitions (and that part is not trivial) involving the race and aesthetic competitions were also lost but there was enough to be able to use the boat project as a theme for lecturing and also for the assessment of student outcome 7.

For assessment, student outcome 7 was used for both cohorts' boat project. For outcome 7, there were three performance elements that were evaluated: Learning Behavior, Information Ability, and Task Completion. The comparison of both cohorts can be seen below. The results were subject to a single tailed test which resulted in the results being statistically significant. It can be seen that the cohort that did the boat project remotely had improved Learning Behavior and Information Ability indicating that the modified boat project was a success in these two areas. However, there was a dip in performance in Task Completion. We noticed that many students were unable to scale their data correctly to predict full-scale protype performance at various wind angles. Typically, all students have some level of difficulty in this area, but when they are in-person, they are able to interact more with their instructors and fellow students to learn. The cohort that was remote had far less engagement with the instructor and many students reported that they self-isolated themselves due to social depression. This could be a reason why the task completion was lower for the remote cohort. It can be concluded that using the matrix and literacy method, we were able to satisfy the ABET outcome 7 in general. This demonstrates the ability of our proposed method to be modified even for remote platforms.

TABLE 3: ABET STUDENT OUTCOME 7 ASSESSMENT

Outcome Element	**2019 (In-person)**	**2020 (Remote)**
Learning Behavior	73.4	78.0
Information Ability	70.5	75.0
Task Completion	80.5	77.5

VI. SUMMARY

The goal of an engineering education is to prepare students to enter the profession of engineering fully prepared to meet the challenges that will come their way. In a real sense, students are invited to join those who have gone before them into the practice of a discipline and an art. One of the authors of this paper was reminded of the element of human tradition when talking with a student who will take the Fluid Mechanics course this summer. He said that his father had been in my class and that his father still has his boat. This summer he is looking forward to following in his father's footsteps and will build his own boat. The Wooden Shoe Regatta project has taught us much over the years about "design-based" teaching that meets the current ABET requirement to teach engineering in the context of practice. Various tools to assess the balance of this curriculum approach have been presented. As we face a future with more and more pressure to present courses in an on-line format, we have been able to assess the strengths of the hands-on and in-person approach by direct comparison of student outcome measurements as well as by informal student comments. While we would not have chosen to take the path we were forced to take in the summer of 2020, it has been an opportunity to understand the strengths of our approach. The enthusiasm shown by the students as we exercise this approach encourage us. If there is one question that should shape our attitude as we prepare our courses, it is not primarily about details of presentation or how we will judge performance – although these are important. The primary question is: How can I best draw students into practice? Each of us, as educators, will answer that question a little differently because we invite students to join us in the subject material based on our own experience with it. Just as we christen the models in the boat race as symbols of the unique potential that each student presents to our profession, we should shape our attitude by the question: How can I best invite students to join me in making this material a part of their lives?

REFERENCES

[1] Accreditation Criteria and Supporting Documents. Accessed on May, 5th, 2021. www.abet.org/accreditation/accreditation-criteria/

[2] S. T. Fleischmann, "Design-Based Teaching in Engineering and ABET 2000 Criteria," in Proc. ASEE Conf., West Point, New York, 2002.

[3] E. D. Hirsch, Cultural literacy, Houghton Mifflin Company, Boston, MA, 1987, pp. 56-57.

[4] Keating, E., "Why do virtual meetings feel so weird?", American Scientist, Vol. 109, pp. 94-97, April 2021.

[5] D. M. Fraser, R. Pillay, L. Tjatindi, and J. M. Case, "Enhancing the Learning of Fluid Mechanics Using Computer Simulations," Journal of Engineering Education, vol. 96, pp.381-388.

[6] A. H. M. F. Anwar, E. Lindsay, and P. R. Sarukklige, "Key Factors for Determining the Suitability of Converting a Fluid-Mechanics Laboratory to Remote-Access Mode," Australasian J. Eng. Edu., vol. 17, pp. 11-17.

[7] G. E. Ellis, C. D. Richards, B. R. Thompson, and R. F. Richards, " A Remote Access Laboratory for Fluids Education in Mechanical Engineering," in Proc. 122nd ASEE Annual Conf., Seattle, Washington, 2015.