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Entrepreneurially Minded Learning: Incorporating Stakeholders, Discovery, Opportunity Identification, and Value Creation into Problem-based Learning Modules with Examples and Assessment Specific to Fluid Mechanics

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Abstract: *A variety of pedagogies have become well-established and widely used in engineering education including problem-based learning (PBL), project-based learning, case-based learning, and inquiry-based learning. All of these classroom techniques certainly emphasize skill-based learning outcomes (e.g., determine the size of a pump), but they do not always emphasize mindset-based learning outcomes (e.g., identify an unexpected opportunity). Incorporating elements of the entrepreneurial mindset into these pedagogies, sometimes referred to as entrepreneurially minded learning (EML), can enhance student learning and produce a more real-world experience. Entrepreneurially minded learning emphasizes discovery, opportunity identification, and value creation with attention given to effectual thinking over causal (predictive) thinking.*

After introducing the concept of EML, this paper focuses on EML within the context of PBL. For a framework to demonstrate how to incorporate stakeholders, discovery, opportunity identification, and value creation, specific examples from Fluid Mechanics courses will be presented. In particular, the PBL course modules will demonstrate assignments that include unexpected design alternatives that the students must discover with scant clues (much like "Easter eggs" hidden in movies or DVDs). When discovered the design alternatives prove to have added value over a traditional design (i.e., value creation). One of the keys to producing these assignments is to incorporate a stakeholder or customer. Because stakeholder feedback is essential to re-evaluate opportunities and/or understanding what is deemed as valuable (i.e., value is subjective), it is important for the assignments to include a real live customer (who can be a fictional role-player). In addition, the examples given in this paper follow a similar theme (or consistent customer) with a bit of added humor. Doing so has shown to create enthusiasm for the assignment and the subject material.

To determine preliminary effectiveness of EML within PBL, both indirect and direct assessments have been performed. For direct assessment, students' EML assignments were evaluated by the instructor to verify inclusion or exclusion of a set of entrepreneurially minded attributes. For indirect assessment, students were surveyed to determine their perceived extent of using particular entrepreneurial mindset skills during an EML assignment. The results have thus far yielded positive results for students incorporating mindset skills into subject-based matter.

1. Introduction

Increasing emphasis has been placed on the engineering education community to implement student-centered pedagogies which will allow the students a more authentic ("real-world") experience. Much

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highly effective pedagogy have proven to be more effective than the traditional "chalk-and-talk" passive lecture methods. These pedagogies include challenge-based learning (e.g., problem-based learning (PBL), project-based learning, case-based learning, inquiry-based learning) (Bransford and Bateman, 2002) and a multitude of active/collaborative techniques (e.g., think-pair-share, quick think, jigsaw, and gallery walk). All of these learning methods excel in student learning of content as well as a variety of process skills such as critical thinking, higher-level reasoning, differentiating views of others, and teamwork (Johnson et al., 1998; Prince 2004). They are also highly effective with individual student accountability. In addition, they have proven to be successful pedagogies within STEM education, in particular with regards to achievement, persistence, and attitudes (Springer et al., 1999).

In 2008, it was noticed that the process outcomes associated with student-centered learning aligned well with the skills associated with the entrepreneurial mindset (Carpenter et al., 2011; Gerhart and Carpenter, 2013) which include persistence, creativity, innovation, time management, critical thinking, global awareness, self-directed research, life-long learning, learning through failure, tolerance for ambiguity, and estimation; all of these attributes are highly coveted attributes of engineers entering the workforce (Berrett, 2013; "How," 2006; American, 1988; Quality, 1994; Fischer, 2013; Maguire, 2012). Over the subsequent years, challenge-based learning and active/collaborative learning (ACL) have demonstrated effectiveness in emphasizing student practice of the skills associated with the entrepreneurial mindset (Carpenter et al., 2011; Gerhart and Carpenter 2013; Liu et al., 2015; Gerhart et al., 2015; Gerhart and Carpenter, 2015; Mynderse et al., 2015; Gerhart et al., "Combining" 2014; Schneider et al., 2014; Gerhart et al., "Effectively" 2014; Gerhart and Fletcher, 2011).

Which skills associated with the entrepreneurial mindset are most often lacking when employing student-centered learning? It is instructive to turn to the Kern Entrepreneurial Engineering Network (KEEN) to further investigate the answer. KEEN is composed of ≈26 engineering colleges spanning the U.S. dedicated to instilling an action-oriented entrepreneurial mindset in engineering, science, and technical undergraduates so that they can create personal, economic, and societal value through a lifetime of meaningful work. The institutions comprising KEEN develop vital resources for building quality entrepreneurial education programs that engage engineering and technical students. As support for those institutions, KEEN (part of the Kern Family Foundation) provides grants, capacity building workshops, networking opportunities, and resources. More specifically, KEEN provides financial and developmental resources to grantee institutions for the development of entrepreneurship curricula, modules, and extracurricular activities like business plan/innovation competitions, speaker series, student entrepreneurship clubs, and seminars. Over the years, faculty at KEEN institutions have created hundreds of ACL and PBL course modules with emphasis on various entrepreneurial aspects. (For the purposes of this paper, a "course module" is a student activity with specific learning objectives which can span in length from one class period to an entire term.)

Because of the broadness of entrepreneurship styles, it is difficult to create a definitive list of skills, attributes, traits, and behaviors associated with the entrepreneurial mindset. However, KEEN has developed a "working" or "living" framework of the entrepreneurial mindset which is best conveyed through the KEEN Student Outcomes, Example Behaviors, and Complementary Skills as shown in the Appendix. This framework has been developed by the faculty within the network which is best described as a community of practitioners. They drew upon various resources including early writers on entrepreneurship and education such as Shelia Carlson, Jeffry Timmons, Deborah Streeter, Raymond WY Kao, and Matthew Ohland. Publications related to the development of the KEEN framework have primarily come from individual members of the network since 2005. (One example is Peterson et al., "Proposed KEEN Initiative Framework for Entrepreneurial Mindedness in Engineering Education," Proceedings of the 2012 ASEE Annual Conference.) The framework is not intended to be a model based on observation. Rather it serves as an assertion by the network and forms the basis of shared investigation. This is similar to the ABET criterion wherein the greater engineering community agrees upon a mission-driven framework (noting that the recently proposed revision from ABET states "These criteria are intended to provide a framework of education…"); a specific institution may add goals and a local framework. Some institutions may even use other entrepreneurial models (such as Sarasvathy's effectual logic theory described later in this paper) alongside or within their investigation of the KEEN framework. Beginning in 2014, the current KEEN framework was modified to its current form as shown in the Appendix. The key to the framework is the "three Cs": Curiosity, Connections, and Creating Value. The three Cs serve as "containers" designed to be somewhat extensible. For example, some universities have effectively created a collection of goals that are an amalgamation of ABET criteria, KEEN outcomes, and additional university criteria. While it is too early in KEEN's existence to have established a body of work describing the impact of these criteria, thousands of instructors and students are employing the KEEN entrepreneurial framework. This KEEN framework along with Sarasvathy's work on effectual logic serve as the basis for the work in this paper.

When perusing the KEEN framework in the Appendix, it became clear that many of the example behaviors and complementary skills are well-represented in common student-centered learning modules, specifically problem-based learning, project-based learning, and many of the less formal active/collaborative techniques. As an aside, a well-formed PBL exercise should start with an ill-defined problem (usually with a hook statement designed to entice the students' interests), which is complex, real-world, and open-ended. In teams, students identify, find, and use appropriate resources to define and solve the problem. Thus by their very nature, well-formed PBL assignments require "integrating information from many sources to gain insight," "applying creative thinking to ambiguous problems," "applying systems thinking to complex problems," "evaluating technical feasibility," "forming and working in teams," "fulfilling commitments in a timely manner," etc. (Melton, 2015). KEEN leadership and a core team of university faculty spent hundreds of hours reviewing newly-minted and classroom-tested PBL and ACL modules to determine what is lacking in regards to student practice of the entrepreneurial mindset. Qualitative assessment revealed that specific example behaviors and complementary skills are less-inherent (or less commonly included) in student-centered learning. These are listed in Table 1.

Before moving forward, it is worthwhile to provide interpretations of a few terms used in the KEEN framework which could possibly have different meanings to different people. Curiosity: This is not simply the act of seeking solutions to problems. Most engineers already inherently do that. Instead, curiosity in the entrepreneurial sense is seeking discoveries beyond the problem at hand which may lead to new opportunities or innovative solutions/services/products. Assess and Manage Risk: This behavior does not necessarily imply that risky ventures are sought and consequently managed. Instead, contingency plans are considered in case of failure or unforeseen circumstances. Unexpected Opportunities: This refers to innovative solutions – those that showcase creativity. Often these are opportunities identified due to a persistence to anticipate the needs of a changing world. Extraordinary Value: Admittedly, value is highly subjective; thus extraordinary value can be even more subjective. For the purposes of the KEEN framework, this is a solution/service/product that is most meaningful to others (stakeholders/customers) to meet a need. Compared to standard solutions (i.e., the way an issue is typically solved), "extraordinary" could imply a more elegant solution, a cheaper solution, a more efficient solution, etc. Complex Problems: This term does not necessarily imply major problems such as those from The Grand Challenges for Engineering. Complex problems implies those which require multiple connections to solve, or the need to integrate information from a variety of sources. Solutions to complex problems may, for example, require technical/scientific acumen coupled with an understanding of regulatory issues and environmental impact (such as in the case for handling cooling water flowrates for a power plant). Systems Thinking: This describes the process of understanding how a subsystem influences a larger system of which it is a part (or vice versa). Design: In reference to the "Complementary Skills" shown in the Appendix, this refers to the process of creating a new product, service, or solution.

Table 1. Entrepreneurial Mindset Example Behaviors and Complementary Skills less common in PBL and ACL modules (extracted from the KEEN Framework in Appendix A).

Student Outcomes		Example Behaviors
Entrepreneurial Mindset	Curiosity	Demonstrate constant curiosity about our changing world Explore a contrarian view of accepted solutions
	Connections	Assess and manage risk
	Creating value	Identify unexpected opportunities to create extraordinary value
Engineering Thought and Action		Evaluate economic drivers Examine societal and individual needs
Collaboration		Understand the motivations and perspectives of others
Communicate		Convey engineering solutions in economic terms
Skill Category		**Complementary Skills**
Opportunity		Identify an opportunity Investigate the market Evaluate customer value, societal benefits, and economic viability Test concepts quickly via customer engagement Assess policy and regulatory issues
Impact		Validate market interest Identify supply chains and distribution methods Protect intellectual property

2. Entrepreneurially Minded Learning

Entrepreneurially minded learning is a relatively new concept – only a few years old. Incorporating some of the Example Behaviors and/or Complementary Skills from Table 1 into student-centered pedagogy is one viewpoint to creating entrepreneurially minded learning course modules. In particular, EML incorporates a pedagogical emphasis on discovery (i.e., curiosity), opportunity identification, and value creation, which is built upon active pedagogies such as problem-based learning. It should be noted that EML is not necessarily entrepreneurship education. Jacob Wheadon and Nathalie Duval-Couetil have succinctly described EML as "focused on developing mindsets and skills in students; preparing students to identify problems and solve them in innovative ways; and measured by how students' knowledge, thinking patterns, skills, and attitudes are changed." Further, they have posited that EML is not "focused solely on venture creation, a repackaged business minor, or measured by how many start-ups are created by students" (Wheadon and Duval-Couetil, 2016). They have also noted a few affective factors that students need to develop (hopefully through EML) which pertain particularly to Curiosity, Connections, and Creating Value (i.e., KEEN's Three Cs as detailed in the Appendix). Students should develop "a belief that they can succeed in value creating activity, a desire to participate in creating new value, and a drive to understand how things work, and how to make them work better." Note that Wheadon's and Duval-Couetil's paper draws upon the efforts of a working group summit convened by KEEN; the reader is encouraged to seek the paper as many particulars of EML contained within it are useful to the comprehension and application of this paper.

When developing EML modules for engineering courses, it is worth understanding the Theory of Effectuation (Sarasvathy, 2008). The "theory posits that entrepreneurs rely more heavily on effectual logic" than on predictive logic (or causal logic) "typically employed by engineers." Predictive (or causal) thinking entails choosing between given means to achieve a pre-determined goal. Effectual thinking on the other hand entails imagining a new goal using a given set of means (Read et al., 2011). Sarasvathy created a useful analogy involving a chef (2001). The causal thinking chef will have a menu (the end goal) and use a variety of ingredients and cooking techniques to realize the menu items. An effectual thinking chef will begin with a pile of ingredients and cooking means and will create a dish (perhaps unexpected to create new value). Which thinking mode is most common in engineering education assignments? Typical end-of-chapter homework problems state the end goal (e.g., determine the force on the structure based on the given conditions). The student has a list of means to solve the problem from within the chapter being studied. Similar to the causal thinking chef, the engineering student must chose the proper technique (cooking method) and the proper equations (ingredients) to solve the problem. EML should differ from traditional engineering student assignments by encouraging effectual thinking.

Through EML, "educators can provide students with educational experiences that will help them to create new value in highly uncertain situations." It is paramount though that the emphasis on developing an entrepreneurial mindset should "not diminish the importance of content knowledge that students need" (Wheadon and Duval-Couetil, 2016).

3. Creating and Implementing Entrepreneurially Minded Learning

Creating an EML assignment may not be second-nature to the engineering educator. This is manifest in the fact that most engineers are causal or predictive thinkers. However there are some key elements to creating an EML. First start small. Use an existing ACL classroom activity and add in an entrepreneurial element. Incorporating an item or two from Table 1 is a good place to start. Also focus on some of these key elements of EML as defined by Wheadon and Duval-Couetil:

- In order to better create value in society, students need to learn how to discover, identify, and dig deeper into real problems rather than just solve given problems.
- Learning through experience and reflection is critical to entrepreneurship education due to the situated nature of entrepreneurial thought and action.
- EML is student-centered and focused on developing a combination of affective factors, thinking patterns, knowledge, and skills.
- EML involves creating learning experiences through which students develop self-efficacy, value-orientation, interest, and curiosity.
- EML involves pedagogical approaches such as problem-based learning, active learning, and others.
- Curricula should focus on activities that help students develop skills and knowledge that will benefit them whether or not they create a new venture.
- Students should be learning how to identify and evaluate problems.

- Instructors should identify problems that allow students to create value for others while making connections with effectual logic as opposed to only predictive logic.
- Students should be graded on how they thought, along with the content of their answers.

In summary, EML should emphasize discovery, opportunity identification, and value creation for others through the use of effectual logic.

3.1. An Example of EML through the Lens of Fluid Mechanics

Fluid Mechanics is typically a junior-level course in the standard curricula of architectural, chemical, civil, and mechanical engineering students. Understanding and selecting pumps is a topic that is often time consuming and thus difficult to cover in the classroom of a Fluid Mechanics course. Nonetheless, it is important. Pumps are devices that increase pressure in a fluid so that it can be transported at a certain capacity (i.e., flowrate). Centrifugal pumps are common, and an example is shown in Figure 1. Pump curves provide detailed information regarding the performance of a particular pump. Note that the pump curves are multi-dimensional including information for a variety of pump speeds, pump sizes, flow rates, and pressures as shown in Figure 2.

Figure 1. A typical centrifugal pump. (Pumps Pool, 2017)

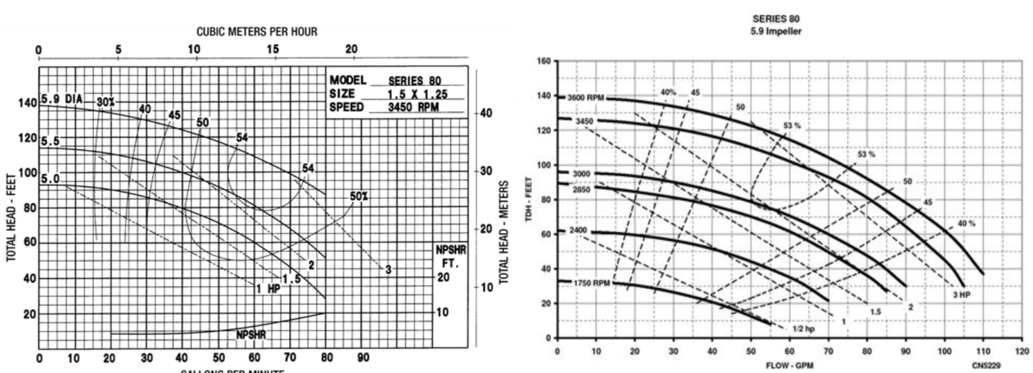

Figure 2. Typical centrifugal pump curves. (MP Pumps, 2017)

A typical homework problem for a pump is as follows:

Using the curves provided, select a pump which can deliver water at 30 gallons per minute to an elevation of 30 ft with a pressure of 40 psi.

Admittedly, this is a relatively simple problem (for an upper-level engineering student) and may be made more difficult to include specific pipes attached to the pump which will require additional pressure. Note that it requires causal (predictive) thinking. The end goal is stated. The student must simply choose the given means and solve the problem.

This problem can be made more effectual by converting it to a PBL assignment. The following PBL assignment has been used at Lawrence Technological University in Michigan:

> You purchased a primitive cabin "up north" situated in the forest near a lake. It has no plumbing and you'd like to upgrade the cabin and turn it into a quaint vacation retreat. Referring to Figure 3, design the water supply system for the cabin meeting the following expectations:
>
> - Two story cabin approximately 30 ft above the lake.
> - Meet basic water needs for comfortable living (i.e., at least shower, faucet(s), etc.)
> - Each water consumption unit can be controlled independently, and also all units must be able to be used at the same time without significantly affecting each other.

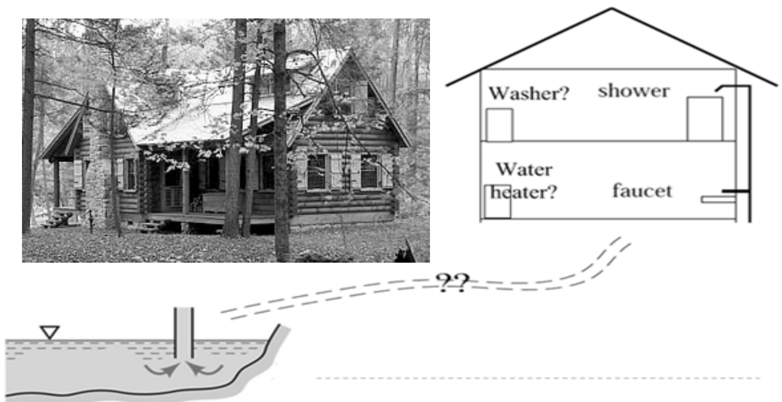

Figure 3. Cabin the woods PBL.
("Is Paradise…", 2017)

This PBL does not lose the content objectives of the original homework problem – choose a pump for a given flowrate and elevation rise. It is a fairly well constructed PBL for the given student population. Based on the standard elements of a PBL, it consists of a hook statement; many people in Michigan own property "up north" or at least are close to someone who does. It is real-world, open-ended (allows for various cabin interiors), ill-defined (how does one get water from a lake to a cabin, what is needed for a piping system), and complex (requires the use of content from throughout the course). For this assignment, the students are arranged into small teams and they must identify, find, and use appropriate resources to fully define their team's problem and solve it. From an entrepreneurial mindset learning standpoint, it incites situational curiosity; the student must examine a multitude of water delivery systems and determine how they operate. It requires connections; the students must integrate information from many sources to gain insight into solving the problem. In addition it requires some of the Example Behaviors listed in the Appendix: apply systems thinking to complex problems, evaluate technical feasibility, examine individual needs, form and work on a team, substantiate claims with data and facts, fulfill commitments in a timely manner (there is a due date). Some of the Complementary Skills are also required for its solution, but mostly just the "Design" column, which is already well covered in the typical engineering curriculum.

Why might this not be an EML assignment? First notice that there is no customer. The problem statement implies that "you" own the cabin; the plumbing system will be designed for the student doing the work. In addition, the problem is lacking the fundamental core attribute of EML: discovery through curiosity which leads to identification of unexpected opportunities to create extraordinary value. Within the Example Behaviors, the problem does not explore a contrarian view of accepted solutions, evaluate economic drivers ("you" can have any budget within your imagination), understand the motivations and perspectives of others, or convey an engineering solution in economic terms. The solution does contain some assessment and management of risk and application of creative thinking, but not to the extent required of many engineering problems in industry. In addition, it is particularly lacking Complementary Skills expected of graduating engineering students such as evaluating customer value and economic viability, testing concepts via customer engagement, assessing policy and regulatory issues, and validating market interest. Focusing on these missing attributes, the PBL assignment can be converted to an EML assignment. Following is the converted assignment given to the students.

Wilderness Resort Lodge

Your rich uncle, Mortimer, has recently purchased a large tract of land in the Upper Peninsula of Michigan. He did not become wealthy by purchasing worthless things, yet the land he bought has no valuable minerals, nor any profit from lumber. It does have a magnificent wilderness resort lodge, but it was abandoned years ago and fell into a dilapidated state. The lodge is known as the Overlook Hotel. (No, not that Overlook Hotel from The Shining; that place makes people go crazy and is located in the mountains of Colorado.) Before Uncle Mortimer can begin restoration of the Hotel, he needs a modest cottage for multi-day stays while he begins planning. Besides a living room and bedroom, the cottage will have a kitchen with a sink and a bathroom with a shower, sink, and toilet. He also wants a spigot on the outside of the cottage for a hose to rinse the dust from his 2014 Ford F-150 SVT Raptor (yes, the plush one with a 6.2L V8 engine). The land has access to electricity. His cottage (and Hotel) will be on a rocky hillside 300 vertical feet above the lake (which is what the hotel will "overlook") and 2200 feet from the lake's edge. A water well cannot be drilled through the rocky hill. After learning of your vast new knowledge of fluid mechanics, he has asked you to design a water system for his cottage. Eventually that same water system will be upgraded to supply the hotel. Your focus should be on the cottage's water system, while keeping in mind that the system will be enlarged in the future. You will need to consider a water delivery system, filter(s), heater(s), a piping system, and other components for this cottage. You must keep in mind that Uncle Mortimer is miserly with his expenses; he did not get rich by wasting money. But Uncle Mortimer is very generous with his family. Therefore if you can design an efficient and cost effective system, you will not only be paid well, you will likely inherit the land and hotel in Uncle Mortimer's will!

Some considerations (NOTE to reader – these may be progressively disclosed to the student by the instructor in stages):

- Ensure that the cottage has typical/sufficient water flow and pressure.
- Be careful with pipe selection (sizing) and material, ensuring that the water is fairly equally distributed throughout the cottage.
- The layout of the water system will determine the layout of the cottage.
- Be cautious that the components and design are not too costly. You should keep track of approximate expenses for components. You do not need to consider installation costs.
- Consider operational expenses for Uncle Mortimer. In other words, choose your water delivery system and heater(s) wisely.
- The hillside continues above the cottage/hotel another 400 vertical feet to the summit in 600 ground feet.
- Consider Upper Peninsula weather conditions.
- You do not need to be concerned with sewage (i.e., sinks, shower, and toilet drains).

- Remember that this system will be upgraded for the entire resort lodge.

Again, the assignment did not lose the content of the original homework problem; the students must still choose a pump which complies with certain flow and pressure requirements. Now there is a customer (i.e., interested stakeholder). The instructor can play the role of Uncle Mortimer. In addition, there will be future customers to consider – the hotel guests. The problem requires the students to evaluate economic drivers (there are multiple solutions with widely varying costs), understand the motivations and perspectives of others (what is needed for the hotel and Uncle Mort's comfort), and convey an engineering solution in economic terms (how much will it cost and what are the operational costs). The solution requires a higher level of assessment and management of risk and application of creative thinking (i.e., the system must be upgraded to supply the hotel with water). To be successful for this assignment, the students must evaluate the customer value and economic viability, test concepts via customer engagement (i.e., at various intervals of design, ask the instructor for feedback), assess policy and regulatory issues (i.e., how much water can be taken from the lake, what electricity load is possible, what is the environmental impact), and validate market interest (i.e., does Uncle Mort approve of the proposed solution). Note also that the student must look ahead to ensure a working solution; the frost depth is 42 inches meaning that the pipeline must be buried to at least that depth to prevent winter freezing.

But what about the fundamental core attribute of EML: discovery through curiosity which leads to identification of unexpected opportunities to create extraordinary value? Or what about exploring a contrarian view of accepted solutions? Admittedly, these may be the most difficult attributes to embed within an EML assignment. One method is to leave the problem so open-ended that the students must create their own problem statement. This creates two issues: 1) the students may not be at a high enough educational level to formulate a problem with the necessary rigor to accomplish the content learning objectives of the course, and 2) the problem will likely lack many of the EML attributes. Instead using an instructor-developed problem statement, the instructor can "hide" unexpected design alternatives that the students must discover with scant clues (much like "Easter eggs" hidden in movies or DVDs). When discovered the design alternatives prove to have added value over a traditional design (i.e., value creation). In this case there is one minor clue given: the hillside continues above the cottage/hotel another 400 vertical feet to the summit in 600 ground feet. This is clearly very steep and seems like a useless piece of information to the fluid mechanics student. With a little bit of investigation (curiosity), the student may discover that the pressure for many water systems is supplied via an elevated tank. To supply the water directly from the lake to the cabin requires a very large pump which is both expensive to purchase and expensive to operate. It is almost impractical to upgrade the pump(s) to supply the water needs of an entire hotel. Thus, a water tank can be placed on top of the hill. A relatively small pump can be run at night (when electricity rates are cheapest) to fill the tank. During the highest use of water at daytime, the tank will supply ample pressure and flowrate. A sensor in the tank can detect when the water level is low and kick-on the pump during the day if necessary. For this solution, no upgrade is needed later. The tank will work fine for Uncle Mort and later for the hotel.

It is through these "hidden" opportunities that the students can begin to employ effectual thinking. The student has a set of means (e.g., all the technical content of fluid mechanics, the ability to explore typical water systems, etc.); they must formulate/devise the imagined ends.

When using this problem, about half of the student teams either discovered the elevated water tank concept or were able to figure it out via well-posed questions to the instructor. Note here that the instructor will need to jump back-and-forth between playing the role of Uncle Mort and the instructor. In other words, the instructor should guide the student to create value for others; it is not expected that they have enough real-world experience to find some of these "Easter eggs." For the students who did not discover the optimum solution, a review/reflection session concerning the solution alternatives solicited a few groans of surprise; they will not soon forget the lesson learned. Note that students excluding an elevated water tank will still fulfill the technical learning objectives and should perhaps receive full credit for the project. Those students which discovered the unexpected opportunity and/or created extraordinary value can receive bonus points.

3.2. Other Ideas for Incorporating Discovery, Opportunity Recognition, and Value Creation into PBL Assignments

Of course there are many projects available that can use a real stakeholder/customer and not an imaginary person such as Uncle Mortimer. There are plenty of real world problems throughout industry wherein the actual customer can be contacted. For the cases presented in this paper, the author has used the same customer (Uncle Mort) for eight EML assignments (and counting) over the past four years. He has found that this has created some "excitement" among the students within the college. Uncle Mort is beginning to "show up" in senior design projects and is anticipated by students enrolling in fluid mechanics courses. (What new thing is Uncle Mort up to now?) In addition, students in the senior-level fluids laboratory course (taken about one year after fluid mechanics) are creating problems for the fluid mechanics instructor to use. They are displaying an interest in the entrepreneurial mind. Of course, Uncle Mort is meant to be humorous and has taken on quite a detailed personality at this point. If the students are enjoying the setting, they are better situated to learn. In essence, it may be worthwhile to create your own reoccurring customer. (As another example, some instructors have "created" a non-profit benevolent foundation to solve societal problems.)

In one assignment, Uncle Mort and Aunt Theodosia were going to have a 20 feet by 12 feet salt water aquarium installed in their mansion. Upstairs in Uncle Mort's office, he wanted a small aquarium which he figured could operate from the same pump. Of course, Uncle Mort is not a fluids engineer, so when the students attempted to design a system using a single pump, the cost and size requirements were unreasonable. Only a few teams discovered that a small $10 pump should operate the upstairs aquarium.

For another assignment, Uncle Mort purchased one of the man-made islands off the coast of Dubai to be used as a residence for extended stays to manage his oil interests (see Figure 4). The island needs a desalination plant and its requisite piping system to supply potable water to the island. Most students designed the water system to be supplied by a large pump at the island shore feeding seawater directly into an expensive reverse osmosis desalination unit. They overlooked a single sentence in the problem statement: "Note that Uncle Mortimer's Island is 2.5 miles from the coast of Dubai." This gave students the option to run pipeline from the Dubai city water supply, determine the pump size, and forego the need to design a desalination piping system. Alternately, the students could design a desalination system that operates with cheap fuel oil (as opposed to a reverse osmosis unit) which Uncle Mort has easy access to. As a third alternative, the students could have explored options for energy recovery pumps common on large desalination plants reducing energy costs. All of these options come with economic advantages and disadvantages. The students needed to discover the extraordinary value.

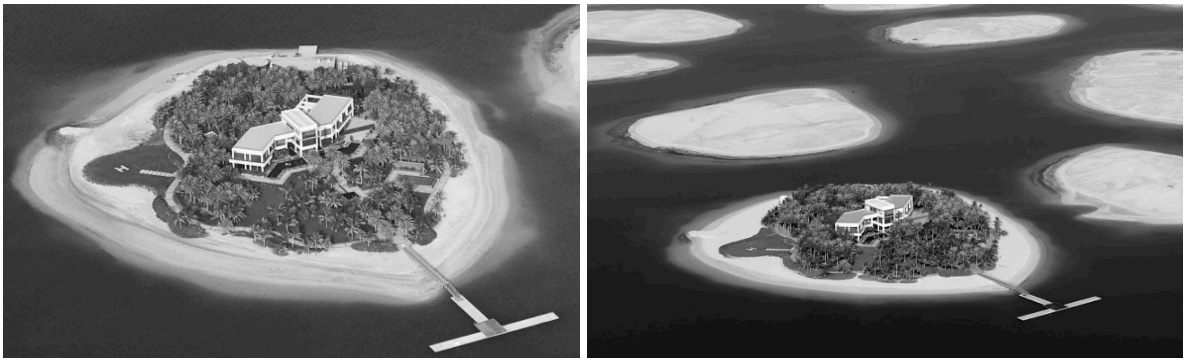

Figure 4. Dubai Islands for sale.
(Home Designing, 2017; Private Islands, 2017)

Additional EML projects have included swimming pool filtration systems for one of Uncle Mort's Florida hotels, a fire suppression system for his "expensive toys garage," a fountain for the Overlook Hotel, a warm weather skiing surface which employs a sprinkler system, and a hydraulic gantry crane to move his 2015 Ski-Doo Renegade X snowmobile valued at $19,000 up and over his 2002 Ferrari Enzo valued at $1,300,000 (Liu et al. 2015; Mynderse et al., 2015).

The incorporation of EML into the classroom is not limited to fluid mechanics. Any engineering course (and in fact any prerequisite math or science course) has opportunities for real world EML assignments. While a thorough description of some of those already employed is beyond the scope of this paper, many can be found in the references (Liu et al. 2015; Mynderse et al., 2015; Gerhart et al., 2014; Melton, 2015) and include heat transfer, mechatronics, wireless communications, structures, and robotics.

When grading the EML assignments, many of the total points are allotted for the process employed by the students (or how they thought). For example, some student teams completely forget to ask important details about the customer needs and thus end up solving a problem that either did not exist or is missing an important aspect. While final technical results are important, they are highly dependent on the value to the customer.

4. Assessment of EMLs

Because EML is a new approach to engineering education, assessment strategies and methods for both 1) the quality of the assignments and 2) the student learning have not been validated and tested for reliability. In addition, it is not a simple task to measure concepts that are often deemed subjective such as value, "identifying unexpected opportunities" (was the opportunity really unexpected), or "managing risk" (was there really a risk for the student). Of course many of the example behaviors are mindsets, thinking patterns (e.g., effectual vs. causal), or attitudes; these can be difficult to measure. Therefore a few different assessment approaches have been piloted which include both direct and indirect results. Note that all of the pilot assessments have been performed with fairly small sample sizes. These results should be viewed as preliminary and indicative only of very general trends.

4.1. Direct Assessment

Direct assessment was performed on the students' reports from the Wilderness Resort Lodge EML assignment. Note: while this assignment was developed by the author with a few years of EML experience and used twice by him, the results given here are from its deployment at another university by a faculty member with limited experience using EML. In addition, the assignment was completed individually by each student (which will remove the collaborative outcome, but arguably still allows for the practice of the entrepreneurial mindset as it pertains to the three Cs – curiosity, connection, and creating value). Student group discussions were encouraged during the duration of the assignment. For this assessment, the instructor focused on the three Cs when assessing students' final reports. As indicated in Table 2, the instructor counted the number of students who complied with each statement out of a total of 30 students (given in percentage).

Table 2. Percentage of student complying with the statement upon reporting results for the Wilderness Resort Lodge EML assignment.

Curiosity	
56.7 %	There are clear contributions to the project beyond that of the minimum requirements given in project hand-out
56.7 %	Methods for the additional contributions were identified. (e.g., mathematical equations, literature research, etc.)
10 %	Possible alternative solutions were identified (e.g., use tank with low-volume flow rate pump and have entire system gravity-fed).
Connections	
100 %	Information from multiple sources were used to generate the solution. (e.g., prior experience and common sense, preliminary design feedback from instructor, lecture notes, online resources, etc.)
90 %	Multiple facets of the project were addressed (plan of pipe layout, engineering feasibility study, accounting for installation and operating cost)
33.3 %	Risk and contingencies were addressed (which was not required).
Creating Value	
13.3 %	Unexpected opportunities/value were explored
30 %	Novel, unique, unexpected approaches/conclusions/solutions were discussed.
16.7 %	Cost-saving possibilities were considered (e.g., use tank with low-volume flow rate pump at nightly electricity rates, solar power for pump, variable diameters)

Under Curiosity, only 10% of the students discovered the alternate solution. This is not surprising as these students have had very little to no practical experience in large water supply systems. In this case it may be valuable to prompt the students to question every aspect of the given problem statement. A single seemingly random sentence ("The hillside continues above the cottage/hotel another 400 vertical feet to the summit in 600 ground feet.") may not be sufficient to incite curiosity.

For Connections, the results of 100% and 90% compliance is further implication that a problem-based learning format inherently requires the student to gather and integrate information from a variety of sources. On the other hand, managing risk is not typically inherent to a well-formed PBL assignment, so it is encouraging to find that a third of the students did account for contingencies.

For Creating Value, the results of 13.3% and 16.7% falls-in-line with the 10% result under Curiosity. It is encouraging that 30% of the students at least explored unique solutions.

4.2. Indirect Assessment

Next, results of indirect assessment are examined wherein students were surveyed at the conclusion of the Dubai Island Desalination EML assignment (before the reports were graded and returned). Thirty students responded to the survey, although five statements indicated with an * on the table were distributed to only eight students because of time constraints between two sections of the course.

For the most part, the average student ratings are encouraging as indicated in Tables 3 and 4. The students appear to at least be gaining an appreciation for the attributes of the entrepreneurial mindset. No response is less than 3.00 and half of them are 4.00 or higher. As with the direct assessment results of the Wilderness Resort Lodge assignment, curiosity or discovery is ranked lowest as evidenced from statements 8 and 9 with ratings of 3.25 and 3.00, respectively. Related to discovering the unexpected opportunities, statement 11 wherein the students assessed risk (or searched for contingencies for their design) is also rated relatively low with a 3.37. While this may be a concern, the students are highly likely to not forget the lesson learned when the easier and cheaper solution was revealed during an after-assignment reflection session. It is hoped that the students will pose more questions (of both the instructor/expert and customer) on future projects.

The highest rating is for statement 16. The students spent significant time during the project gaining valuable insight about the island and its use by Uncle Mortimer (e.g., how often is the island inhabited, what is the maximum number of people on the island at a time, what are the specifications of the mansion, landscaping needs, etc.). Unfortunately, the students did not ask about the resources available to Uncle Mort which could assist in the technical and economic aspects of the design (e.g., how cheap can you obtain fuel oil).

Table 3. Students' mean rating of statements concerning the Dubai Island Desalination EML assignment. On a scale of 1 to 5, 1 indicates "strongly disagree" and 5 indicates "strongly agree."

	average	std. dev.
1. My project design satisfied the customer's needs and goals.	4.16	0.58
2. I consider the results of my project successful.	4.13	0.67
3. I found my work on the project to be satisfying.	4.03	0.75
4. The real-world application of the project motivated me to do my best work.	4.10	0.83
5. The open-ended nature of the project motivated me to do my best work.	3.83	0.93
6. The project improved my technical skills in reporting a solution to a customer.	3.79	0.97

Table 4. Students' mean rating of statements concerning the Dubai Island Desalination EML assignment. The scale is 1 = none at all, 2 = slightly, 3 = on some occasions, 4 = many times, 5 = throughout most of the project. (Statements with * were only distributed to 27% of the students.)

During the course of this project, to what extent did you:	average	std. dev.
7. Explore a contrarian view of accepted (i.e., typical) solutions.*	4.00	0.53
8. Identify an unexpected opportunity for your design.*	3.25	0.71
9. Create extraordinary value for a customer or stakeholder.*	3.00	1.07
10. Integrate information from many sources to gain insight.	4.07	1.00
11. Assess and manage risk.	3.37	1.05
12. Persist through failure.	3.71	1.22
13. Apply creative thinking to ambiguous problems.	3.80	0.83
14. Apply systems thinking to complex problems.	3.83	0.86
15. Evaluate economic drivers.*	3.50	1.07
16. Examine a customer's or stakeholder's needs.*	4.50	0.76
17. Understand the motivations and perspectives of others.	3.96	0.84
18. Convey engineering solutions in economic terms.	3.57	0.97
19. Substantiate claims with data and facts.	4.09	0.79
20. Work with your team.	4.17	0.90

Finally, the Gantry Crane EML assignment was assessed via student surveys. This assignment was used in fluid mechanics, heat transfer, and mechatronics courses simultaneously. The students from each course were only responsible for designing the parts of the system pertaining to their respective course. Full results (including direct assessment by the instructors regarding the PBL aspects of the problem) are available in references Liu et al. 2015 and Mynderse et al., 2015. A summary of the fluid mechanics student results are given in Tables 5 and 6. Twenty-one students completed the survey. It is important to note that the Gantry Crane assignment did not include any hidden clues, thus unexpected opportunities and extraordinary value were less likely to arise, and in fact survey statements pertaining to those attributes were not included at the time of the assignment.

Table 5. Students' mean rating of statements concerning the Gantry Crane EML assignment. On a scale of 1 to 5, 1 indicates "strongly disagree" and 5 indicates "strongly agree."

	average	std. dev.
1. My project design satisfied the customer's needs and goals.	4.05	1.00
2. I consider the results of my project successful.	3.95	0.97
3. I found my work on the project to be satisfying.	3.81	1.05
4. The real-world application of the project motivated me to do my best work.	3.81	0.91
5. The open-ended nature of the project motivated me to do my best work.	4.00	0.76
6. The project improved my technical skills in reporting a solution to a customer.	3.82	0.79

Table 6. Students' mean rating of statements concerning the Gantry Crane EML assignment. The scale is 1 = None at all, 2 = slightly, 3 = on some occasions, 4 = many times, 5 = throughout most of the project.

During the course of this project, to what extent did you:	average	std. dev.
7. Integrate information from many sources to gain insight.	4.19	0.80
8. Assess and manage risk.	3.81	0.67
9. Persist through failure.	4.19	0.66
10. Apply creative thinking to ambiguous problems.	4.05	0.79
11. Apply systems thinking to complex problems.	4.19	0.66
12. Understand the motivations and perspectives of others.	4.00	0.62
13. Convey engineering solutions in economic terms.	3.81	0.91
14. Substantiate claims with data and facts.	4.29	0.63
15. Work with your team.	4.38	0.73

The ratings are generally similar to those for the desalination assignment, if not a bit higher. Higher ratings are likely due to the nature of the assignment; the problem was slightly less complex with less information needed from the customer.

4.3. Student Comments

For the Dubai Island Desalination and Gantry Crane projects, students were asked what they liked or appreciated about the project. Many of the students commented that they appreciated the real-world and open-endedness of the projects. A few students commented that they liked the creativity that they were able to use. One student completing the desalination project commented, "I enjoyed being able to think on my own to determine how this system would best suit Mortimer while using my engineering knowledge I've gained in this class and in previous classes."

Students were also asked what should be changed about the projects. Three students responded that too much detail was given that was not needed. Of course this is a typical situation an engineer faces in industry – the need to sort out relevant from irrelevant information. Interestingly, some of the information or detail that was deemed unnecessary proved to be highly valuable, as one student commented, "Although it was a real world scenario, I felt a lot of details weren't defined and it created more questions. For example, we didn't know if the 2.5 miles off of Dubai was pertinent information." It was, and that is exactly what the student should be asking the instructor about. Nineteen students responded that more information, guidelines, or constraints should be given. One student commented on the Gantry Crane project: "I feel like a bit more directions should be included to narrow down what's needed to be included and what's not, at least budget-wise." By design, much information should be left out of the EML (or PBL) problem statement, as this is the case in a real-world engineering problem. The student should be learning to ask questions or search for relevant information.

5. Conclusion

When creating entrepreneurially minded learning activities for a course, it is important to keep in mind the different way an entrepreneur thinks using effectual logic rather than a typical engineer using causal or predictive logic. EML assignments should prompt the students to look beyond the technical aspects of the problem and not just focus on a single solution or the most common solution. Economics should play an important role in the evaluation of the problem being solved. One particular EML method explored in this paper involves the inclusion of unexpected design alternatives that the students must discover with scant clues which may help to incite discovery and opportunity recognition. Typically the design alternatives should create added value for the customer over traditional design.

EML assignments differ from PBLs in that they often include a stakeholder or customer. Because stakeholder feedback is essential to re-evaluate opportunities and/or understand what is deemed as valuable (i.e., value is subjective), it is important for the assignments to include a realistic customer (who can be a fictional role-player). This is important to entice effectual over causal thinking. To add some enthusiasm and consistency to the EML assignments, an instructor can use similar themes between courses (or a consistent customer). A bit of added humor adds some enjoyment for the students.

Preliminary assessment indicates promising results both directly and indirectly. Students are at least noticing the importance of effectual logic and the implications of a solution for a stakeholder.

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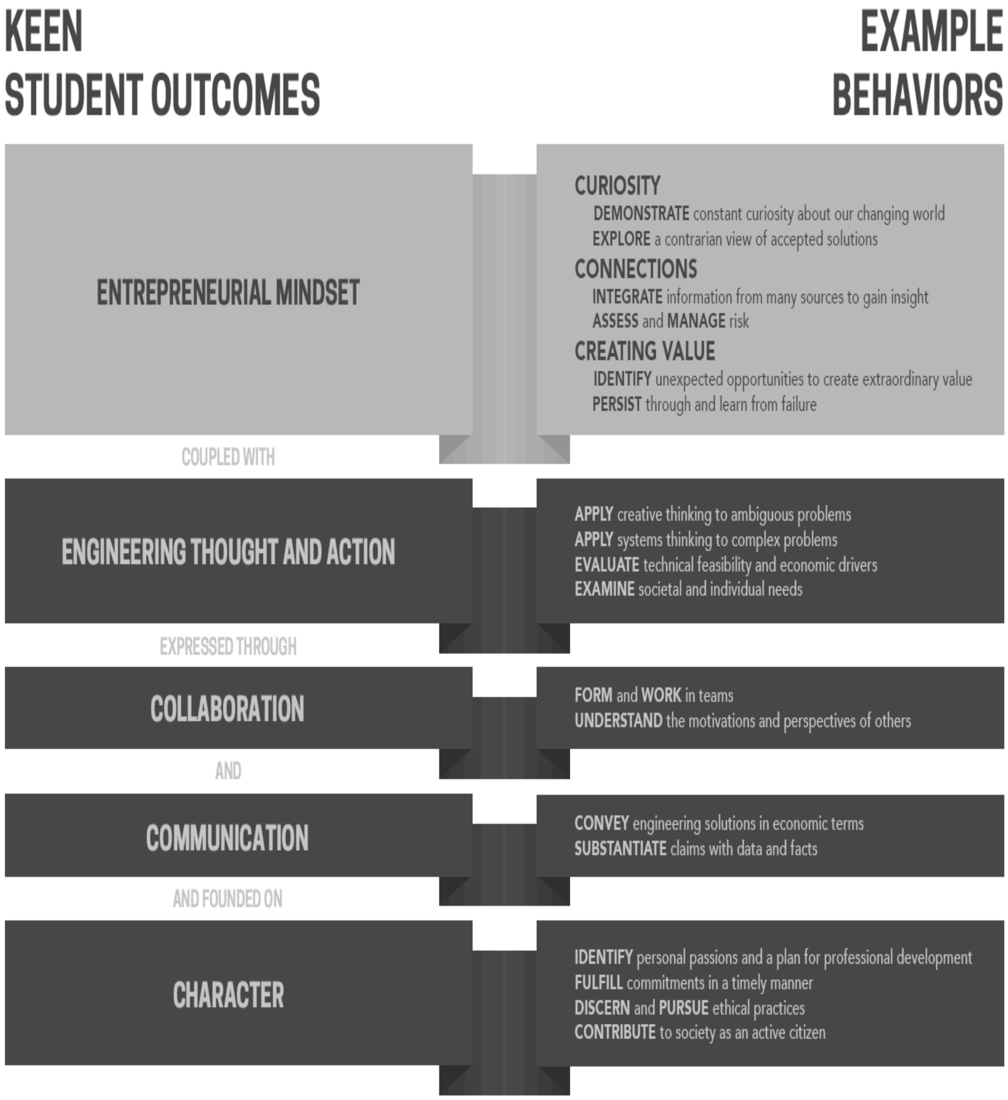
Appendix: Kern Entrepreneurial Engineering Network Framework

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Perform technical design
Communicate an engineering solution in terms of societal benefits
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Analyze solutions
Validate market interest
Evaluate technical feasibility customer value societal benefits economic viability
Develop new technologies (optional)
Develop partnerships and build a team
Test concepts quickly via customer engagement
Create a model or prototype
Identify supply chains distribution methods
Assess policy and regulatory issues
Validate functions
Protect intellectual property
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