Full Paper: A Framework for Engineering Problem Scoping Leading to Mindful Engineering Problem Solving

Cassie Wallwey, Virginia Polytechnic Institute and State University

Dr. Cassie Wallwey is a Collegiate Assistant Professor in the Department of Engineering Education at Virginia Tech. Her research interests center on student-centered and inclusive learning practices and principles including student engagement in learning, feedback and assessment, self-regulation of learning, and student motivation. Cassie got her PhD in Engineering Education from Ohio State University and her MS and BS in Biomedical Engineering from Wright State University.

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Introduction & Project Background

The title of engineer is becoming increasingly synonymous with "problem-solver," which is accurate given the responsibly of engineers to actively participate in innovating solutions to research, industry, and societal challenges both small and large. To this point, widely recognized and well-regarded institutions of higher education frame the field of engineering research and practice as the world's "problem solvers" on their college's websites or home pages (e.g., [1], [2]). In the last twenty-five years there have been calls for the ongoing need for entrepreneurial innovation to support national and global economies and growth [3] – some of these calls and explorations of what this might look like have been specific to engineering fields [4]. There are many interpretations of what entrepreneurial innovation looks like in the education and training of engineering students to better prepare them for societies' needs and demands. For the work presented in this paper, entrepreneurship in engineering education is being conceptualized as aspects of a student's engineering education the support the development and growth of students entrepreneurial mindset (EM) - which is defined for this work as a collection of mental habits that put particular focus and emphases on engineers' impact and value in our society [5].

This work's framework of EM comes from the ongoing work of the Kern Entrepreneurial Engineering Network (KEEN). This network is a coalition of 61 universities that is working to better grow and develop an entrepreneurial mindset (EM) in engineering students to prepare them to address societal needs and global challenges. Through Entrepreneurial Minded Learning (EML) and the 3C framework (Curiosity, Connections, and Creating Value) [5], engineering programs within the KEEN network and faculty engaging with the network through their many faculty professional development programs [6] are working to equip students with entrepreneurial mindsets to accompany their "standard" engineering curriculum skills sets.

There is literature that has documented the integration of EM and EML implementation within various programs and universities using a variety of assessment tools and metrics. Scholarship in these spaces have noted improvements to student learning / performance outcomes related to professional skills, customer-focused design, global awareness, and increases in students demonstrating curiosity, connection-making, and value recognition and creation – to name a few examples [7]-[10]. The majority of EML curricular integration has happened in problem-solving and design-focused spaces and courses, but this works seeks to better understand if introducing EML before problem-solving or engineering design focused lessons, activities, or projects sets students up to more readily carry those mindsets into their own engineering design processes.

First-year engineering students are often excited and eager to begin their journey as engineers. As such, they are often so eager to put on the "problem solver" hat that they jump to a single design solution before fully considering and understanding all aspects of the problem they seek to solve as well as the ethical, societal, environmental, and economic impacts (value added /

created or potential shortcomings / unintended consequences) of multiple possible solutions – skipping an important step in the engineering design process that is referred to as "problem *scoping*" at my current institution. We define problem *scoping* (which precedes problem *solving*) as learning all there is to know about the problem, its direct and indirect stakeholders and their relationships with one another, current solutions already in place or attempted in the past, and their widespread social, economic, and environmental impacts, as well as the ethical and social responsibilities of engineers - all prior to designing and evaluating possible design solutions.

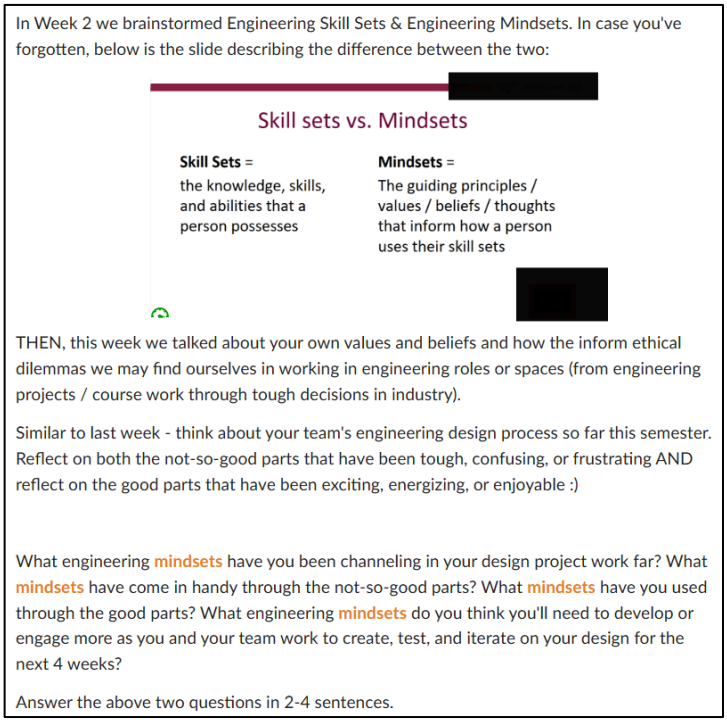
A series of modules (lessons, activities, and assignments) were designed using the KEEN Network's 3C Framework for EM and implemented to help "slow down" students' problem-solving process and encourage them to spend more time scoping a problem before creating their own innovative solutions through design ideas while simultaneously engaging EM. These modules were implemented through the "problem scoping" portion of the design process in a first year engineering course sequence. While these modules were designed to aid students in engaging an EM throughout problem scoping, I was curious to know if introducing and practicing EM at the problem *scoping* phase of the engineering design process led to an increase in EM later in the semester when students were in the problem *solving* (design, build, test, revise) phase of their design project.

Specifically, the research question that guided this exploration was: *Do students who were taught problem scoping leveraging the EM 3Cs framework self-report more instances of engaging mindsets related to EM throughout the problem-solving design portion of the first-year program sequence?*

Project Evaluation Methods

To answer this question, two first-year engineering course sections (both completing the same design project assignment) were considered. One section was taught ill-structured problem scoping by using problem scoping modules that I designed to engaged students EM by leveraging the 3Cs and then moved on to do the design/build portion of the first-year course curriculum with myself as the instructor. The other section of students was taught ill-structured problem scoping through a standard format by various other instructors in the department, but then were all enrolled in my section of the course for the design/build portion of the first-year course curriculum. Both sections started each course with the first couple of lessons being brainstorming, discussing, and mapping of engineering skill sets and mindsets they have and/or aspire to develop in college. These lists of skill sets and mindsets were primarily student generated, but I ensured EM-related skill sets and mindsets also were included in the discussions and mappings if they weren't identified in the student's brainstorm portion. I note this to clarify that both sections had equivalent exposure to terms such as "mindset", and examples of mindsets such as "curiosity", "empathy", etc. before engaging in the design project.

Mid-way through the design project, both sections of students were asked the same question on an in-class weekly check-in survey. Figure 1, below, depicts that question that students were prompted to answer.


In Week 2 we brainstormed Engineering Skill Sets & Engineering Mindsets. In case you've forgotten, below is the slide describing the difference between the two:

Skill sets vs. Mindsets

Skill Sets = the knowledge, skills, and abilities that a person possesses

Mindsets = The guiding principles / values / beliefs / thoughts that inform how a person uses their skill sets

THEN, this week we talked about your own values and beliefs and how the inform ethical dilemmas we may find ourselves in working in engineering roles or spaces (from engineering projects / course work through tough decisions in industry).

Similar to last week - think about your team's engineering design process so far this semester. Reflect on both the not-so-good parts that have been tough, confusing, or frustrating AND reflect on the good parts that have been exciting, energizing, or enjoyable :)

What engineering mindsets have you been channeling in your design project work far? What mindsets have come in handy through the not-so-good parts? What mindsets have you used through the good parts? What engineering mindsets do you think you'll need to develop or engage more as you and your team work to create, test, and iterate on your design for the next 4 weeks?

Answer the above two questions in 2-4 sentences.

Figure 1: Image of the open-ended survey prompt provided to students mid-way through their design project in which they were solving a design problem of their 6-student design team's choosing.

These survey responses from both sections were analyzed by using the KEEN Network's recently released Habits of Entrepreneurial Mindset guidelines that are meant to build upon the existing 3Cs KEEN Framework. The KEEN Network leadership writes in their recently released document that its purpose is to drive home "the importance of cultivating mental habits rather than merely labeling activities as embodying the 3Cs" [11, pg. 1]. They also write that this expansion of language and vocabulary in their framework beyond the 3Cs should serve as "a tool for faculty to sharpen the definitions of the 3Cs with specific characterizations, reinforcing that EM is a collection of interrelated mental habits" [11, pg. 1].

In accordance with these recommendations, I utilized this expanded Habits of EM Framework as a lens with which to read students' responses to the survey question shown in Figure 1. Any time a student expressed having used a "Habit of EM" in their design project or plans to use or develop a "Habit of EM" in the future of their design project, a tally was placed under that "Habit of EM".

Project Evaluation Results and Implications

Table 1 depicts the counts for across all Habits of EM for each of the two sections. The two sections (both with enrollments of 72 students) had 68 and 65 students complete the survey, respectively. It should be noted that while the Habits of EM are meant to expand upon and be

more specific as to how students can embody the broader 3C Framework, quiet a few habits are mapped back to general categories, three of which are curiosity, connections, and creating value.

Table 1: Counts of instances of students bringing up Habits of EM in responses to the reflection question posted in Figure 1.

HABITS OF ENTREPRENURIAL MINDSET		3C Framework Problem Scoping Lessons / Activities / Project	Standard Problem Scoping Lessons / Activities / Project
Curiosity	Inquisitive	6	1
	Contrarian Thinking:	11	8
	Opportunity Seeking	2	1
	Experimentation	3	2
	Embracing Ambiguity	3	1
Connections	Creativity	16	8
	Systems Thinking	5	0
	Implications Thinking	1	0
	Strategic Thinking	0	4
	Assess and Manage Risk	0	2
Creating Value	Value Awareness	1	0
	Customer-Centric Thinking	9	0
	Scale	0	0
	Persistence	8	15
	Socially Mindful	0	0
Action Orientation / Agency	Initiative	2	4
	Resilience	16	16
	Continuous Improvement	8	5
	Adaptable	15	10
	Resourcefulness	10	12
EM-Enhancing Foundation	Character	4	0
	Growth Mindset	6	2
	Intellectual Humility	0	0
	Accountability	1	6
	Metacognition	0	0
	TOTALS	117	85

The total counts in this table indicate that the answer to the research question posed is, yes – the section that was introduced to problem scoping using a framework that was based on the 3Cs did

bring up more Habits of EM in their responses overall. However, when looking category by category across the five broad EM habits in the left-most column, some categories have rather distinct differences (Curiosity: Δ12, Connections: Δ8, and Action Orientation / Agency: Δ6), but in others don't have particularly large differences in each category (Creating Value: Δ3, EM Enhancing Foundations: Δ3).

There are also interesting observations to be made with regards to individual line items. For instance, the mention of "creativity" is double for the section that learned problem scoping through the 3C framework, but alternatively, mentions of "persistence" is nearly double for the section that learned problem scoping in the standard course format. This lop-sided reporting can also be observed between "growth mindset" and "accountability" within the same overarching EM Habit category of "EM-Enhancing Foundations". For both sections, however, the EM Habits category with the most mentions were the "Action Orientation / Agency" habit. Anecdotally, I hypothesize that this is the case due to where in the design process this week's check-in fell in the overall course. In both sections this question was asked approximately one week before the criteria testing results of the first prototype were due, so around this point is when many teams would be finalizing their initial prototypes or testing their initial prototypes against their established criteria. At this point many teams are identifying ways in which their designs may not work as they had planned, thus very possibly inspiring the responses that mapped to this category most readily based on their location in the engineering design process cycle.

One additional salient mindset that didn't map to the "Habits of EM" as they have been presented to the KEEN & Engineering Unleashed Faculty Development community [11] was many mentions (21 for the 3C Framework section and 19 for the Standard section) of a "teamwork" and "collaborative / collaboration" mindset. This result is worth reporting as, while it wasn't as prevalent a mindset as the EM-related mindsets, it was brought up by students as important and impactful more than any one singular line-item mindset presented in Table 1 for both sections.

While the results of this small sample of only two sections of first-year engineering students indicate that students self-report having engaged in (or future plans to engage in) Habits of EM in the problem-solving engineering design process more when the KEEN 3C framework was used to facilitate lessons and activities related to problem scoping, the magnitude of *how much* more was inconsistent across the five broad Habits of EM categories and individual habits within those categories. This indicates that while the larger trend presented here may suggest that earlier introduction may lead to more entrepreneurial mindset activation in the future, it is by no means a guarantee. In fact, I believe these results more readily speak to the importance of engineering educators being diligent in communicating the importance, utility, and benefits of students identifying and developing habits of EM across the entirely of a course, project, or curriculum.

The differences between these two sections, and in particular the inconsistencies by row and variation in differences indicates to me that students who engaged in lessons and activities that intentionally engaged students in these habits of mind don't consistently self-report leveraging these habits significantly more across the board. For this reason, I believe there remains an

ongoing need for continued development related to best practices in how to engage students in entrepreneurial mindset growth and development throughout the engineering curriculum. Our educational community should embrace opportunities to reinforce these habits as much as we can to best prepare our engineering students to live up to the title of "problem-solver" that our society has placed on them.

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