

## **A Scaffold and Competency-Based Learning Approach to Innovation-Related Thinking Frameworks**

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## **A Scaffold and Competency-Based Education Approach to Introduce Innovation-Thinking Frameworks**

*Abstract*—Over the past several years, interest in competency-based education has steadily increased particularly in relation to vocational education, which prepares individuals for careers requiring specific craft, trade, or technical skills. In these cases, competencies are commonly “obtained and demonstrated” through distance learning by watching short videos, completing assignments, and passing online assessments demonstrating student ability to accomplish a series of learning objectives. This approach to competency-based education ensures students are able to master “doing” but provides little emphasis on “thinking.” As such, little is known about how to incorporate competency-based education into traditional and professional bachelor degree programs such as engineering, which requires a greater focus on knowledge and skill integration. The purpose of this paper is to highlight a new approach to learning that goes beyond the proverbial “checking boxes” to provide an approach for demonstrating the integration of abilities and reflection. This innovative and experimental approach offers three unique attributes. First, it is competency-based in that students are required to demonstrate mastery of meeting core innovative competencies through submission of an artifact (“transdisciplinary-doing”) and reflection (“transdisciplinary-thinking”). Second, it is transdisciplinary in that learning experiences integrate the humanities into engineering, design, and technology skill sets. Finally, it is scaffold in that instruction of each of the four modules builds on the other, further enhancing and grounding the learning experience. This paper will explain our unique yet standardized approach through a semester-long course introducing engineering and technology students to innovation-related frameworks as an immersive approach to increase deeper transdisciplinary thinking through innovation. This funnel method is intentionally applied to guide students from (a) System’s Thinking - big picture, holistic perspective to (b) Design Thinking - human-centered approach to problem solving to (c) Problem-Market Fit Analysis – value proposition identification, connecting customer needs to features of the product bundle to (d) Business Model Development – identifying and evaluating key abilities required to support bringing a new product to market. This funnel down innovation approach assists students in narrowing their scope and, at the same time, offers them a continuous push towards transdisciplinary doing and thinking.

*Keywords*—*competency-based, innovation, interdisciplinary, scaffold, mastery*

## 1. Introduction

Engineers play a critical role in the economy by addressing pressing problems and creating solutions that are new and innovative. This role is not played in isolation, but rather requires collaboration and leadership. It is a role that involves technical skills but also requires curiosity, an ability to connect pieces of knowledge to discover solutions, and a focus on value creation—which are all characteristic of innovation-thinking frameworks such as entrepreneurial-minded learning [1], systems thinking [2], design thinking [3], value proposition canvas [4], and business model canvas [5]. These innovation-thinking frameworks are not just applicable for start-ups, and are not a matter of simply repackaging business for engineering students [6]; rather, they emphasize the development of innovation-thinking among engineering students that allows them to identify and solve problems. Because innovation-thinking develops over time and requires practice, the role of engineering educators is to discover opportunities throughout a student’s coursework to infuse this approach into learning [7].

One approach to innovation-thinking is through the scaffold and competency-based education. The benefit of scaffold learning is that it progressively and iteratively leads students towards greater learning and depth of understanding [8]. The benefit of competency-based education is the focus on subject mastery [9] and authentic learning [10]. The research question is as follows:

1. How can the new approach improve students’ understanding of why the approach is important for the workforce and future employment?

This paper will explain our unique, yet standardized approach through a semester-long course introducing engineering and technology students to innovation-related frameworks. This scaffold and funnel approach to design and innovation is intentionally applied to guide students from (a) System’s Thinking - big picture, holistic perspective to (b) Design Thinking - human-centered approach to problem solving to (c) Problem-Market Fit Analysis – value proposition identification, connecting customer needs to features of the product bundle to (d) Business Model Development – identifying and evaluating key abilities required to support bringing a new product to market. This funnel down innovation approach helps students narrow their scope, while at the same time, the continuous push towards transdisciplinary doing/thinking has students thinking “outside the box”.

## 2. Background

### 2.1 Competency-Based Education

“Competency-based education (CBE) is an outcome-based, student-centered form of instruction whereby students progress to more advanced work upon mastering the necessary prerequisite content and skills [11].” Although CBE is not new, it has increasingly been receiving much attention as a method for reaching a more diverse and inclusive student population. Scholtz and colleagues [12] shared results from an intervention conducted in an information systems degree program which incorporated competencies based on enterprise resource planning (ERP) systems. They found that students perceived satisfaction with the hands-on approach and there was an increase in student self-efficacy related to ERP systems and concepts. Mojab et al [13] analyzed entrepreneurship education to determine what entrepreneurship competencies are ideal for information technology students. As a result, the

program has turned more towards analyzing multi-dimensional issues rather than simply focusing on task-oriented topics. McDonald [14] conducted a case study analyzing the impact of incorporating CBE self-paced mini-courses into traditional degree programs. The findings suggested an increase in student interest and motivation in comparison to students completing entirely self-paced CBE programs. Baughman, Brumm, and Mickelson [15] also completed a case study focused on implementing CBE within student professional development topics, resulting in five key course competencies for an undergraduate level industrial technology course. Throughout the course, students were assessed using a 360-degree evaluation process. The implications suggest the benefit of applying self- and peer-assessment techniques to CBE. □

## **2.2 Scaffold Assignments**

“Scaffolding assignments assist students as they generate solutions to complex problems, goals, or tasks, helping increase and integrate their higher order skills in the process. [16]” Scaffolding is a common pedagogical approach in higher education used to leverage prior learning and to promote higher level skill development. Wass and colleagues [17] conducted a longitudinal study to assess the influence of scaffolding on zoology undergraduate students’ development of critical thinking skills. Their analysis suggested the greatest benefit occurred when incorporating verbal scaffolding and lecture conversations. Raes and colleagues [18] performed a scaffolding experimental design within a science course aimed to increase information-related problem-solving. The three different experimental conditions were technology-enhanced scaffolding, teacher-enhanced scaffolding, and both. The researchers found that the ideal approach was both with a focus on multiple scaffolding. Belland et al. [16] conducted a meta-analysis of computer-based scaffolding in STEM. The results provided evidence that computer-based scaffolding positively affects cognitive outcomes regardless of the topic area and/or grade level. Together, CBE and scaffolding, have shown promising impacts with respect to self-regulated learning and student reflections [19].

## **3. Methods**

### **3.1 Participants**

Participants included undergraduate students enrolled in a newly offered bachelor’s degree program in transdisciplinary studies in technology. Ten students participated in the study, including five females and five males. All participants were enrolled full-time at the research-intensive university located in the Midwest, U.S.A. Five of the participants were freshmen, two were sophomores, and three were junior level students. The study design was approved by the university IRB #1808020877 as Exempt Category (1). As a result, students were notified that the class assignment would be used for research purposes.

### **3.2 Study Design and Data Collection**

At the beginning of the semester, students were given a design challenge: “How might University students, faculty, staff, and visitors better access to healthy and affordable food?”. This design challenge was chosen as it is relatable to students from multiple backgrounds, regardless of disciplinary focus. Throughout the semester, the students participated in a series of four scaffold modules (shown in Fig 1): (a) System’s Thinking - big picture, holistic perspective to (b) Design Thinking - human-centered approach to problem solving to (c) Problem-Market Fit Analysis – value proposition identification, connecting customer needs

to features of the product bundle to (d) Business Model Development – identifying and evaluating key abilities required to support bringing a new product to market. Each module included a design activity incorporating a new framework (shown in Fig 2) and a reflection component.

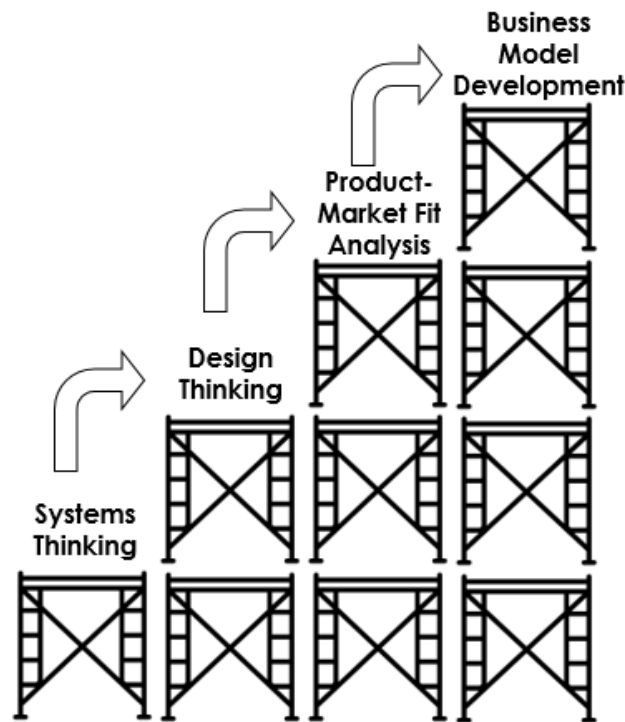


Fig. 1. Scaffold Modules

### Design Activities

Module 1: Systems Thinking is based on a philosophy that everything is interconnected and that a problem/opportunity must be examined within the context of a larger configuration. There are many parts of a problem/opportunity, and all the parts interrelate and create a system. Systems' Thinking is a tool that provides an understanding of the interconnectedness of all things. The artifact directions are as follows: (1) Use PowerPoint (or another visualization software) to draw the system from an Inputs-Processing-Outputs perspective. (2) Find at least three articles online which provide motivation for this challenge. Use the articles (URL footnotes at the bottom of the document) as support to justify and identify opportunities for improvement within each area of the system.

Module 2: Design thinking is a solution-focused method incorporating different perspectives and is often used by interdisciplinary teams. The iterative approach promotes a focus on innovation through experimentation. In addition, the human-centered nature of the process integrates continuous sharing of knowledge, feedback, and collaboration, as exemplified in this Empathy-based assignment. The artifact directions are as follows: Use the worksheets [modified version of dSchool Wallet Project] and associated notes taken during class to (1) provide an overview of the design thinking process and (2) summarize your key findings. The information should be limited to one 8.5 x 11 document and developed using software. □

Module 3: The Problem-Market Fit Analysis describes how value is created for the customer. The value proposition canvas visually shows how value is created for the customer. It ensures

the gains and pains of the customer jobs (customer needs) are identified, and solved by a specific product or service that relieves pain or creates gain (demonstrated by design features), while taking into consideration current solutions (competitive quantitative performance), and clearly explaining the value proposition summary (What are key differentiators distinguishing your product or service from current solutions?). Good customer interviews are a cheap and fast way to kick off the search and design of your problem-market fit. Here are a few hints for conducting interviews: Adopt a beginner's mindset, Listen more than you talk, Ask "why" to get real motivations, Remember: the goal is to learn, not sell, Always open doors at the end (provide a way for them to follow up as needed). The artifact directions are as follows: (1) Fill in the attached template based on your findings from the design thinking empathy assignment. (2) Identify your archetype. (3) Interview 5 people that fit the archetype. Ask questions to obtain qualitative feedback related to the problem-market fit. (4) Update the original filled-in value proposition canvas to account for the new findings. Use colors, shapes or other methods to clearly identify the new findings from the initial draft. The information should be limited to one 8.5 x 11 document and developed using software.

Module 4: Business Model Development, using the business model canvas, is a visual strategic management and lean startup template for developing new or documenting existing business models. It is a visual chart with elements describing a firm's or product's value proposition, infrastructure, customers, and finances. It assists firms in aligning their activities by illustrating potential trade-offs. The artifact directions are as follows: (1) Fill in the attached template based on your findings from the value proposition assignment. (2) Re-evaluate your customer archetype. (3) Interview 5 people that fit the archetype. Ask questions to obtain qualitative feedback related to the Business Model Canvas. (4) Update the original filled-in Business Model Canvas to account for the new findings. Use colors, shapes or other methods to clearly identify the new findings from the initial draft. The information should be limited to one 8.5 x 11 document and developed using software.

### Reflection Component

Upon completing each design activity, students were required to submit a five-page reflection responding to a standard set of self-regulated learning prompts [20-22]. An example sub-set of prompts are as follows:

- *Identify what type of job you might like to have in the future.*
- *Why is this competency important for this type of job?*
- *Why are assignments like these important in preparing you for entering the workforce?*
- *Why is development in the concepts, skills, and prior knowledge required for assignments like these important to future employers?*
- *In the future, how might you extend your knowledge related to this competency area?*

### **3.3 Data Analysis**

Data analysis included both an artifact and reflection for each of the four modules. Due to the qualitative nature of the research, the goal of the analysis was to explore potential consistencies, surprises and themes within the data. The NVivo 12 qualitative analysis software was used to analyze the reflections. NVivo allows for systematic coding and

management of themes. All data documents were imported into NVivo. The researchers reviewed, coded and analyzed the documents several times, and themes were identified [23].

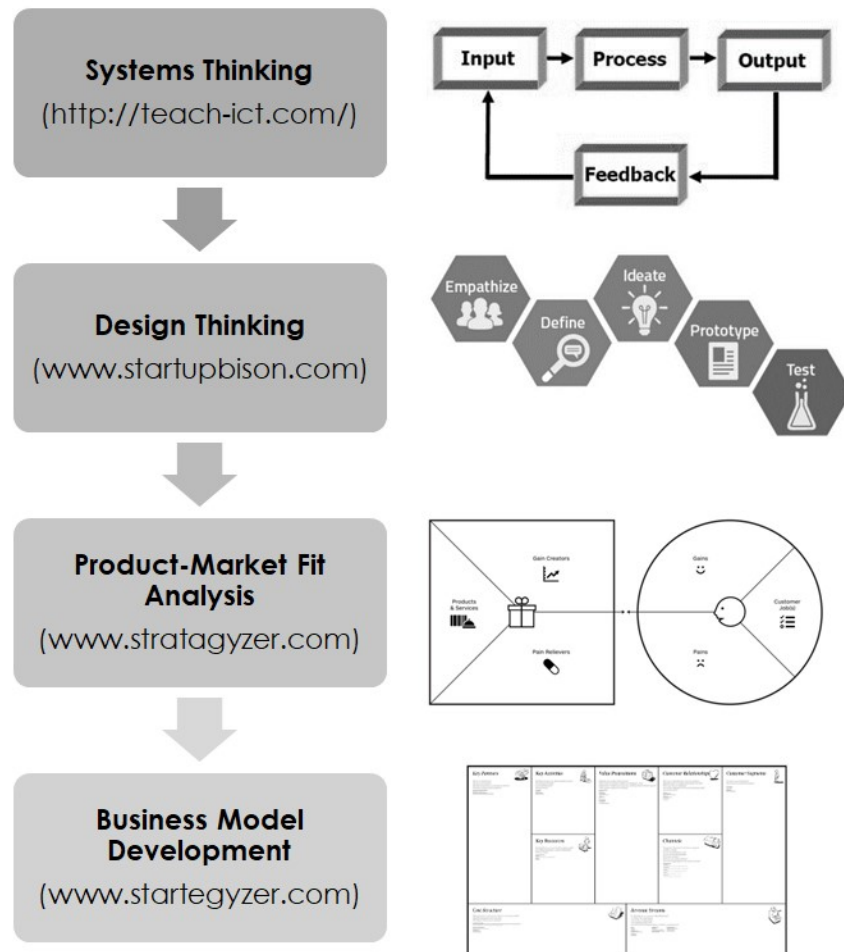


Fig. 2. Module Frameworks

#### 4. Results and Discussion

With regards to the Systems Thinking assignment, students were able to recognize why the learning activity was important outside of the classroom particularly in relation to workforce preparation and securing future employment. Throughout the reflections, students highlighted the importance of a holistic and practical approach to problem identification. Example quotes are as follows:

- *Once I go into the industry I realize it's much more effective to take a little more time to think about the decision rather than just diving into whatever action that I think is better at that exact point in time.*
- *If I were to find my future in marketing, I would most likely have to use systems thinking to develop a convincing advertising campaign by presenting why people need things, and how these things would help.*
- *From a personal standpoint, I think these types of assignments and reflection help define not only the student we are going to be but also the person we will be in the future.*
- *The assignment helped me to increase some of my knowledge about how inputs-processing-outputs diagrams help to showcase a problem in a systems-thinking way.*

- *Looking at a problem holistically and seeing how parts interact to bring about a solution will never be something that just disappears from this world.*
- *System thinking is also a skill that is largely desired nowadays - the ability to understand what needs to be done in what order and how it is to be done is the basis to a large part of any joy, and undoubtedly highly sought-after.*
- *This way of thinking can be very useful when dealing with big projects that are difficult to grasp at first.*
- *I can use this perception in system thinking in my future development to consider the impact of what I design or use to design to help the whole system rather than just the current subject.*
- *This assignment allowed me to better understand multiple concepts at once without spending days and or even hours on an assignment.*

In response to the Design Thinking assignment, students were able to recognize why the learning activity was important outside of the classroom particularly in relation to workforce preparation and securing future employment. Throughout the reflections, students highlighted the importance of developing empathy through active listening, the importance of feedback, and the necessity to gain multiple perspectives. Example quotes are as follows:

- *To an employer, someone that is deeply grounded in design thinking is sure to be more rational and less brash when making important deals.*
- *It is my hope that by learning the skills of interviewing, communicating, empathizing, ideation, iteration, research and inquiry, I will have more success at creating less biased work and working well with a team.*
- *Design thinking is critical to working in a team because there is room for feedback from people who may have different perspectives than you.*
- *It is important for society to have the skill of design thinking because that way products are designed with the end user in mind.*
- *The interview was a good learning experience for me in particular. It not only taught me how to understand someone else's point of view better, but it could also be applied to job interviews in the future.*
- *From a career perspective, I think that this learning experience has taught me a lot about using the resources supplied with respect to the task on hand. □*
- *This can be not only be employed in the working environment but also into everyday life. Being able to identify what the problem is and also what is causing that problem.*
- *When getting a job, being able to show that you can think about a problem holistically and be able to problem solve, is an important skill for employees.*
- *From a career perspective, I'm excited about this competency completion because I feel like it's very relevant to my area of interest in terms of being able to take that initial iteration into a final design.*
- *Design thinking is critical to working in a team because there is room for feedback from people who may have different perspectives than you.*

In considering the Value Proposition Canvas assignment, students were able to recognize why the learning activity was important outside of the classroom particularly in relation to workforce preparation and securing future employment. Throughout the reflections, students highlighted the importance of the market analysis and identifying the product-solution fit. Example quotes are as follows:



- *I think as I move into graduate school as well as a career it is important to be able to understand the target marketplace, and design catered toward what the user needs.*
- *This does not only have to apply to the workforce. The purpose of the value proposition canvas is to make sure you are aware of all of your problems before you attempt to create a solution, undoubtedly returning a better, more complete solution.*
- *For me especially, the problem identification process is crucial for my future as an Engineer. Instead of going through multiple iterations of a design or product, by using the Value Proposition Canvas, I can identify what features of the product are the most significant before I start designing and prototyping.*
- *This assignment was very insightful in that it taught me not only to shoot for the general niche as the target but also find out if there are any ways to incorporate an outside niche group to appeal to, as well.*
- *I feel as though this way of thinking would help with efficient processes in the workforce and also with relationship problems.*
- *Throughout this process, I believe I did improve my ability to be a better problem solver and will continue to ask better more well-rounded questions to get closer to the solution.*
- *The skills I was able to practice and perspectives that I tinted my work with matter to an employer and hold merit in the workforce by demonstrating that I can work in the Value Proposition Canvas in order to design for a specific archetype of a user, as well as communicate and iterate around that user.*
- *In biomedical engineering, I will be designing products to be used by medical professions to help someone in need. Along with identifying the true issue that needs to be solved, I will also need to identify my customer or the person who will be receiving my product.*

Upon reflection of their experience with the Business Model Canvas assignment, students were able to recognize why the learning activity was important outside of the classroom particularly in relation to workforce preparation and securing future employment. Throughout the reflections, students highlighted the importance of evaluating business viability. Example quotes are as follows:

- *I think as I move into a career setting it is becoming more and more important to think about the feasibility of a project. I think having the skillset of being able to create a business model canvas can help you see the financial aspects of a value proposition in another light.*
- *Personally, this matters to me for the sake of my academic experience and my value in the eyes of employers. This will have provided me with the skills necessary and give me a step up in the business.*
- *If a person wants to start a business, the Business Model Canvas is an essential part of the foundational layers of that person's company. An entrepreneurial mindset along with the usage of the Business Model Canvas ensures that any new product or company will have economic value.*
- *It matters to me to be able to employ entrepreneurship in my everyday life. Being able to see a business or idea as a whole and to apply business concepts is important when trying to bring a design to the market.*
- *In the work world, being able to come up with an original idea is an important and rare skill to have. But, what is even harder to find is someone who not only can come up with an idea but understand what is necessary for that idea to work.*

- *By sharpening this skill and opening the entrepreneurial door, I think this assignment helped me put a good step in the right direction for understanding what it will take to be an entrepreneur in the real world.*
- *This would be helpful to any startup in getting a structured layout of what they need to accomplish and how they should run the business.*
- *Having to interview someone, gather information and use that to quantify your data into a business model is what employers are looking for.*
- *Being observant of the opportunities being changed, presented and removed by time is a very perishable skill, as you must catch up to and evolve with your business.*

## 5. Conclusions

In summary, a funnel approach was intentionally applied to guide students from (a) System's Thinking - big picture, holistic perspective to (b) Design Thinking - human-centered approach to problem solving to (c) Problem-Market Fit Analysis – value proposition identification, connecting customer needs to features of the product bundle to (d) Business Model Development – identifying and evaluating key abilities required to support bringing a new product to market. As a result, students were able to recognize why the learning activity was important outside of the classroom particularly in relation to workforce preparation and securing future employment. Students noted the importance of a holistic and practical approach to problem identification, developing empathy through active listening, gaining multiple perspectives, completing a market analysis, identifying the product-solution fit, and evaluating business viability.

Due to the smaller sample size ( $n = 10$ ), the results cannot be viewed as conclusive. However, they do offer some insight into the benefit of integrating innovation frameworks into the design classroom using a scaffold approach which allows students the ability to narrow their scope as they traverse the design challenge. Future research should investigate this approach across different design challenges, using a larger subset of students, and incorporate quantitative and explanatory data analysis.

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