Board 68: Integration of Learning by Evaluating (LbE) within the 5E Instructional Model in Engineering-Design Education

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Integration of Learning by Evaluating (LbE) within the 5E Instructional Model in Engineering Design Education

Introduction

The integration of the 5E Model [1], [2] into design thinking education represents a significant advancement in pedagogical strategies [3], [4], [5], [6]. It is also widely used in fields like engineering and technology where problem-solving and innovation are key. This model, with its phases of Engage, Explore, Explain, Elaborate, and Evaluate, provides a structured framework that complements the fluid and dynamic nature of design thinking. The 5E Model facilitates a learning environment that is both systematic and adaptable, allowing students to not only acquire knowledge but also to apply it in practical, real-world contexts (see Figure 1).

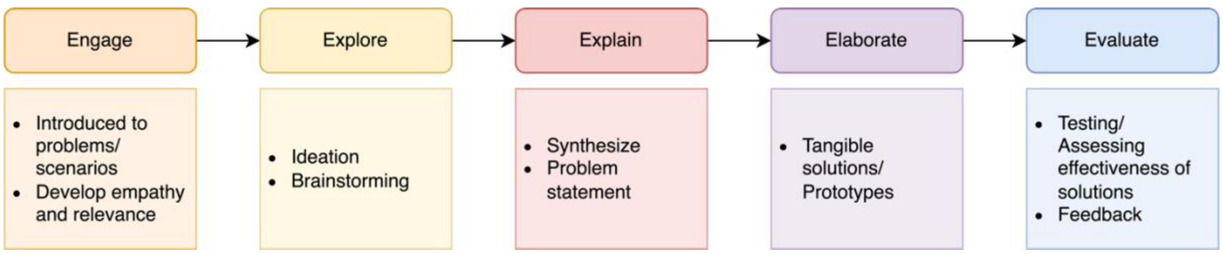

Figure 1. 5E instructional model and its implementation in the design thinking context

The 5e process starts with the ***Engage*** phase, where students are introduced to real-world problems or user scenarios, fostering empathy and relevance. This sets the stage for the ***Explore*** phase, paralleling the ideation aspect of design thinking. Here, students brainstorm and research extensively, allowing for a free flow of creative ideas without immediate constraints. The ***Explain*** phase then guides students to synthesize and articulate their findings, akin to defining a clear problem statement in design thinking. The process continues with the ***Elaborate*** phase, where students develop tangible solutions or prototypes, reflecting the prototyping stage in design thinking. This hands-on approach encourages the practical application of their ideas, emphasizing testing and refinement. Finally, the ***Evaluate*** phase mirrors the testing phase in design thinking, where students assess the effectiveness of their solutions and gather feedback. This not only allows for reflection but also encourages iterative improvement, a core principle of design thinking.

The 5E Model empowers educators to deliver a rich and dynamic learning experience, crucially enhancing students' problem-solving capabilities, creativity, and critical thinking skills [1]. This pedagogical approach is particularly effective in aligning with the principles of design thinking, transforming students from passive recipients of knowledge to active contributors in the learning process [3], [7]. They become adept at navigating and addressing complex design problems through this immersive educational experience. To augment the effectiveness of this model, researchers have integrated a novel assessment approach known as Learning by Evaluating (LbE) [8], [9], [10], [11], which derives its methodology from Adaptive Comparative Judgment (ACJ).

ACJ is recognized as a comprehensive assessment method [12]. It has been widely used to appraise the quality of diverse outputs, including student work [13], [14]. It involves a process where individuals compare pairs of items and discern the more effective one, fostering a deeper understanding and critical evaluation (see Figure 2). LbE, based on the ACJ method, enhances this approach by incorporating an additional reflective element. In LbE, students not only engage in comparative assessment but also articulate their reasoning through commentary on the items being compared. This dual process of evaluation and reflection enables learners to gain insights both from the items under review and from their own analytical thought processes. Such an approach is instrumental in the context of design thinking education, as it encourages students to critically assess and learn from existing designs, thereby enriching their own design and problem-solving skills.

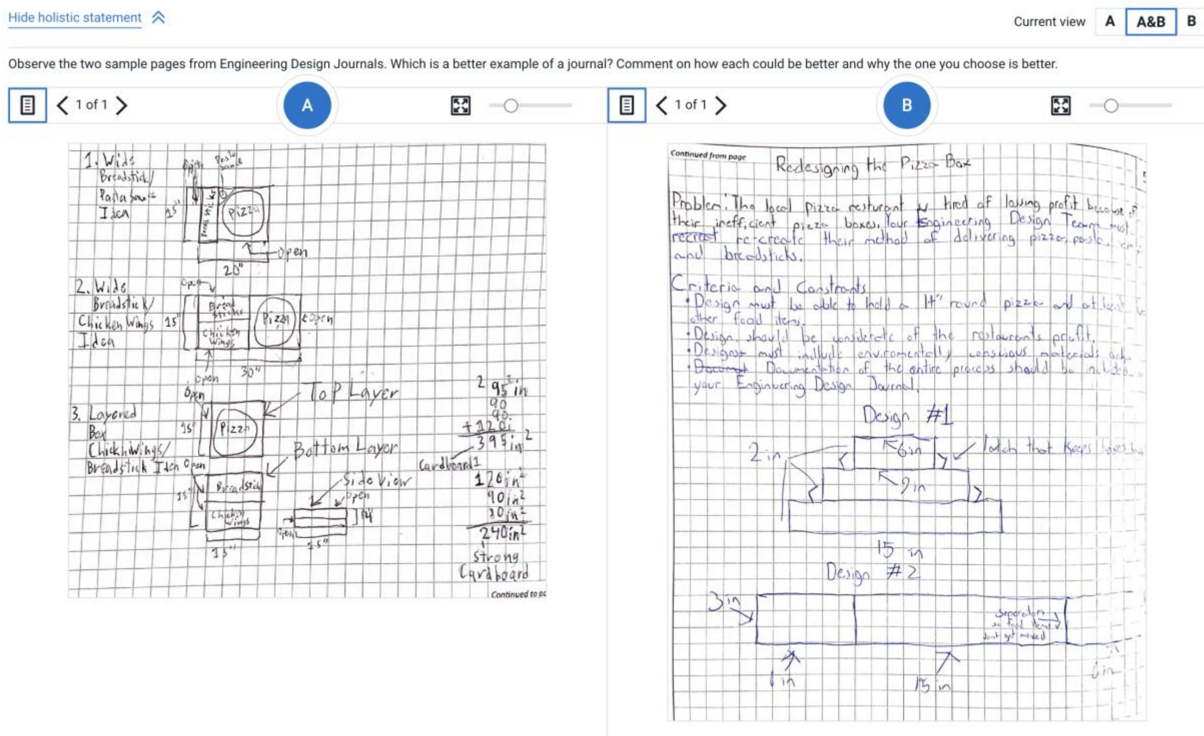

Figure 2. An example of students' LbE interface comparing engineering design journals of a pizza box redesign project

Incorporating LbE within a design thinking classroom structured around the 5E teaching model is anticipated to significantly enhance the learning experience, particularly in fostering critical thinking and deepening understanding through reflection. Further, the integration of LbE with the 5E model would promote explorative learning, elaborative thinking, and practical problem-solving skills. Given that teachers in the current study base their courses on the 5E instructional model, this study aims to delve into how the LbE model is incorporated into the current 5E teaching practices to enhance meaningful student learning. Through content analysis, the study seeks to explore the application of LbE within design thinking settings as a component of effective design thinking education.

Therefore, the primary objective of this research is to examine how educators meaningfully integrate LbE within the 5E instructional framework in technology education. Participants in this study were educators teaching the Foundations of Technology (FoT) course. The research aims to not only identify the presence of LbE within the 5E Model but also to critically evaluate its alignment and efficacy in the context of design thinking pedagogy. Such an analysis is expected to yield valuable insights into the dynamic interaction between LbE and the 5E Model, enriching our understanding of effective instructional strategies in design thinking education.

Backgrounds

Adaptive Comparative Judgment (ACJ)

Adaptative Comparative Judgement (ACJ) is a tool used for summative assessment, formative assessment, and student learning [8]. ACJ derives from comparative judgement, developed by psychologist Thurstone in 1927, who built an evaluation approach based on humans inherit nature to discriminate between two items and choose the better one. By doing this, it is assumed that each evaluation is made independently of one another and has a high repeatability level to an equal extent [12], [15]. As this comparison approach proved effective in evaluating open-ended work, researcher Pollitt took Comparative Judgement, added the inclusion of an algorithm, and created ACJ (Bartholomew 2021).

Learning by Evaluating (LbE)

Learning by Evaluating (LbE) is a pedagogical strategy that stems from ACJ. ACJ is an assessment approach where evaluators (who are typically teachers or grading professionals) judge open ended work through a series of one-on-one comparisons. After each comparison takes place, an algorithm is applied to the previously noted scores, sequentially pairing samples of similar quality together. ACJ has been noted as effective due to its validity, reliability, and robustness [12]. On the other hand, peer formative assessment is another strategy used in educational settings to allow for peer engagement. Though this can be an effective technique, it can commonly fall short of its expectations due to the time, effort, and planning which is involved [16]. LbE is a combination of both ACJ and peer formative assessment, promoting ACJ in students' hands as a deliberate assessment tool and student learning device [16].

5E Instructional Model

The 5E Model in teaching and learning is an instructional approach that fosters an engaging, student-centered classroom environment [1], [7], [17], [18]. The 5E Instructional Model, renowned for fostering student-centered learning environments, has gained substantial traction within engineering and technology education realms [19], [20]. This model, underpinned by constructivist learning theories, is tailored to meet the unique pedagogical requirements of these disciplines, as evidenced by its extensive coverage in contemporary academic literature [17], [19].

Table 1 outlines the application of the 5E Model in a technology/engineering design thinking context:

Table 1. 5E Model in the design thinking context

Phase	Details
Engage	This initial phase is pivotal for integrating real-world engineering challenges into the learning framework. It leverages industry-relevant scenarios to pique students' interest, thereby establishing a direct connection between academic concepts and their practical applications.
Explore	During this stage, students engage in collaborative problem-solving and hands-on experimentation. Activities such as prototyping, coding, and model-building are central, facilitating the application of theoretical knowledge to practical tasks.
Explain	This phase involves a collaborative dialogue between students and educators, focusing on the analysis and discussion of the exploration outcomes. It serves as a conduit for introducing and assimilating technical terminology and formal concepts within the context of their empirical experiences.
Elaborate	Tailored to extend learning, this phase involves more intricate or extensive project work. Students are encouraged to refine their solutions, incorporate advanced technologies, and consider the broader societal and environmental implications of their work.

Evaluate	The evaluation phase transcends traditional assessment methods by incorporating peer reviews and reflective practices on the design process and final outcomes. This comprehensive assessment strategy focuses on both technical skills and the overall problem-solving methodology, highlighting the importance of continuous improvement and practical relevance.

The integration of the 5E Model in engineering and technology education cultivates a dynamic learning environment where students actively engage in experiential learning, collaborative problem-solving, and the application of classroom concepts to real-world challenges [7], [20].

Recently, the International Technology and Engineering Educators Association (ITEEA) evolved the traditional 5E instructional model into the 6E model (https://www.iteea.org/6e-learning-bydesign) — comprising Engage, Explore, Explain, Engineer, Enrich, and Evaluate — to enhance its discipline instructional framework. This expansion, tailored specifically for the engineering design context, integrates engineering design with inquiry-based learning. By doing so, it places a strong emphasis on technological literacy, which offers numerous advantages when incorporated into technology and engineering education content.

Methods

The current research focused on the integration of Learning by Example (LbE) into the Foundations of Technology course to enhance engineering design experiences involved voluntary participation from high school teachers teaching the course, aiming to capture their perspectives on technology education within this culturally and linguistically diverse district. Data were collected through semi-structured interviews, conducted both virtually and in-person. This was performed to deeply explore the teachers' experiences and perceptions of technology education. For the analysis of teacher interview, we employed Qualitative Content Analysis (QCA) techniques [21], [22]. This approach involves initially defining research questions, followed by selecting the material for analysis and creating a coding frame that evolves as the material is examined with the research question in mind. This flexible framework of QCA enabled us to develop coding categories deductively, adapting to the diverse nature of our student reasoning. In our content analysis, each code was independently assigned by two researchers to ensure the reliability of the coding process. Any discrepancies encountered were resolved through group discussions. To further enhance the reliability of our findings, we employed investigator triangulation [23], [24]. This involved engaging a diverse team of researchers, each contributing different perspectives. These varied viewpoints helped in gaining a more comprehensive understanding of the data, thereby enriching and solidifying the reliability of our conclusions.

Research Context

This research was conducted in collaboration with a DeKalb County Public Schools in Atlanta, Georgia[1], characterized by its diverse students. According to the districts report [25], it serves a student body representing over 155 nationalities, with proficiency in more than 185 languages, illustrating a remarkable breadth of cultural and linguistic diversity. The study engaged students and teachers from the Foundations of Technology course [26], a preliminary class in the engineering and technology education pathways. Participation was voluntary and conducted with consent. The focus was on teachers integrating LbE into their instruction as a means of enhancing engineering design comparison. Prior to students embarking on their engineering design projects, LbE was implemented to expose them to peer designs from previous cohorts, fostering learning through critique.

[1] We obtained comprehensive consent from the students, their parents, and the school district for the disclosure of the school district's name (file 2021-015).

Participants
In the Spring of 2023, our research was focused on five schools within this district. The participants for this study were high school teachers teaching the Foundations of Technology (FoT) course. This course choice was intentional, as it represents a fundamental component of the district's technology education curriculum and provides a critical insight into design thinking across diverse student populations. By centering our study on FoT course teachers, we aimed to gather nuanced perspectives on technology education from those directly involved in its delivery.

Data Collection
In this study, data were collected using the semi-structured interview technique, a method extensively acknowledged as the principal data collection tool in phenomenological research. This method is particularly advantageous for exploring complex and nuanced subjects, as it allows for both guided and open-ended questioning. The semi-structured interview format facilitates a comprehensive exploration of the teachers' experiences and perceptions while providing the flexibility to uncover new insights, as outlined in relevant research methodology literature [27], [28]. This technique is particularly suited to our study's objective of understanding the nuances of technology education in diverse classroom settings.

The interviews were administered by two members of the research team, utilizing both virtual and face-to-face methods to accommodate the preferences and circumstances of the participants. Specifically, one interview was conducted via Microsoft Teams, while the remaining four were carried out in person. The duration of the interviews varied, with a minimum length of 45 minutes and extending up to an hour and a half. This range ensured a sufficient depth of conversation to explore the research questions comprehensively.

Data Analysis
Initially, in adherence to ethical research practices and to maintain confidentiality, all identifiable information, specifically the names of the participating teachers, was redacted from the interview transcripts. Subsequently, each teacher was assigned an alias, ranging from Teacher A to Teacher E, to facilitate anonymous yet distinct referencing throughout the analysis and discussion phases of the study.

The transcription of the interviews was initially conducted electronically utilizing web-based transcription software to facilitate a prompt and efficient preliminary text. To ensure accuracy and fidelity to the original audio, two researchers meticulously reviewed the automated transcriptions by listening to the recordings and making necessary corrections. This secondary review process was essential for validating the transcriptions, adjusting any discrepancies, and refining the text to accurately reflect the content of the interviews.

In the transcription of the interviews, verbatim accuracy was prioritized to preserve the authenticity of the participants' responses. Grammatical inconsistencies inherent in spoken language have been retained, except in instances where such irregularities impeded the clarity and context necessary for interpreting the teachers' answers. This approach ensures that the data analysis is grounded in the actual language used by the participants, reflecting a true account of their expressed views and experiences.

Subsequent to the anonymization of the interview transcripts, the research team undertook a thorough and iterative review of the interviews. This involved multiple readings of the interview content to gain a comprehensive understanding of the data. This process of immersion is a critical step in qualitative analysis, as it enables researchers to familiarize themselves deeply with the nuances and intricacies of the responses, thereby laying a solid foundation for the subsequent coding and analysis phases.

Finally, in the analysis of the data accrued from this study, we employed a deductive analysis approach, as delineated in the works [29], [30]. This methodological choice was particularly apt, given that deductive content analysis is renowned for its efficacy in examining the applicability of existing theories or models within new contexts [31]. Central to our analysis was the development of an unconstrained matrix (grounded in the principles of the 5E Model).

Table 2. An example of coding the data to the categorization matrix: 5E Model

"How does LbE contribute to or hinder the introduction of design thinking concepts in your teaching approach?"	
Engage	- **Contribution**: Engages students by providing real-world contexts that pique their interest in design thinking, fostering curiosity. - **Hindrance**: If not carefully framed, LbE can overwhelm students with complexity before they grasp the fundamentals of design thinking.
Explore	- **Contribution**: Allows students to actively engage in problem-solving, promoting hands-on exploration of design concepts. - **Hindrance**: Without structured guidance, students may focus on the experience rather than the exploration of design principles.
Explain	- **Contribution**: Encourages students to reflect and articulate their design thinking processes, enhancing their understanding. - **Hindrance**: Students may struggle to verbalize their thought process without a clear framework linking the experience to design thinking.
Elaborate	- **Contribution**: Requires students to apply design concepts in new, complex situations, which deepens their design thinking skills. - **Hindrance**: Students might face difficulty in abstracting and applying learned design thinking concepts to different contexts without explicit connections.
Evaluate	- **Contribution**: Facilitates the evaluation of students' understanding and application of design thinking through both process and product assessment. - **Hindrance**: Measuring the impact of LbE on students' design thinking can be challenging without clear evaluative criteria linked to design thinking objectives.

Within this framework, we crafted distinct categories, each aligning with the facets of the 5E Model. This structured approach facilitated a focused examination of the data, allowing us to directly test the integration and effectiveness of LbE within the 5E Model-driven instruction, specifically in the context of design thinking.

Findings

This study examined the integration and effectiveness of LbE within the 5E instructional model in the context of design thinking in engineering education. The findings are organized according to the phases of the 5E model: Engage, Explore, Explain, Elaborate, and Evaluate (see Figure 3). In the figure, grey-shaded boxes serve to visually underscore the specific challenges and constraints that were identified during the implementation of LbE within the 5E instructional framework.

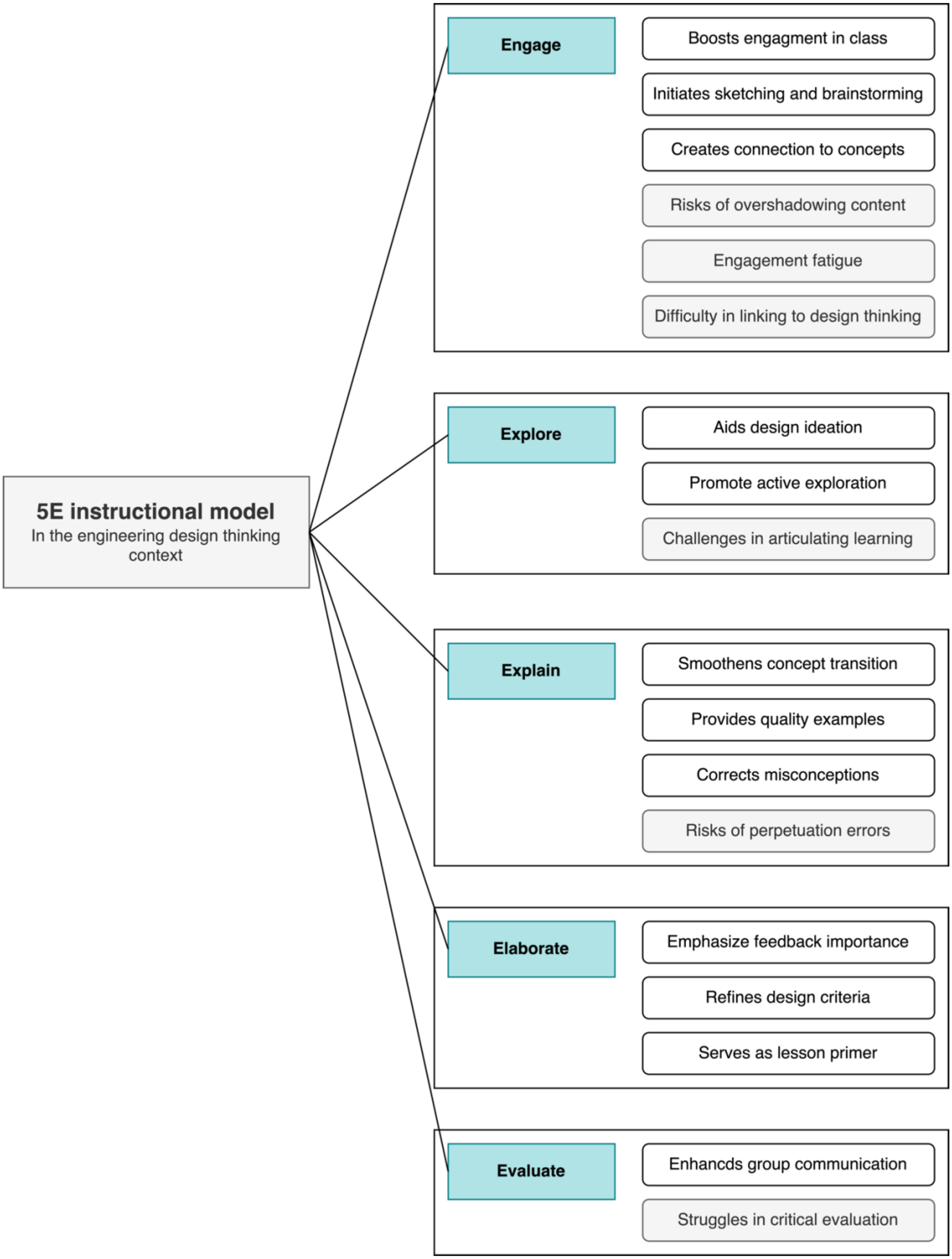

Figure 3. Findings from the content analysis: Implementing LbE within the 5E instructional model in the design thinking context

Engage

The incorporation of LbE into the Engage phase was found to significantly increase student engagement and excitement.

> **Teacher A:** *"… Um I like, I like the different way of approaching the lessons and I think it just gives me a better way of reaching the students. So I think I'm not only with this group, but with some of my other classes it's a benefit.".*

Also, strategies such as using signature experiences and warm-up questions facilitated an immediate connection to the material.

> **Teacher C***: "… that really kind of gives them a starting point you know we talk about the kids having like prior knowledge that kind of pulls out their prior knowledge before we even start the concept."*

Further, LbE sessions served as effective references for initiating sketching activities, successfully drawing students into the engineering curriculum and enhancing their engagement with brainstorming tasks.

> **Teacher D**: "*it gets them prepared to do a better job with the lesson or whatever I'm putting out*".

At the same time, there is a risk that the initial excitement generated by LbE activities may overshadow the deeper content goals, potentially resulting in a superficial understanding of design thinking concepts.

> **Teacher A***: "But it was horrible because I was really trying to get them to understand the different types of ways that we can do …"*

However, over-reliance on the novelty of LbE could lead to diminished returns in student engagement over time, who recognize it as tedious activities.

> **Teacher B**: *"They got bored sometimes, really".*

Moreover, some students may struggle to see the connection between engagement activities and the larger design thinking framework.

> **Teacher E**: "*I think the issue with doing more is really being intentional having the time to be intentional um is that's really what it is …"*

Explore

During the Explore phase, LbE was instrumental in assisting students with design ideation and investigating constraints and criteria for their projects.

> **Teacher D**: *"And so I would give them all of those different ones and see if they could take that to come up with a unique because my, my challenge was for them to create a backpack that didn't already exist. So I get more excited when they think and come up with something totally different".*

The hands-on nature of LbE sessions encouraged active exploration and priming of sketches, allowing students to embody design thinking principles through tangible experiences.

> **Teacher B**: *"Um, I used it as a **primer for sketching**. We had talked about sketching um earlier but I knew we were getting ready to get into technical sketching. So I, I wanted some of those um concepts were overlap and so we did it, so I **definitely think it was a primer**."*

However, some limitations were observed when incorporating LbE sessions, suggesting a need for careful structuring to align with design thinking objectives.

> **Teacher E**: *"Um, Well, the biggest is (providing) them **not confusing criteria because that's right after the lesson**, you know…"*

If it is not well-structured, students may also find it difficult to articulate what they have learned from LbE activities, and teachers may struggle to link these experiences to theoretical design principles effectively.

> **Teacher A:** *"The challenge lies in the **transition from hands-on experiences to conceptual understanding**. If the structure is lacking, students are left with experiences they enjoy but cannot describe or learn from in a meaningful…"*

Explain

The Explain phase benefited from the introduction and clarification of LbE, which smoothed the transition into other related concepts.

> **Teacher A**: *"Well I did come across one of the responses. Um but um in our first period really good because I talked about the aesthetics. It was and we **had talked about universal design** and all the easy to use. Um they could grab it. It was just really great. And I was like this is what you need. And we've talked about **design and why we design and how we design for everyone**."*

Additionally, by providing concrete 'good' and 'bad' examples, students could better discern quality in design, aiding the learning process.

> **Teacher D**: *"…Well. I want to pull **my students' work the ones that I feel like are stellar and take pictures of goals. Also want to put some stuff that's not so good**, you know in there and have them to see why um those are gonna be the most beneficial because I look at that, that vex robotics, they have a sample workbook, design workbook and I think it's very a good example for students to use…"*

The use of LbE also served to redirect misconceptions, reinforcing correct understanding and application of design thinking principles.

> **Teacher C**: "*…**should not make students make the mistakes that I've seen in the past** to make sure that they're conscious of why they have to do it a certain way…*"

However, it also provides possibilities for misconceptions to be perpetuated if LbE experiences are not accurately debriefed.

Elaborate

In the Elaborate phase, LbE was used to deepen students' understanding by emphasizing the importance of feedback in the iterative design process.

> **Teacher B**: "*… For me, I want to hit home, you gotta design and feedback is important. How are you gonna know how to make it better? And sometimes somebody has made it better and they can tell you what you can do and you need them to tell, right? So for me that's what I wanted them to carry away. Like the* ***importance of wanting that feedback to make your products better****. And so we'll see…*".

It also helped students refine their criteria and constraints and fostered better design and brainstorming skills.

> **Teacher A**: "*And what, like, so they go through all the steps in the design cycle each time, but but when I get to a new step, it's really focused on that, like the last one, although they did the whole process, my real focus was on them coming up with* ***good criteria and constraints***"

LbE acted as a primer for lessons and a substitute for traditional 'redesigning' activities, revealing students' prior understanding and preparing them for subsequent challenges.

Evaluate

Finally, the Evaluate phase revealed mixed outcomes. Group-based presentations, facilitated by the LbE process, were noted to enhance communication and evaluation skills.

> **Teacher E**: *"… Feels really good when they're in a group and they built something, the marshmallow launcher (presentation) was like a huge success, but then they had to communicate right and I made them share a presentation and everybody has to do something and I'm feeling really good about it because like we walked through the design process, we did the problem, we did criteria and constraints. We did research."*

However, students encountered difficulties when required to articulate their reasoning and evaluate their work critically. This suggests that while LbE can be a powerful tool for experiential learning, additional scaffolding may be needed to support effective communication and evaluation of design thinking in student projects.

> **Teacher B***: "… think most with the evaluation process. Um, and I think I hit on a lot of it is they don't know how to communicate what they're looking at that's better but getting them to put it in words is the hardest thing."*

Discussion

The current study delves into the nuanced role of LbE within the 5E instructional model, specifically in the context of design thinking in engineering/ technology education. This examination aims to unpack the complexities and dynamics of LbE's integration across different instructional phases. By analyzing its impact and the associated challenges, the discussion seeks to illuminate the intricate interplay between experiential learning and the acquisition of design thinking skills. The insights gleaned offer a comprehensive understanding of how LbE, when adeptly integrated, can enhance the educational experience in engineering design, while also highlighting the critical need for strategic implementation.

In the *Engage phase*, LbE markedly improved student engagement, stimulating early involvement with design thinking tasks. However, this initial enthusiasm requires careful moderation to prevent it from eclipsing the core content goals and to mitigate the risk of activity fatigue, which can emerge from repetitive LbE use. A critical issue noted was the difficulty in connecting these engaging activities with the design thinking framework comprehensively. During the *Explore phase,* LbE effectively facilitated design ideation, promoting hands-on exploration. Yet, the efficacy of this phase hinged on the structured delivery of LbE sessions. Without meticulous planning, students struggled to express their experiential learnings, highlighting a gap in linking practical experiences with theoretical knowledge. The *Explain phase* saw LbE ease the introduction of complex ideas and correct misconceptions. Providing tangible examples was pivotal in aiding students' understanding of design quality. However, insufficient debriefing post-LbE activities risked the persistence of misconceptions. In the *Elaborate phase*, LbE's emphasis on feedback significantly contributed to understanding the iterative nature of the design process. While LbE served effectively as a lesson primer, there was a notable need for it to dovetail with the rigors of design thinking to ensure relevancy and depth in student learning. The *Evaluate phase* underscored the dual role of LbE in enhancing communication skills and highlighting the need for increased support in students' self-evaluation abilities. Critical evaluation by students was a noted challenge, suggesting a requirement for more structured guidance in the evaluative aspects of design thinking.

In essence, the integration of LbE within the 5E model demonstrated clear benefits in engaging students with design thinking in engineering education. Nonetheless, the study revealed that the effective incorporation of LbE is highly dependent on strategic planning. Ensuring that LbE activities are purposefully structured is vital for achieving targeted learning outcomes in design thinking. It is through such deliberate instructional design that LbE can optimally contribute to the development of robust design thinking competencies in engineering students.

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