# BOARD # 378: Improving Student Design Through Critical Evaluation: Results from Four Years of Learning by Evaluating (LbE) Research

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# Improving Student Design Through Critical Evaluation: Results from Four Years of Learning by Evaluating (LbE) Research (NSF DRK-12 #2101235)

## Introduction

Design is a central focus of high-school engineering courses. Curricula at this level include a wide-range of engineering contexts, highlighting the consistent ways of thinking and being as an engineer [1], [2]. Design experiences foster creativity, problem solving, and critical thinking, and frequently heighten students' motivation by allowing them to work on real-world problems [3].

A typical engineering design pedagogy engages students in the design process, culminating in a presentation of their process and product to the class. While design is iterative and should include opportunities for revision and improvement, for beginning design students early stages of the design process may not develop clarity or traction that moves the design process forward [4]. As students refine their ideas, phases of learning may also seem distinct from phases of evaluation: evaluation is most often conducted by the teacher, at the end of the project.

Instead, we are developing and testing an instructional approach called Learning by Evaluating (LbE) to develop students' capacities as designers, through funding by the NSF Division of Research on Learning. In LbE, *students* evaluate curated artifacts two at a time *prior to beginning* their design work, in order to prime them for learning while designing (a more detailed instructional model is given later and in our earlier work [5], [6]). The side-by-side comparison of artifacts especially supports students' engineering thinking and argumentation [7]. We posit that these comparisons (and the surrounding instructional experiences) can grow students' design mindset (helping them begin to think like designers), critical thinking and reasoning (by demanding that they make and justify decisions), and design performance (as students apply their thinking). In addition to direct impacts on student learning, our project has formalized teachers' roles as co-researchers, bringing meaningful changes in design thinking pedagogy.

## Project Overview/Timeline

The project expands the reach of the LbE approach by partnering with high school teachers and students in Dekalb County, Georgia. The project focuses on 9th-grade engineering students taking the Foundations of Technology (sometimes called Foundations of Engineering). For the first two years of this project, our approach used design-based research (DBR) to refine the LbE approach in classrooms and develop the feasibility of widespread implementation. DBR is particularly appropriate for developing prototypical experiences in tandem with developing theory [8]. The third year of our project commenced our plans to assess performance of the LbE approach compared to typical design pedagogy through quasi-experimental design. Through a no-cost extension we have continued a fourth year of data collection related to the effectiveness of LbE.

Across the study our approaches have been collaboratively developed *in situ* with teacher and student participants. For example, we have built on an initial concept of the LbE approach through insight during classroom observations, reflections with teachers and students, analysis of student performance during the experience, and numerous outreach activities with design educators. Effort during the no-cost extension has also made progress towards the sustainability of the LbE experience, which is one of the thematic findings reported below, by allowing us to develop artifacts related to the experience and deepen our understanding of adoption by new teacher participants in the study.

**Refined Implementation Approach for LbE**

The initial approach for LbE has been validated through classroom observation, feedback from partner teachers, and fundamental research related to student's critical thinking and reasoning during the experience. Overall, these activities align with best practices for supporting engineering argumentation and reasoning [7], [9]. Planning to conduct LbE is facilitated by several resources we have recently developed including an instructional planning template, video vignettes portraying implementation, and a growing library of artifacts which can serve as the basis for future comparative sessions.

The LbE approach is inserted at the beginning of the design process steps as students are oriented to the problem. Preparation conducted by teachers for the experience has three phases similar to a backward design model [10]. These phases include 1) identification of the learning outcomes or topic of interest, 2) identifying the holistic statement criterion by which students will compare the curated artifacts, and 3) curating a collection of artifacts. Learning outcomes may be identified as key concepts that the teacher wants to emphasize through the upcoming design experience or areas that students have struggled with in the past. The holistic statement allows for the operationalization of the learning objectives. Effective statements are open-ended and guide students to choose one item over another item based on subjective criteria related to the learning focus. Next, the teacher curates images for the session. A range of images can be used, from past student work, to real-world artifacts, or creative images for inspiration.

The classroom implementation has three phases which are 1) teacher introduction and modeling, 2) students' comparisons and justifications, and 3) class discussion or debrief. Over time we have observed that effective introductions to the experience emphasize the timeliness of LbE—that it is related to the upcoming design work and that making these comparisons will offer insight to students—and the timing—that students should take adequate time to make the comparisons without a rush. Teachers can model a thorough comparison by thinking out loud, pointing out trade-offs in each of the images portrayed, and emphasizing a clear justification for the decision. When making and explaining the decisions, students adopt perspectives related to the design. Therefore, the class wide debrief serves as an important opportunity to elicit student thinking and build consensus about design values.

**Thematic Findings**

A range of research has been produced by our project team, studying different facets of the experience—including both student and teacher thinking. In an effort to integrate our work for presentation in this community, two thematic findings are presented here with evidence from

several perspectives within the project. The basis of these themes was reflection and discourse by our project team about the main insights obtained and reported on in manuscripts and conference proceedings to date. Following an initial tabulation, these insights were organized and labeled for their conceptual similarity, as follows.

### *Sustaining Instructional Development*

The DBR approach of our project has provided opportunities for iteration in many deliverables and artifacts. While the LbE instructional approach is principal of these artifacts, in the course of our project, we have also been able to iterate on the professional development approach to help teachers' adoption of the strategy. Our most recent professional development design proved effective, as teachers new to the approach quickly understood and applied it. Several features of effective professional development [11] were included in our agenda:

- Teachers familiar with the approach provided *models of effective practice* during the session, providing a vision for what the experience might look like through their demonstration and testimonial.
- *Active learning* and *collaboration* were included in the session as teachers prepared their own application of the LbE approach and reported to small groups. The small groups provided an opportunity for *feedback*, and a member of the research team provided *coaching and support* to each small group.
- The professional development included *follow-up* on teachers' practice through classroom observations as part of the research project. Additionally, several artifacts and guides from the professional development were enduring references for teacher-participants.

This formal structure for onboarding to LbE has also been supported by fundamental inquiry on this topic during the recent year of our project. We have taken a new year on the project as an opportunity to explore how teachers new to the approach understand and apply LbE compared to our research team and other teacher-participants who are more experienced with the approach. Study of teachers' intentions when preparing for LbE, observations during the sessions, and reflection afterwards shows that even for experienced teachers there are ongoing opportunities to develop instructional practices with LbE [9]. This comparison also revealed the "momentum" that teachers familiar with LbE can build—i.e., seeing opportunities for instruction which might be particularly potent through LbE while grading or anticipating lessons, and fluency in curating artifacts. This finding also reinforces the importance of the library of artifacts we are curating, as a means to overcome inertia in starting with LbE.

### *High School Students as Novice Design Thinkers*

The focal outcome of the project has been to improve students' design thinking abilities by affecting their design thinking mindset and critical thinking skills. The predominant findings from research involving student work can be seen to characterize students as novice design thinkers. Several aspects of our research show that students use a limited rationale and surface-level characteristics when justifying decisions. The framing of students as novices may be appropriate given their limited prior exposure to design [4]. Still, our ongoing research may

demonstrate the effectiveness of LbE in enhancing students' performance, and their growth over time in their class experiences.

The terse explanations given by students have been described in several prior publications [12], [13], [14]. Sentiment analysis of students' comments revealed that students favored simple reasoning and did not use trade-offs in their explanations (i.e., they described only positives of the selected item or negatives of the not selected item in their explanation) [12]. We wondered whether students' reasoning was filtered by the writing process that is part of our research procedures and LbE. Cognitive barriers come into play between thinking and writing due to memory, cognitive load, and other factors [15], [16]. However, in verbal protocol analysis, which required students to think aloud during their comparison process, we found that the range of features mentioned by students in their thinking and writing was consistent [14]. Students' thinking was not necessarily filtered because it was already limited. Moreover, when we are attentive to the features of student comments, presentation quality (even when it is due to system errors unrelated to the content of the artifacts) is a strong predictor of whether students will select an idea [17].

We hope to explore further variations with LbE that might encourage students to take more time and use deeper reasoning in their comparative process. Teacher comments qualitatively reflect the improvements they see in student work. We have witnessed thorough conversations following the comparative process of LbE, where students demonstrate sound reasoning about what matters in this design and why. Our ongoing analysis of student design work may shed further light on students' critical thinking abilities and their growth in this area.

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**References**

[1] International Technology and Engineering Educators Association, *Standards for technological and engineering literacy: The role of technology and engineering in STEM education*, 2020. [Online]. Available: https://www.iteea.org/STEL.aspx

[2] (2013). *Next generation science standards: Engineering design in the NGSS*.

[3] G. Strimel, "Authentic education," *Technology & Engineering Teacher,* vol. 73, no. 7, pp. 8–18, 2014.

[4] D. P. Crismond and R. S. Adams, "The informed design teaching and learning matrix," *Journal of Engineering Education,* vol. 101, no. 4, pp. 738–797, 2012, https://doi.org/10.1002/j.2168-9830.2012.tb01127.x.

[5] A. Jackson *et al.*, "Learning by evaluating (LbE): Engaging students in evaluation as a pedagogical strategy to improve design thinking," in *Proceedings of the 2023 ASEE Annual Conference & Exposition*, Baltimore, MD, 2023. [Online]. Available: https://peer.asee.org/42934.

[6] S. R. Bartholomew, N. Mentzer, and A. Jackson, "Lessons from Dilbert: Clarifying design expectations," *Technology and Engineering Education,* vol. 1, no. 1, pp. 7–13, 2023. [Online]. Available: https://www.iteea.org/journals.

[7] A. Wilson-Lopez *et al.*, "A systematic review of argumentation related to the engineering-designed world," *Journal of Engineering Education,* vol. 109, no. 2, pp. 281–306, 2020, https://doi.org/10.1002/jee.20318.

[8] A. Collins, D. Joseph, and K. Bielaczyc, "Design research: Theoretical and methodological issues," *Journal of the Learning Sciences,* vol. 13, no. 1, pp. 15–42, 2004, https://doi.org/10.1207/s15327809jls1301_2.

[9] W. Lee, N. Mentzer, A. Clevenger, A. Jackson, and S. Bartholomew, "Integration of learning by evaluating (LbE) withing the 5e instructional model in engineering design education," in *Proceedings of the 2024 ASEE Annual Conference & Exposition*, Portland, OR, 2024.

[10] G. P. Wiggins and J. McTighe, *Understanding by design*, Expanded 2nd ed. Alexandria, VA: Association for Supervision and Curriculum Development, 2005, pp. xi, 370 p.

[11] L. Darling-Hammond, M. E. Hyler, and M. Gardner, "Effective teacher professional development," Learning Policy Institute, Palo Alto, CA, 2017. [Online]. Available: https://learningpolicyinstitute.org/product/effective-teacher-professional-development-report

[12] N. Mentzer, W. Lee, A. Jackson, and S. Bartholomew, "Learning by evaluating (LbE): Promoting meaningful reasoning in the context of engineering design thinking using adaptive comparative judgment (ACJ)," *International Journal of Technology and Design Education,* vol. 34, no. 3, pp. 1145–1169, 2023, https://doi.org/10.1007/s10798-023-09853-7.

[13] N. Mentzer, W. Lee, A. Jackson, and S. Bartholomew, "Defining and evaluating argumentation quality in the context of design thinking: Using high school students' design critiques from foundational engineering courses," *Design and Technology Education: An International Journal,* Manuscript submitted for publication 2024.

[14] D. Bayah, A. Jackson, N. Mentzer, and S. Bartholomew, "Investigating cognitive discrepancies between verbalized and written feedback in 9th-grade engineering students' evaluation processes," presented at the 1909 Conference, Memphis, TN, November 14–15, 2024, Paper presentation. [Online]. Available: https://the1909conference.org/.

[15] R. T. Kellogg, "Long-term working memory in text production," *Memory & Cognition,* vol. 29, pp. 43–52, Jan 2001, https://doi.org/10.3758/BF03195739.

[16] J. Sweller, "Implications of cognitive load theory for multimedia learning," *The Cambridge handbook of multimedia learning.*, R. Mayer, Ed., New York, NY: Cambridge University Press, 2005, pp. 19–31.

[17] S. R. Bartholomew, L. Zhang, E. Garcia Bravo, and G. J. Strimel, "A tool for formative assessment and learning in a graphics design course: Adaptive comparative judgement," *The Design Journal,* vol. 22, no. 1, pp. 73–95, 2019, https://doi.org/10.1080/14606925.2018.1560876.