Building Engineers from the Ground Up

A Scaffolded Design Process for PreK-12 Learners

BY LEE K. JONES, YUJIRO FUJIWARA, AND AMANDA L. MEYER

Introduction

The engineering design process (EDP) is by now a familiar structured approach to integrating engineering principles into PreK-12 education and beyond. Supported by educational frameworks like NGSS *(National Research Council [NRC], 2012; NGSS Lead States, 2013)* and ITEEA *(Standards for Technological and Engineering Literacy (STEL), 2020)*, the EDP has become a cornerstone in STEM education. While the EDP, in different forms, is likely to be found on walls of science and engineering classrooms everywhere, efforts have been made to promote the idea that the EDP is not specific solely to STEM subjects *(STEL, 2020)*. Instead, the EDP is a concept that can be used across all subjects and contexts to promote process- and action-oriented learning, focusing on reflection and evaluation. At its core, the EDP is an iterative and cyclical process, encouraging continual refinement and adaptation to achieve the best possible outcomes, whether in engineering or other fields. While its fit within an engineering class is obvious, with thoughtful integration, an adaptable EDP can also enrich subjects like art, writing, and math—areas where students engage in creative problem solving and produce unique solutions. Beyond traditional classrooms, the EDP has potential applications in informal education environments such as STEM camps, museums, and afterschool programs. These settings often engage diverse learners with varying levels of prior knowledge, making a scaffolded approach to design thinking especially beneficial.

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Like many models or processes in education though, there is no single, universally agreed-upon EDP. The designs that can be found on posters in classrooms across the world will vary in flow, phrasing, and style. All educators bring unique styles, and all classrooms have distinct needs, so this diversity is understandable. This diversity allows educators to tailor the EDP to fit their instructional approaches and reflects the value of teacher agency and flexibility. However, while sometimes beneficial, these variations can also present challenges. For one, the lack of a specific EPD model can make it challenging for new or inexperienced educators to select or adapt a model. Those without a background in STEM may also feel particularly overwhelmed by technical terms and may overlook the EDP's broader applicability to non-STEM subjects. So, instead of adopting and using a design cycle to support students, teachers assign projects with a focus on the end product instead of the process.

Additionally, inconsistencies across classrooms and grade levels that use the EDP can create challenges for students. Students might get a fragmented understanding of engineering design principles during the transition between grades and classrooms if there is no agreed upon model shared among teachers. Moreover, many EDP models are complex and not easily adaptable to younger audiences or non-STEM contexts. For instance, terms like "identify constraints" and "prototype" might make sense in a high school robotics course but can feel out of place in a language arts project or a first-grade classroom.

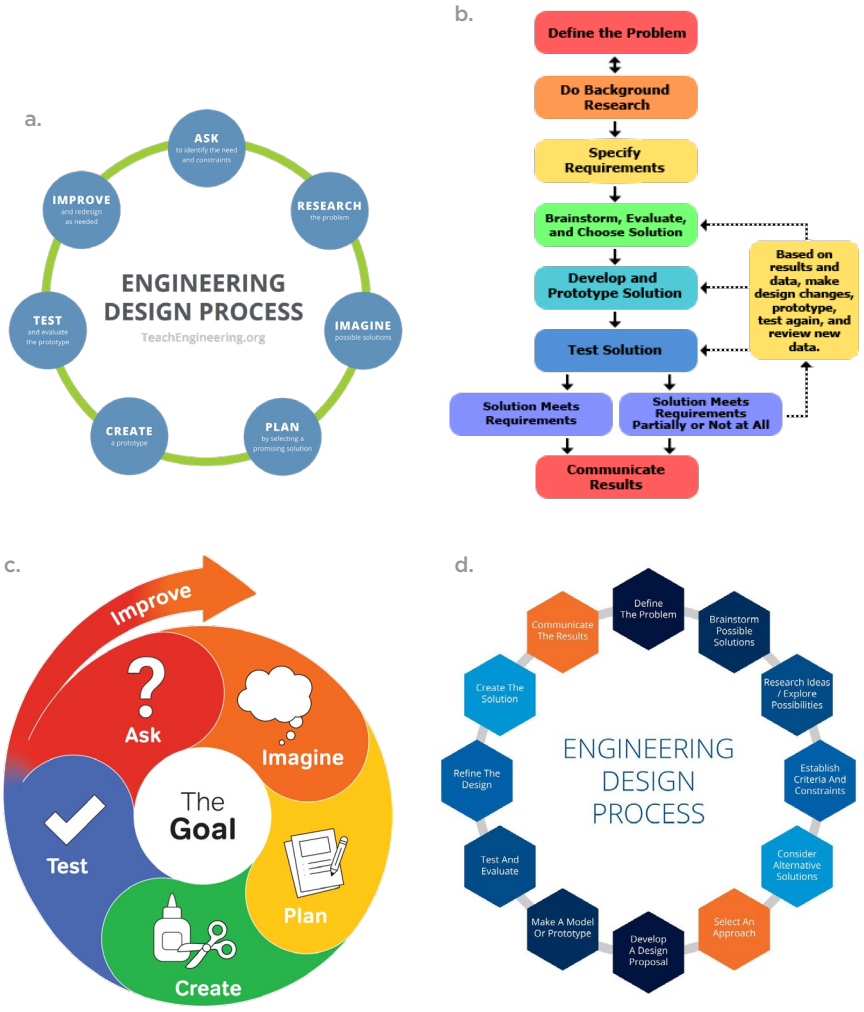

Figure 1. Examples of engineering design cycles. (a) Teach Engineering (2025), (b) Science Buddies (2025), (c) Youth Engineering Solution (2025), and (d) TWI Ltd (2025).

Arguably, there is no perfect EDP model, nor will this paper attempt to claim otherwise. A search of the internet and a visit to STEM classrooms will turn up a variety of models, all with their own strengths (Figure 1). However, what can be agreed upon and seen across models is that the EDP is based on important elements that make it effective in focusing creative tasks on the *process* over the *product*. The ideal model is one that best addresses these accepted elements, helps guide students through the creating process, and fits an educator's style and context. However, a degree of consistency within a school or district can help ensure that students develop a comprehensive understanding of the EDP and apply it across various contexts, even outside the classroom. This article presents a scaffolded engineering design model that can be used seamlessly from PreK through high school and beyond.

Framework

Although there is no perfect EDP model, there is always room for change and/or improvements to address some of the issues shared previously. Along with these issues, many models specifically focus on engineering/STEM content and lack scaffolding to make the model accessible across multiple grade levels. The EDP model presented later in this article will attempt to address these various issues with a model that maintains the important EDP elements while providing PreK-12 scaffolding.

EDP ELEMENTS

Despite the variation in models, most educators can agree on the key elements of an EDP. Though they vary in language and order, all EDP models tend to have some common elements. Table 1 shows an outline of these elements.

Another important design quality of all EDP models is their cyclic nature. Many, if not all, models direct students to take their original ideas back to the beginning of the process to iteratively and further refine their solution. The desire of an EDP to focus on the process over the product means a constantly evolving design until the time comes for the communication stage. A step is not designed to be completed once, but instead iteratively repeated in this cyclic fashion until the product is completed, or ready for submission.

Whichever EDP model is used, you will likely see all the elements in one form or another. Revisiting Figure 1 will allow you to see all the pieces from Table 1 in one form or another. For example, in the cycles shown in Figure 1, "Problem Identification" is also described as "Ask" and "Prototyping" is also described as "Model" or "Create." In some cases, elements like *Testing* and *Analysis* might be given as a single step or *Refinement* simply implied by cyclic arrows connecting all the steps in a repeating loop. No matter the model used, it is important that all of these elements are addressed.

SCAFFOLDING

The job of a classroom teacher is a constant balancing act, and scaffolding is one of the many challenges they face. The term *scaffolding* was first used by Wood et al. *(1976)* to describe temporary support tailored

EDP ELEMENTS	DESCRIPTION
Problem Identification	Students must understand the problem or challenge, including identifying the criteria and constraints.
Research and Background Knowledge	Students gather information to understand the problem better, including prior knowledge or new research. This helps students establish a foundation before ideation.
Brainstorming and Ideation	Students generate a variety of ideas to solve the problem, allowing students to explore multiple pathways before locking into one.
Planning and Selecting a Solution	Students select the best possible solution and create a design/plan for its construction.
Prototyping	Students build models or prototypes to help visualize and test their ideas
Refinement	During the building process, issues will undoubtedly arise. Rather than ignoring them or giving up, students refine their initial idea.
Testing	Students test out their models to see if they work. They collect data to help inform them if the model is working.
Analysis	This step includes analyzing performance, identifying strengths and weaknesses, and making informed decisions about potential improvements or issues.
Communication and Presentation	Students should be able to present their findings and communicate their ideas professionally, rationalizing their decisions and choices.

Table 1. The basic elements of an EDP model.

to a student's current level of understanding. This support enables students to do things they could not do independently by controlling tasks or elements that are still beyond a learner's reach. As students become more competent, the scaffolding is gradually removed, and they take more and more responsibility for their learning.

When presented with a challenging task or problem to solve in the classroom, a student may feel overwhelmed and unable to proceed without proper support. The EDP helps to scaffold problem solving by providing students with defined steps that give some level of hand holding. The models of EDP are themselves a form of scaffolding as they provide students with guidance on how to solve the problem. With time, though, it can be expected that students learn how to solve a problem without needing to be explicitly told the next step in the design process. A real engineer probably will not have an EDP model hanging in their office to show them what to do next. However, through extensive training, an experienced and qualified engineer will naturally incorporate all of the steps of the EDP. PreK-12 students, not having this experience and training, cannot reasonably be expected to solve a challenging problem on their own without guidance. Similarly, it cannot be expected that young students will be able to handle large, complex EDP models like high school students. Steps like *research* and *analysis* would require more teacher support for lower elementary students but could be introduced as students become independent readers and researchers.

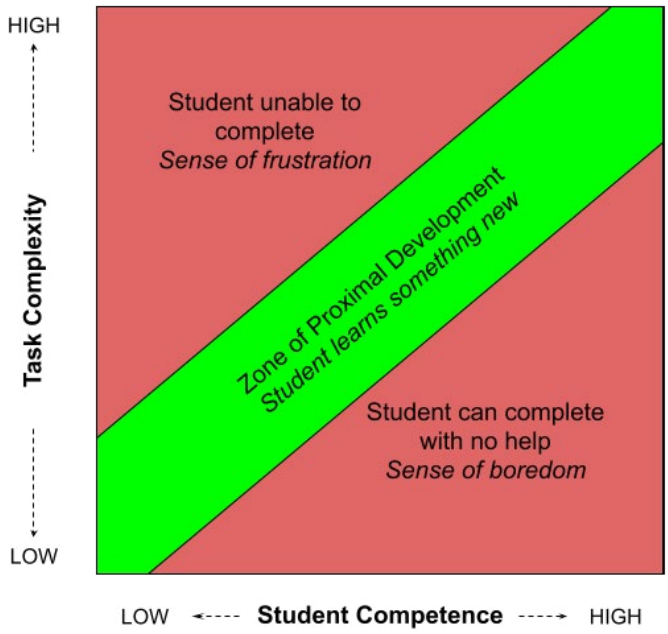

Figure 2. Zone of Proximal Development as a function of challenge and competence.

Vygotsky *(1978)* further defined this idea with his *Zone of Proximal Development* (ZPD). ZPD describes the "sweet spot" for learning as a range between what a student can do independently and what they can achieve with guidance. The most effective instruction occurs within

this zone. On a chart like the one shown in Figure 2, ZPD is a band between the level of challenge and level of [student] competence. If the challenge goes too far beyond student reach, they get anxious and are unable to complete the task. But, if it is too easy, they get bored and are not growing as learners. Over time, as the students build up their skills, their level of competence also rises. Hence, the teacher needs to increase the level of challenge to maintain the students' position within the ZPD and continue their development.

Regarding the EDP, a model will guide students as they develop engineering and problem-solving skills. In selecting and adapting an EDP model for students, educators must choose steps that fit within a student's competence and challenge them to solve the task without overwhelming or confusing them further. For example, giving a kindergarten student a 12-step process that includes terms like *specifying the requirements* or *developing a design proposal* would be well above their level of competence. On the other hand, asking a senior in high school to *imagine* and *build* will be well below their level of competence and create a sense of boredom. Like the rest of the PreK-12 curriculum, scaffolding and staying within the ZPD is a critical part of the EDP that is often overlooked.

In summary, a proper PreK-12 model for EDP must contain, overtly or discretely, all the elements of the EDP. However, the model also needs to keep in mind the ZPD of the audience and provide proper scaffolding as students build their competence. From a PreK-12 viewpoint, the challenge this presents is finding a way to teach and use the EDP in a way that can also be scaffolded for students as they build up their skills. Introducing new models for the EDP every year from early childhood through high school and on to university creates a disjointed flow that isn't scaffolding but rather just reintroducing the EDP. For this reason, we would like to present a new model for the EDP that intentionally addresses scaffolding and stays within Vygotsky's ZPD.

The New Model

While reviewing currently available EDP models, no version was found to be inherently incorrect. Each provides a use for a given group or setting as long as it contains the elements defined earlier. However, what is missing from all other models is a way for educators, schools, and districts to provide a more seamless transition that maintains a clear developmental EDP model in PreK through high school.

In developing a new EDP model, the goal was to (1) focus on the key elements of the EDP as outlined in Table 1, (2) use terms that are easy to understand/adapt, and (3) provide a scaffolded layout that could be used from PreK-12. To begin, the decision was made to address scaffolding by reducing the complexity of the language and the number of steps used for lower grade levels. Matching the grade bands found in *Standards for Technological and Engineering Literacy*, the model starts with two steps in simple language (*Imagine* and *Make*) for the PreK-2 grade band. It next expands to a four-step process with more complexity (*Explore*, *Design*, *Create*, and *Check*) for the 3-5 grade band. As we reach middle school (6-8) and high school (9-12), the language and the steps continue to increase in complexity and steps, with an eight-step and twelve-step process.

Figure 3 shows this process, starting with the simplest form (two steps) and progressing to the most complex (twelve steps). While older, more experienced students might not be overwhelmed by typical EDP steps *Identify Needs*, *Define Constraints*, and *Explore Existing Solutions*, these steps may be more challenging in elementary school. However, in essence, these same steps can be made more abstract by simplifying them to *Understand the Challenge* and *Gather Information* for a middle-grade audience. Again, this language is likely to be understood by a student in Grades 6-8,

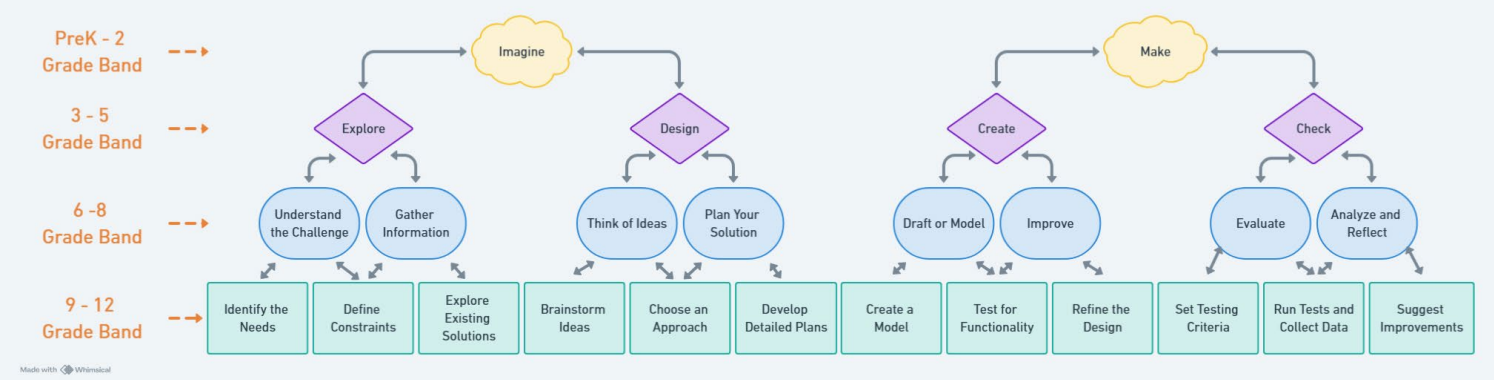

Figure 3.

but it can be further abstracted by condensing them to a single step, *Explore*, for students in Grades 3-5. This leads to a four-step process for the upper elementary students, *Explore*, *Design*, *Create*, and *Check*. Like the previous scaffolding, this works well for students in the second-grade band (3-5) but may not be appropriate for the youngest audience, PreK-2. For this group, the two steps *Imagine* and *Make* were selected. Through this process of abstracting and reducing, all the elements of the EPD are addressed across all grade bands as the initial steps of *Imagine* and *Make* are expanded and detailed to reach the cumulative 12-step process.

This model fits with scaffolding and ZPD by using an increasing number of steps and complexity to grow with the competence of a student. You can imagine how a middle or high school student would be bored with *Imagine,* or a kindergarten or 5th grade student might feel confused or overwhelmed by terms like *Analyze and Reflect*. This concept takes developmental needs into consideration and uses age-appropriate language and step numbers.

Another intentional element of this model is the selection of terms. Terms in the first three grade bands were selected to open the potential for using this model in non-STEM courses. Language in these stages was selected to be more universal in nature and not necessarily specific to engineering or STEM courses. For example, *prototype* is a word commonly used in STEM courses but not often used outside of those classrooms. However, a prototype is just a preliminary model or version of a product. In a writing class, a *draft* is analogous to a *prototype.* So, rather than using the STEM-specific term of *prototype*, the decision was made to call this stage *Draft or Model*. However, when a student reaches high

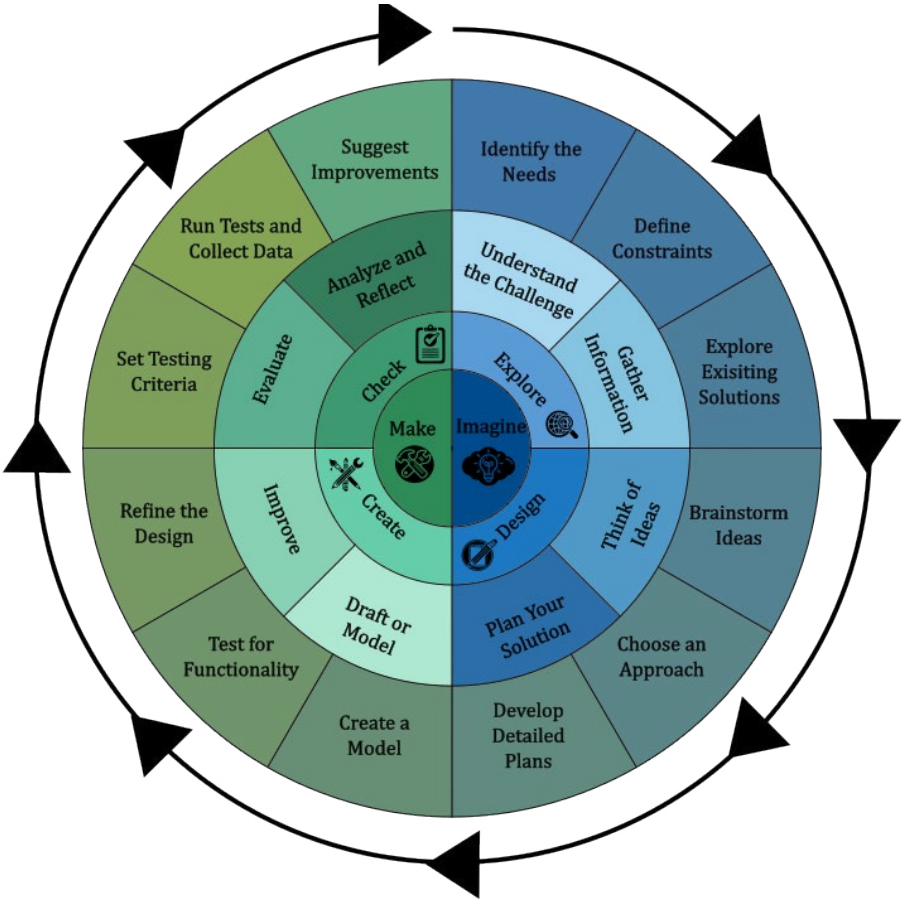

Figure 4. The wagon wheel model for the scaffolded engineering design process model.

school, they reach a point where they need an EDP model more aligned with the engineering field. The language in the apex cycle of 12 steps is more specific to a traditional high school STEM course. This is not to imply that non-STEM courses in high school have no use for the design process. Instead, it can be assumed that the 8-step process will fit well within the non-STEM curriculum from 6-12.

A wagon wheel model was selected to demonstrate the cyclic nature of EDP. It consists of four concentric circles that form tiers and are divided equally to create each layer's number of steps (2, 4, 8, and 12). The layout maintains a flow where it is easy to see how the 2, 4, 8, and 12-step processes are connected, and each circle is simply an expansion of the previous. Two more mostly cosmetic additions were also added to the model. First, a color scheme was selected to help visualize the connection between the stages. Starting with blue and green in the center, the colors change in shade to show new steps while maintaining the base color to show their origins. Second, graphics were added to the center (two-step) and middle (four-step) phases. These graphics provide early learners with visual cues to represent the stages. Once introduced, these icons can be used interchangeably with words to help students identify the step they are on.

As mentioned, this 4-tier model was designed to align with the *STEL* grade bands. Along with this, the different EDP cycles align with the *STEL 7 Design in Technology and Engineering Education* (TEE) benchmarks for that level. Like the benchmarks, each tier of the EDP model progressively builds on students'

understanding and application of design concepts. This helps ensure that, as students move through the grade bands, they engage with design thinking at an appropriate level of complexity. A table showing the *STEL* 7 benchmarks addressed by this model, as well as an overview of the focus of the model and benchmarks, are shown in Table 2.

Implementation Strategies

The goal for this model is not a single-use adoption for a stand-alone teacher or classroom but rather for it to be strategically implemented as a school-wide or district-wide tool. The beauty of this design is that it maintains the key elements of the EDP but makes it accessible across content areas and scaffolds in a way that allows it to be used from PreK-12 without the inconsistency created by using different models in all classrooms. Truthfully, if this model is adopted by only a single teacher at a school while others maintain their own selected model, then it is not serving its intended purpose of being a systematic and scaffolded approach to the EDP.

Along those lines, however, the beauty of this model is not in the terms used, the colors, or the icons. Most importantly, this model is a template or a guide to large-scale adoption. Stakeholders at a school or district may take this model, make their own adaptations, and still reach the intended purpose of developing consistency and scaffolding. The only elements that must remain in place to be effective are the expanding format and agreed-upon language used across a school.

Viewed as a whole, the model may look complicated, but another intentionality in the design is its ability to be taken and displayed in distinct

GRADE BAND	OVERVIEW	STEL 7 - DESIGN IN TEE BENCHMARKS ADDRESSED
PreK-2	Emphasis on playful exploration and basic understanding of design concepts	**7A**. Apply design concepts, principles, and processes through play and exploration. **7B**. Demonstrate that designs have requirements. **7C**. Explain that design is a response to wants and needs. **7D**. Discuss that all designs have different characteristics that can be described. **7E**. Illustrate that there are different solutions to a design and that none are perfect. **7F**. Differentiate essential skills of the technology and engineering design process.
3-5	Emphasis on basic application and evaluation in the design process	**7H**. Illustrate that there are multiple approaches to design. **7I**. Apply the technology and engineering design process. **7J**. Evaluate designs based on criteria, constraints and standards. **7L**. Apply universal principles and elements of design. **7M**. Evaluate the strengths and weaknesses of existing design solutions, including their own solutions. **7N**. Practice successful design skills.
6-8	Emphasis on detailed planning, iterative refinement, and assessment	**7P**. Illustrate the benefits and opportunities associated with different approaches to design. **7Q**. Apply the technology and engineering design process. **7R**. Refine design solutions to address criteria and constraints. **7S**. Create solutions to problems by identifying and applying human factors in design. **7T**. Assess design quality based upon established principles and elements of design. **7U**. Evaluate the strengths and weaknesses of different design solutions.
9-12	Emphasis on optimization and detailed documentation	**7W**. Determine the best approach by evaluating the purpose of the design. **7X**. Document trade-offs in the technology and engineering design process to produce the optimal design. **7Y**. Optimize a design by addressing desired qualities within criteria and constraints. **7AA**. Illustrate principles, elements, and factors of design. **7BB**. Implement the best possible solution to a design.

Table 2.

units, as shown in Figure 5. Each stage could be shared individually, all together, or in combination. When used in kindergarten, there is no need to display all the steps and stages, so the first two-step image alone can be shared and displayed in the classroom. However, in a transitory grade, like Grade 3, where students move from the two-stage up to the four-stage process, showing both might be handy so students can visualize the connection. The concentric circle design allows any combination or single stage to be easily displayed across a school or district.

INTEGRATING OTHER STEL BENCHMARKS

The article focused on *STEL* 7 as an alternative to the many models, offering a grade-level-appropriate unified approach. The goal is not to separate the benchmarks but to demonstrate how a comprehensive design cycle tailored to age can minimize confusion about the design process. While emphasizing the design process for general applications, the design cycle presented here does not take precedence over the other benchmarks within specific activities or fields.

For instance, teachers and students design a project using robotics elements to tackle environmental issues such as water scarcity within a farming application. Addressing *STEL*-8J (Use devices to control technological systems) as an objective benchmark, students go through the design cycle proposed without forgetting about the objective benchmark.

Additionally, through this design cycle, students realize how *STEL*-1L (Explain how technology and engineering are closely linked to creativity, which can result in both intended and unintended innovations) comes to life when students iterate their design, coming up with new ideas as they create, check or evaluate, and reflect on improving their original ideas.

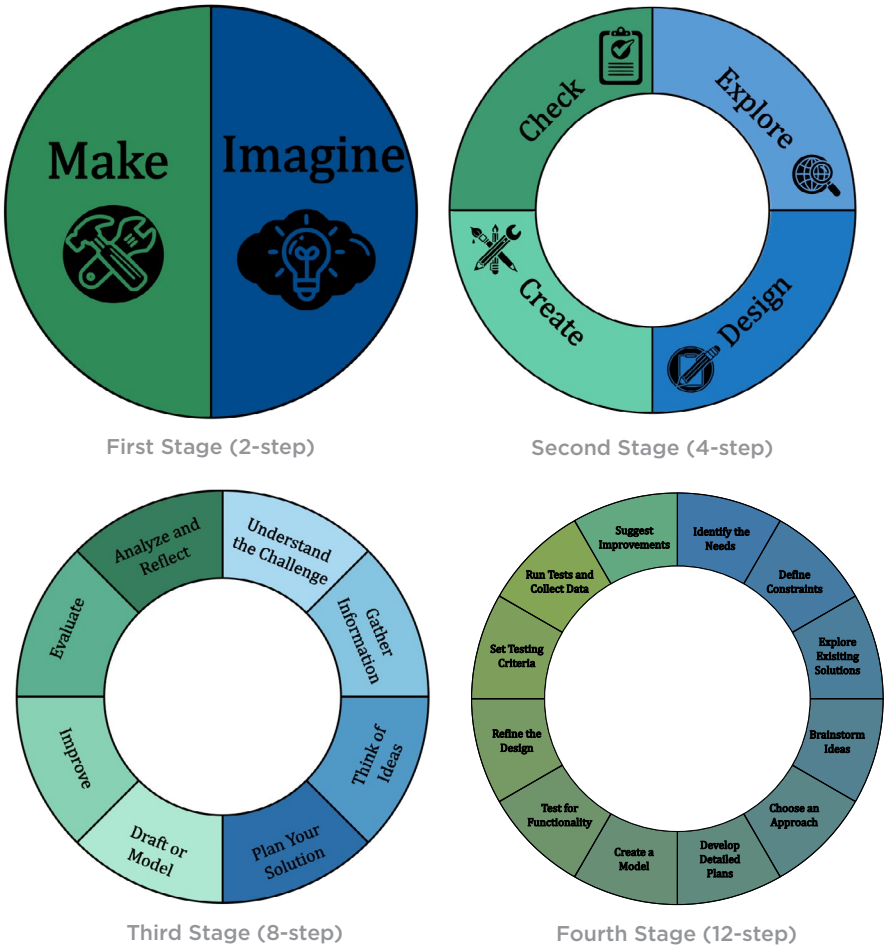

Figure 5.

This iterative process allows students to understand design as a creative process and a response to human needs and the natural environment, as seen in benchmarks like *STEL*-1A. Emphasizing the role of systems and components within technological solutions within a design (*STEL* 2) directly complementing the *STEL* 7 design benchmarks.

Another example is the incorporation of *STEL* 3, which addresses the integration of knowledge, technologies, and practices and fosters a multidisciplinary approach to innovation (e.g., *STEL*-3H). This approach to innovation cannot be separated from the design cycle and encourages students to apply their design skills in broader contexts. Additionally, students constantly test and refine their designs as they procure high quality in checking in their designs, which cannot be separated from *STEL*-8I.

Thus, while this article focuses on the design benchmarks, teachers must intentionally connect to the other ITEEA Technological and Engineering Literacy Standards.

INFORMAL LEARNING APPLICATIONS

Informal learning settings, such as STEM camps, museums, and afterschool programs, also provide unique opportunities to implement this scaffolded EDP model. These environments often cater to mixed-age audiences and short-term engagement periods, making the tiered structure of this model useful. For instance, STEM camps can guide participants

through progressively complex design challenges, aligning with the four-step or eight-step models depending on the age and experience of the learners. Museums can use the two-step or four-step processes to structure interactive exhibits, with the model's visuals and cyclic design to encourage iterative thinking. By using this EDP model in these contexts, informal educators can use visual aids, facilitate training, and provide feedback mechanisms aligning with the model's core principles.

Conclusion and Future Directions

This EDP model offers a simple yet systematic approach that aligns closely with *STEL* 7 benchmarks, supporting a gradual yet progressive development of design thinking across grade levels. By embracing the iterative and cyclical nature of the EDP, this model not only aligns with developmental stages but also fosters a mindset of continual improvement and creative problem solving. The gradual introduction of more complex design concepts as students mature avoids overloading them with sudden shifts in engineering frameworks; instead, it allows them to experience design as a scaffolded toolkit, becoming increasingly detailed and sophisticated with every grade-band advancement. It's worth noting that the terms and age grouping shared in this article and model are merely suggestions. The key idea is to create a school-wide or district-wide model that works without implementing too many competing models.

Future applications and opportunities for this model in the classroom also lie in possible cross-disciplinary integration. The EDP could open up opportunities for engineering design principles to be used within other core subjects for applied learning opportunities. A common issue may be time limitations and constraints to dedicate to engineering-related curriculum activities. This model can tackle engineering-based problems while addressing literacy, lab design, or math. Advanced examples of these cross-disciplinary applications can go from a simple English paper iteration or coding to a more complex project, such as designing efficient irrigation systems with minimal water flow rates and waste or urban design initiatives. Feedback from educators is welcomed to help refine the model further; readers are invited to share their insights by completing a brief survey at *https://bit.ly/scaffoldEDP*.

References

National Research Council [NRC]. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (p. 13165). National Academies Press. *https://doi.org/10.17226/13165*

NGSS Lead States. (2013). *Next generation science standards: For states, by states* (p. 18290). National Academies Press. *https://doi.org/10.17226/18290*

International Technology and Engineering Educators Association (ITEEA) (2020). *Standards for technological and engineering literacy: The role of technology and engineering in STEM education.* Author. *www.iteea.org/STEL*

Science Buddies. (2025). *Steps of the engineering design process* [Diagram]. Science Buddies. Retrieved January 24, 2025, from *www.sciencebuddies.org/science-fair-projects/engineering-design-process/engineering-design-process-steps*

TeachEngineering. (2025). *Engineering design process* [Diagram]. TeachEngineering. Retrieved January 24, 2025, from *www.teachengineering.org/k12engineering/designprocess*

TWI Ltd. (n.d.). *Engineering design process flowchart* [Diagram]. TWI. Retrieved January 24, 2025, from *www.twi-global.com/technical-knowledge/faqs/engineering-design-process*

Vygotsky, L. S. (1978). *Mind in society: Development of higher psychological processes* (M. Cole, V. Jolm-Steiner, S. Scribner, & E. Souberman, Eds.). Harvard University Press. *https://doi.org/10.2307/j.ctvjf9vz4*

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*(2), 89–100. *https://doi.org/10.1111/j.1469-7610.1976.tb00381.x*

Youth Engineering Solutions. (n.d.). *Engineering design process* [Diagram]. Youth Engineering Solutions. Retrieved January 24, 2025, from *https://youthengineeringsolutions.org/why-yes/engineering-design-process/*

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