Chapter 9
Formative Assessment in Hands-On STEM Education

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ABSTRACT

This chapter serves as an introduction to transdisciplinary learning, Integrative STEM Education, and current methods for infusing formative assessment into hands-on instruction at the elementary level. Subscribing to the approach that formative assessment is a process that takes place in the classroom to enable learning, the chapter discusses the use of engineering notebooks, competency-based assessment, and qualitative assessment (rubrics and portfolios) in the context of formative assessment while facilitating hands-on learning opportunities. In addition to introducing each of these topics from a research and literature perspective, examples are provided and discussed from a practical perspective. No one formative assessment is better than another, however, one type may be more practical due to the teacher's willingness to try new things, development of students, standards teacher is measuring, type of lesson/unit, time, available resources, and associated costs.

INTRODUCTION

As a society, we are solidly in the 21st century. However, our learning priorities are just starting to catch up with the ideas and processes needed to prepare students for the society and systems they will inherit in the future. As educators work to provide environments and curricula in which students can thrive and effectively prepare for students' futures, topics such as college and career readiness, 21st century skills, STEM (science, technology, engineering, math), formative assessments, hands-on learning, and others are being explored by practitioners and researchers alike. This chapter will explore the unique role

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of formative assessments in STEM education through the numerous opportunities for observation that hands-on learning provides to directly assess students' learning processes. These opportunities to assess student knowledge, skills, and abilities when engaging in hands-on STEM activities are pivotal moments that have broader impacts regarding students' levels of activation, efficacy in STEM content areas, and career interests, especially in terms of formative assessment where the feedback is low-stakes. STEM education will be explained in terms of transdisciplinary learning and the development of Integrative STEM Education as model of hands-on-education in a STEM classroom and how formative assessment plays a role in the learning process. Finally, this chapter reviews several options of formative assessment that can be used in conjunction with Integrative STEM Education at the elementary level, including engineering notebooks, competency-based assessment, portfolios, and rubrics.

Formative assessment is an important part of the learning process; it allows for growth to occur more readily in a hands-on context, like that found in Integrative STEM education, because it allows for instant or near-instant correction and discussion. The cause and effect of decisions and processes are identifiable and reteaching can occur in a more timely manner, and also in a manner that has more meaning for the student. Like pebbles being thrown in a lake, teachers' decisions make create ripples in their students' lives. Researchers are currently investigating these ripples and their effects through the lenses of STEM literacy and career interest in STEM fields. Early and often seems to be a recurring theme found in the literature, as such, the inclusion of STEM education at the elementary level is an important step for American Education.

The Next Generation Science Standards (NGSS) provide an engineering education focus that was not previously included in most public science education (Next Generation Science Standards Lead States, 2013) and also requires varying forms of ongoing formative assessment. The inclusion of engineering in all grade levels science curriculum supports early exposure to STEM education and a belief that young children are capable of this level of thinking (Moomaw & Davis, 2010). Furthermore, STEM education shows promise in teaching for future science, technology, engineering, and mathematics as one cohesive learning experience. However, the rebranding of science or engineering content as STEM does not fulfill the true educational movement. STEM education is a style of education that uses pedagogical skills from all of the disciplines to teach in a way that resembles how education will be used in real-life. The challenges that future generations will solve will require scientific and mathematical knowledge, and STEM education is perfectly placed to teach kids content and skills, such as critical thinking, problem-solving, and creativity (Ernst, 2009; Bybee, 2013; Peterson, 2017). One way teachers can better prepare their students is by providing them opportunities to solve engineering design challenges using everyday recyclables and inexpensive materials. It is important for students to build connections between the challenge and their other schoolwork, so building the challenges into the curriculum (as opposed to stand alone) is recommended. Design challenges like this help students learn adaptability, complex communication, non-routine problem solving, self-management, social skills, and systems knowledge (Dym, Agogino, Eris, Frey, & Leifer, 2006; Peterson, 2017). The use of engineering design challenges aligns with best practice and policy priorities set by President's Council of Advisors on Science and Technology (Holdren, Lander, & Varmus, 2010).

Recently, policymakers have renewed interest in promoting STEM in K-12 education with the Every Child Succeeds Act (ESSA), the National Science Foundation funding focus, and the US Department of Education's list of educational priorities. At the elementary level, STEM education focuses on hands-on STEM introductory classes and occupations to interest students into wanting to pursue STEM careers, not require them to gain a certain number of credits in secondary education. In particular, the hands-on, or learning by experience, aspect is critically important to engage students in STEM education. Many studies have reported that students will learn better and actively improve their understanding of new knowledge and skills when they are involved in hands-on learning because it is seen as a more realistic experience. Young students are encouraged to explore the world and lesson on their own terms actually using their hands to examine, manipulate, and learn more with further opportunities. Hands-on learning specifically compliments STEM educational philosophy and supports the use of formative assessments as a way to enhance learning in a STEM context.

BACKGROUND

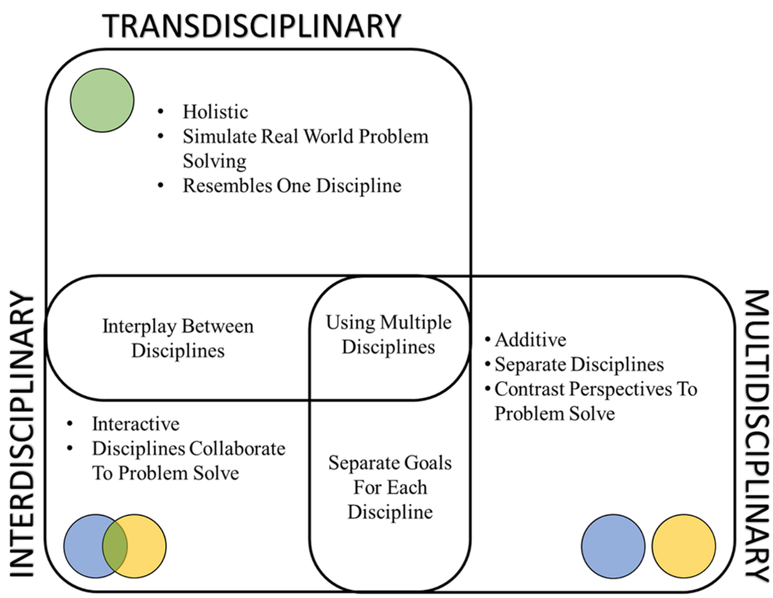
Transdisciplinary Learning

Transdisciplinary learning is based on the theory that knowledge and learning can be best achieved at the highest level of curricula integration (Brooks & Brooks, 1993; Kaufman, Moss, & Osborn, 2003). Philosophically constructivist, transdisciplinary learning is the exploration of a concept, issue, or problem from multiple discipline perspectives. This should not be confused with two related terms, multidisciplinary and interdisciplinary. Multidisciplinary learning uses more than one discipline in a learning environment, however the boundaries between those disciplines are clearly defined and have their own educational goals (Garner, 1995; Park & Son, 2010). Interdisciplinary learning takes education one step further than multidisciplinary approaches and focuses on the collaboration between multiple disciplines, but still work from a discipline-specific framework to solve problems (Dyer, 2003; Park & Son, 2010). While both interdisciplinary and transdisciplinary learning have interplay between disciplines, transdisciplinary tends to take a more holistic approach.

As mentioned above, transdisciplinary learning represents the highest level of curricula integration. This is not to say that it is always the best option, however. Every approach, be it content specific, multidisciplinary, interdisciplinary, or transdisciplinary, has its own set of advantages and disadvantages. The disadvantage of transdisciplinarity, a holistic problem-solving method, can also be considered a strength. This approach simulates real-world application. This can be problematic at times for school systems that emphasize disciplinary structure through standardized testing where it can be difficult for a teacher to justify the change in focus which limits the pedagogical approach that a teacher can use to align their lessons and units. Figure 1 shows the relationship between multidisciplinary, interdisciplinary, and transdisciplinary learning that can be used by teachers to help identify which approach fits their specific circumstances.

Research done on specific pedagogical approaches help to justify transdisciplinary learning by showcasing the advantages in a way that aligns more clearly to both real-world and school-based objectives. Some effective uses of transdisciplinary learning include design-based learning (DBL), which is a pedagogical approach that guides students in constructing their own knowledge and developing real-world problem-solving skills by engaging them in technology and engineering design to create a physical artifact (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004). DBL uses the engineering design process as a catalyst for using content knowledge in a practical way to solve a problem. Figure 2 shows an example of a literacy-based lesson that utilizes DBL to enhance and expand the learning process.

Figure 1. Comparison of Multidisciplinary, Interdisciplinary, and Transdisciplinary Learning

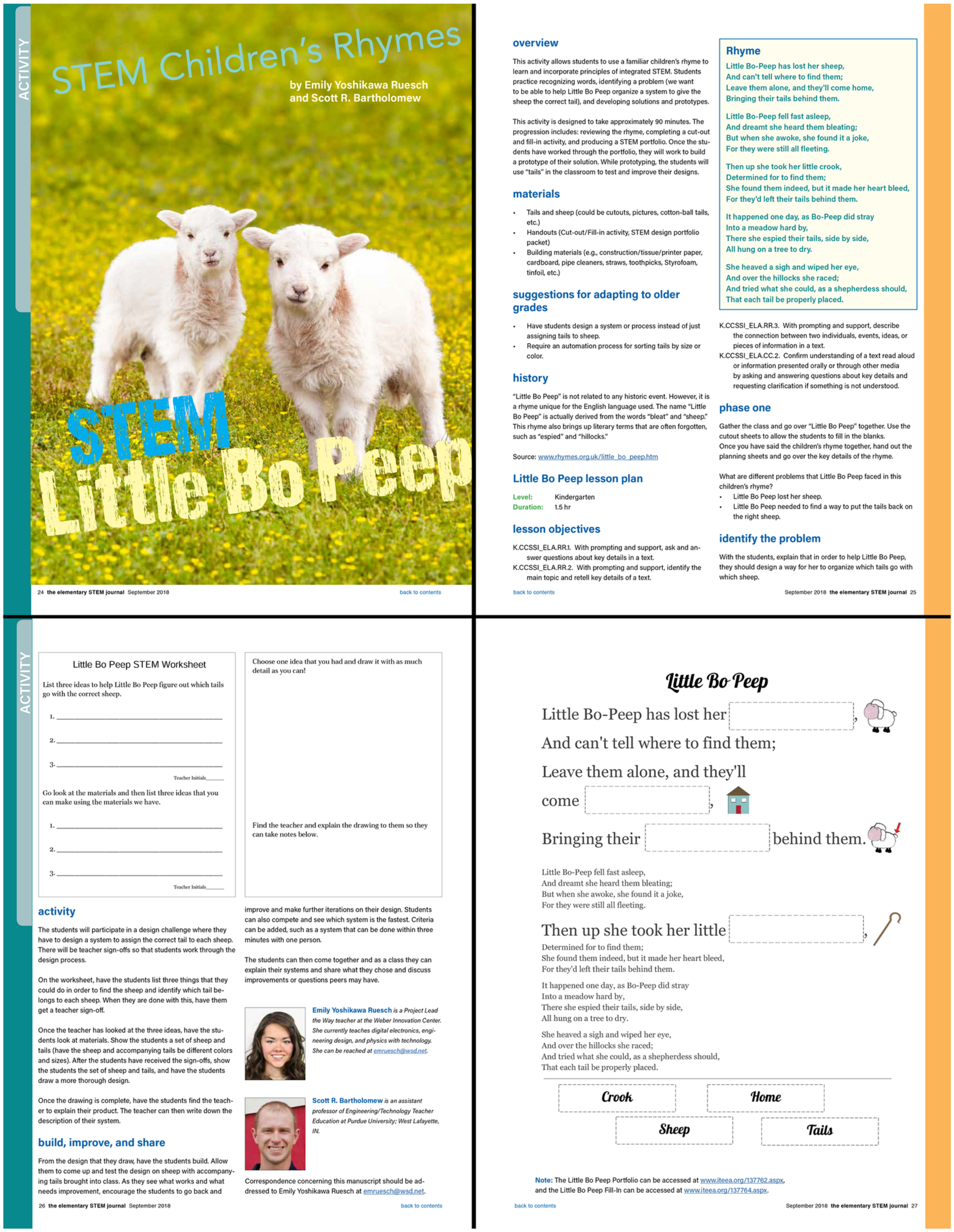


The design process is a crucial part of DBL; while it is often depicted as a circle such as in Figure 3, movement through the design process is non-linear to allow for constant questioning, evaluation, and improvement (Hill-Cunningham, P. R. & Hunt, A. B., 2018). Figures 3 through 7 below visually represent five popular design process visuals used to introduce the engineering design process at the elementary level. The process a teacher selects can be based on any number of variables; while not exhaustive, the following are things a teacher may consider when selecting what process to utilize:

- School-wide adoption
- Aligning age of student to complexity/ number of identified steps
- Curriculum selection
- Visual preference
- Previous experience of self and/or students with a process

Along with the theme of STEM education, design challenges that intentionally utilize multiple disciplines in STEM can use the design process to require students to learn and apply relevant math and science concepts to create an appropriate solution (Kanter, 2010; Berland, 2013). These opportunities are important at the elementary level because research shows that there is a positive impact on elementary students' perceptions and dispositions toward STEM with early exposure to STEM initiatives/activities (DeJarnette, 2012). A great pedagogical approach that utilizes DBL as a catalyst to transdisciplinary learning is Integrative STEM Education. This approach gives structure to curricula and ties topics from all STEM content areas together in a real design context (Sanders, 2008; Sanders, 2012; Wells, 2013).

Figure 2. DBL example from Elementary STEM Journal (Yoshikawa Ruesch & Bartholomew, 2018)



ACTIVITY

STEM Children's Rhymes

by Emily Yoshikawa Ruesch and Scott R. Bartholomew

STEM Little Bo Peep

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overview

This activity allows students to use a familiar children's rhyme to learn and incorporate principles of integrated STEM. Students practice recognizing words, identifying a problem (we want to be able to help Little Bo Peep organize a system to give the sheep the correct tail), and developing solutions and prototypes.

This activity is designed to take approximately 90 minutes. The progression includes: reviewing the rhyme, completing a cut-out and fill-in activity, and producing a STEM portfolio. Once the students have worked through the portfolio, they will work to build a prototype of their solution. While prototyping, the students will use "tails" in the classroom to test and improve their designs.

materials

- Tails and sheep (could be cutouts, pictures, cotton-ball tails, etc.)
- Handouts (Cut-out/Fill-in activity, STEM design portfolio packet)
- Building materials (e.g., construction/tissue/printer paper, cardboard, pipe cleaners, straws, toothpicks, Styrofoam, tinfoil, etc.)

suggestions for adapting to older grades

- Have students design a system or process instead of just assigning tails to sheep.
- Require an automation process for sorting tails by size or color.

history

"Little Bo Peep" is not related to any historic event. However, it is a rhyme unique for the English language used. The name "Little Bo Peep" is actually derived from the words "bleat" and "sheep." This rhyme also brings up literary terms that are often forgotten, such as "espied" and "hillocks."

Source: www.rhymes.org.uk/little_bo_peep.htm

Little Bo Peep lesson plan

Level: Kindergarten
Duration: 1.5 hr

lesson objectives

K.CCSSI_ELA.RR.1. With prompting and support, ask and answer questions about key details in a text.
K.CCSSI_ELA.RR.2. With prompting and support, identify the main topic and retell key details of a text.

Rhyme

Little Bo-Peep has lost her sheep,
And can't tell where to find them;
Leave them alone, and they'll come home,
Bringing their tails behind them.

Little Bo-Peep fell fast asleep,
And dreamt she heard them bleating;
But when she awoke, she found it a joke,
For they were still all fleeting.

Then up she took her little crook,
Determined for to find them;
She found them indeed, but it made her heart bleed,
For they'd left their tails behind them.

It happened one day, as Bo-Peep did stray
Into a meadow hard by,
There she espied their tails, side by side,
All hung on a tree to dry.

She heaved a sigh and wiped her eye,
And over the hillocks she raced;
And tried what she could, as a shepherdess should,
That each tail be properly placed.

K.CCSSI_ELA.RR.3. With prompting and support, describe the connection between two individuals, events, ideas, or pieces of information in a text.
K.CCSSI_ELA.CC.2. Confirm understanding of a text read aloud or information presented orally or through other media by asking and answering questions about key details and requesting clarification if something is not understood.

phase one

Gather the class and go over "Little Bo Peep" together. Use the cutout sheets to allow the students to fill in the blanks. Once you have said the children's rhyme together, hand out the planning sheets and go over the key details of the rhyme.

What are different problems that Little Bo Peep faced in this children's rhyme?

- Little Bo Peep lost her sheep.
- Little Bo Peep needed to find a way to put the tails back on the right sheep.

identify the problem

With the students, explain that in order to help Little Bo Peep, they should design a way for her to organize which tails go with which sheep.

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ACTIVITY

Little Bo Peep STEM Worksheet

List three ideas to help Little Bo Peep figure out which tails go with the correct sheep.

1. ______
2. ______
3. ______

Teacher Initials_____

Go look at the materials and then list three ideas that you can make using the materials we have.

1. ______
2. ______
3. ______

Teacher Initials_____

Choose one idea that you had and draw it with as much detail as you can!

Find the teacher and explain the drawing to them so they can take notes below.

activity

The students will participate in a design challenge where they have to design a system to assign the correct tail to each sheep. There will be teacher sign-offs so that students work through the design process.

On the worksheet, have the students list three things that they could do in order to find the sheep and identify which tail belongs to each sheep. When they are done with this, have them get a teacher sign-off.

Once the teacher has looked at the three ideas, have the students look at materials. Show the students a set of sheep and tails (have the sheep and accompanying tails be different colors and sizes). After the students have received the sign-offs, show the students the set of sheep and tails, and have the students draw a more thorough design.

Once the drawing is complete, have the students find the teacher to explain their product. The teacher can then write down the description of their system.

build, improve, and share

From the design that they draw, have the students build. Allow them to come up and test the design on sheep with accompanying tails brought into class. As they see what works and what needs improvement, encourage the students to go back and improve and make further iterations on their design. Students can also compete and see which system is the fastest. Criteria can be added, such as a system that can be done within three minutes with one person.

The students can then come together and as a class they can explain their systems and share what they chose and discuss improvements or questions peers may have.

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Little Bo Peep

Little Bo-Peep has lost her ______,
And can't tell where to find them;
Leave them alone, and they'll
come ______,
Bringing their ______ behind them.

Little Bo-Peep fell fast asleep,
And dreamt she heard them bleating;
But when she awoke, she found it a joke,
For they were still all fleeting.

Then up she took her little ______,
Determined for to find them;
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She heaved a sigh and wiped her eye,
And over the hillocks she raced;
And tried what she could, as a shepherdess should,
That each tail be properly placed.

Crook Home Sheep Tails

Note: The Little Bo Peep Portfolio can be accessed at www.iteea.org/137762.aspx, and the Little Bo Peep Fill-In can be accessed at www.iteea.org/137764.aspx.

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Figure 3. 12-step Engineering Design Process (International Technology and Engineering Educators Association, 2013)

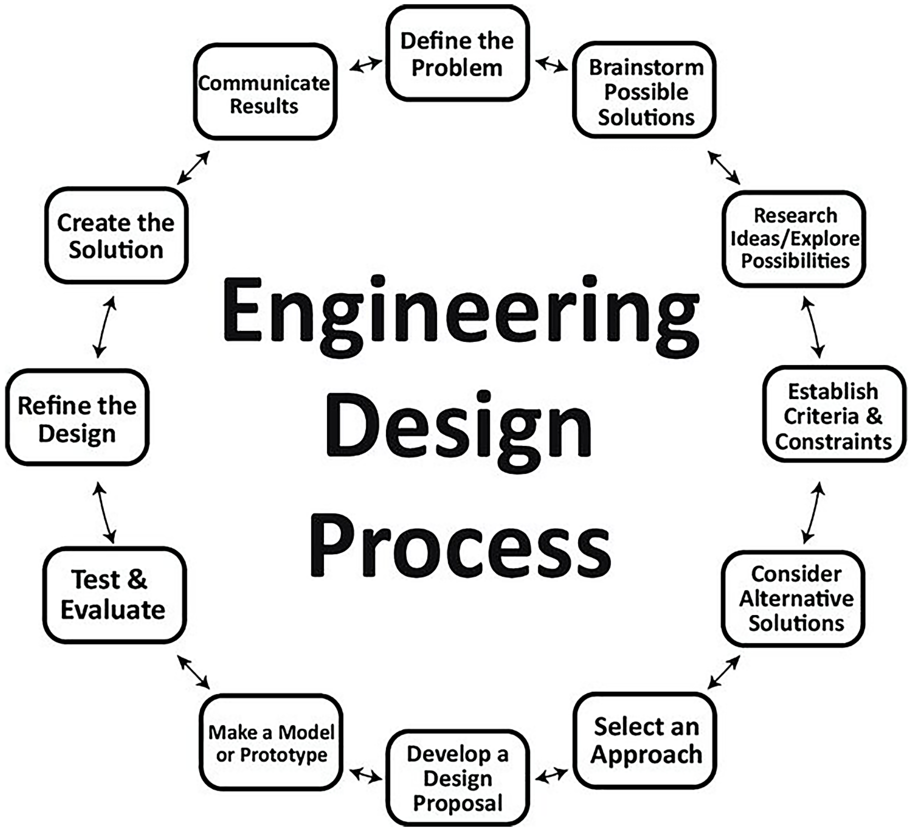


Figure 4. Informed Design Cycle (Burghardt & Hacker, 2004)

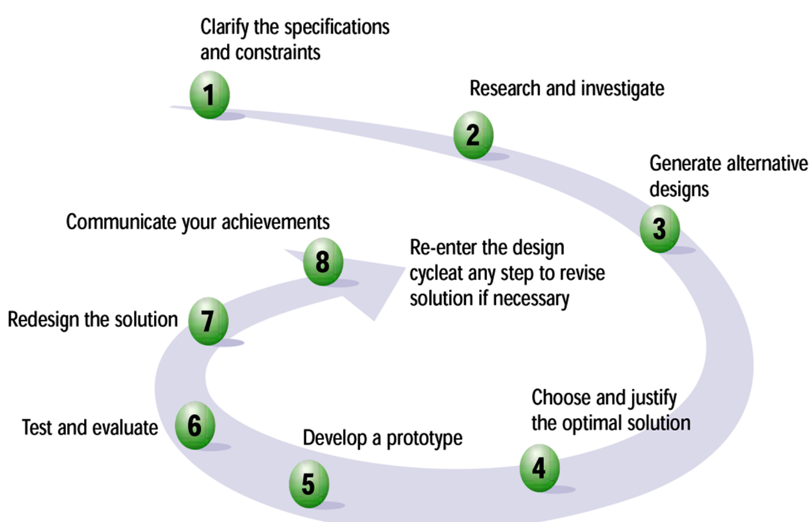


Figure 5. Engineering Design Process (EIE, n.d.)

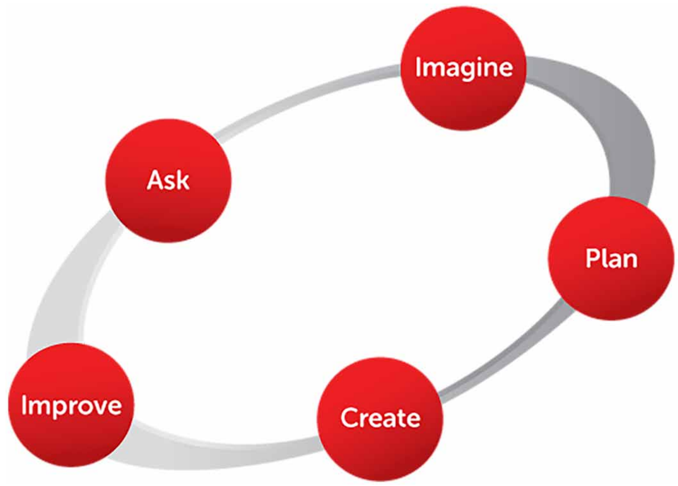


Figure 6. PBSKids Design Process (PBSkids, n.d.)

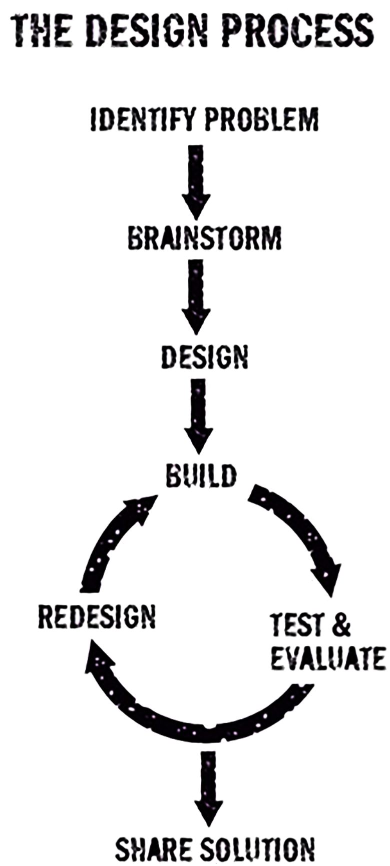
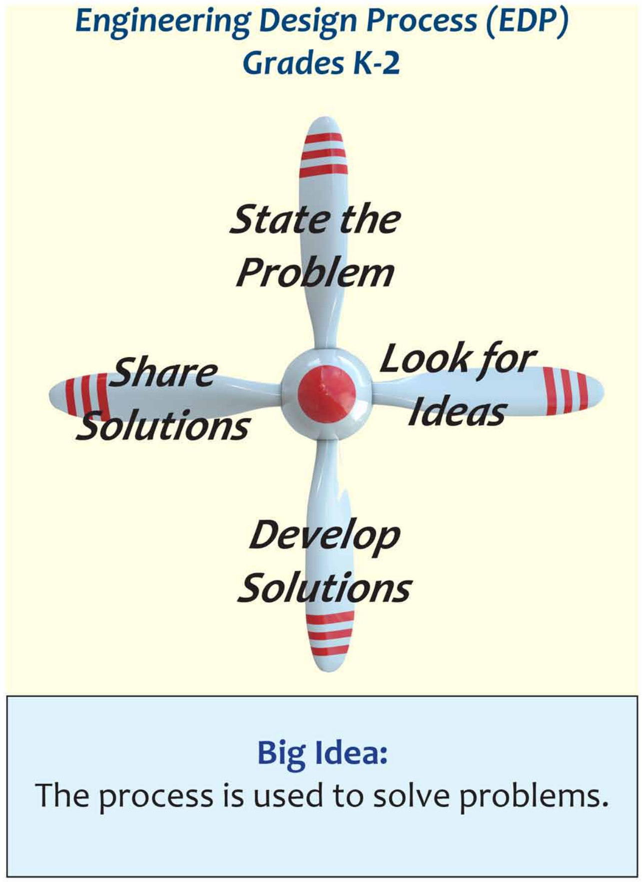


Figure 7. K-2 EBD (Engineering ByDesign) Engineering Design Process (ITEEA, n.d.)



Integrative STEM Education

Integrative STEM Education (I-STEM Ed.) is a way of resituating learning for students in the 21st century; it increases understanding, performance, and engagement with a more purposeful and relevant curriculum based on connections between the subjects and real-world problems. It is an approach that can be used from Pre-K through post-graduate education. Integrative STEM Education is defined as:

the application of technological/ engineering design based pedagogical approaches to intentionally teach content and practices of science and mathematics education concurrently with content and practices of technology/engineering education. Integrative STEM Education is equally applicable at the natural intersections of learning within the continuum of content areas, educational environments, and academic levels (Ernst & Wells, 2012).

At its core, I-STEM Ed. intentionally integrates "the concepts and practices of science and/or mathematics education with the concepts and practices of technology and/or engineering education" (Sanders & Wells, 2010). I-STEM Ed. is conceptually different from most current practices in that it is designed to be "thoughtfully and effectively articulated across multiple school grades/bands," (Sanders, 2012, p. 104). It provides "a unique and powerful context for meaningfully organizing STEM knowledge for future retrieval/use" (Sanders, 2012, p. 109).

Additionally, through the Integrative STEM Ed. approach, students are able to develop skills, such as critical-thinking, problem-solving strategies, creative-thinking processes, and oral and written communication, that have been identified as critical to develop in an educational setting (Brown, 2006). Brown further found that when engaged in integrated curriculum students "use thought processes", think critically and creatively, solve problems, work on interpersonal skills and communications, and "they can begin the process of becoming lifelong learners" (p. 781-783). He also said that "curriculum integration involves students in genuine democratic activities that can yield solutions to practical problems they experience" (p. 781). Groups build projects using the engineering design model, such as those designed with an I-STEM focus, more than meet this need while providing an opportunity for both students and teachers to use feedback to make ongoing adjustments as needed in the learning process.

For schools where students see a single teacher for multiple subjects, like in most elementary schools, it can be easier to implement as there is not a need for common planning time. I-STEM Ed. is an active process for students, they are constantly *doing* and technology education is often the avenue used for them to implement the learning from other content areas. Providing students access to, and training on, everything from a simple hammer and nails to 3D printers allows them to create. The process of creation is often where learning is most visible, however, few teachers feel comfortable assessing learning via a hands-on approach. Comfort with the formative assessment of hands-on learning is important for teachers, as it tells the teacher if learners have arrived at the intended destination before a high-stakes summative assessment.

A lack of comfort assessing learning through hands-on approaches does not mean educators do not see the value in the process of creation as a learning tool, however. Even in 1970 educators were identifying the need for differentiated lessons that included a variety of formative and summative assessment techniques (Maley, 1970). Experienced teachers inherently understand the connection between their actions and student outcomes. Elementary teachers seem to be aware they are helping to shape their students personalities just as much as their academic excellence. As mentioned earlier in the chapter, teachers' decisions create ripples in their students lives, just as pebbles being thrown in a lake. The smallest choice can make a major difference; this is true for their academic content knowledge, but also for their personalities.

Students' Essential Skills

Personality variables such as grit and efficacy are helping to shed light on academic success perseverance in STEM careers. However, grit, self-efficacy, and prosocial behavior (among others) are all essential skills that benefit all students, regardless of career aspirations, and can be improved through STEM education efforts. This is especially true for children who enter elementary school with deficits in these areas (traditionally those from low-income families), as early interventions minimize the achievement gap between low- and middle-income families (Chien, Harbin, Goldhagen, Lippman, & Walker, 2012). The use of I-STEM Ed. in the elementary classroom affords teachers the opportunity to work on some of these essential skills.

Self-Control

Self-control is the voluntary regulation of impulses (behavioral, emotional, and attentional) in the presence of temptations or diversions (Duckworth & Seligman, 2005). Research in which teachers rated first graders' self control, assessed by the child's ability to plan, evaluate, and self-regulate, found that self-control is related to language and mathematics achievement (Normandeau & Guay, 1998; Zumbrunn, Tadlock, & Roberts, 2011). DBL, with its goals of producing an end product, professional behavior, and metacognition, can provide a system and structure in which students can practice and improve these skills, especially with the use of engineering notebooks (Geitz & de Geus, 2019). The Duckworth Lab focuses on two traits that predict achievement: self-control and grit.

Grit

Grit is the tendency to sustain interest in and effort toward long-term goals as shown by working through challenges (Duckworth et al., 2007) Usually, individuals who are "gritty" are also more self-controlled, but the correlation is not perfect (Duckworth & Gross, 2014). Grit is a skill that is encouraged in I-STEM Ed. The integrative nature of the engineering design process encourages seeing failures as progress; working through failures in the design process allows students to learn how sustained focus can lead to progress. With high engagement levels, hands-on learning is ideal for teaching kids to persist when things get hard. Building a stick-with-it attitude through failures and setbacks in these settings allow for transfer of skills to other situations in the future. Both self-control and grit feed into the construct of self-regulated learning, a cyclical process in which students plan for a task, self-monitor performance, and reflect on the outcomes, using the reflection to adjust and prepare for the next task (Zimmerman, 2002).

Mindset

Children set out to complete a task through "mastery orientation" or "performance orientation" (Dweck & Leggett, 1988). With mastery orientation, students are concerned with mastering new tasks over time by increasing their competence and abilities; engineering notebooks align well with encouraging this mentality. In contrast, with performance orientation, students are concerned with positive external judgments of their competence; this is often visible in the students that want to know exactly what is necessary to get an "A". I-STEM Ed. supports the growth of mastery orientation in students by encouraging students to take risks, explore challenging tasks in a low-stakes way, and celebrating failure as a part of the learning process. These orientations are foundational to Dweck's growth mindset research. Growth mindset does not deny that people have different skill levels, it simply acknowledges that everyone can improve their underlying ability (Dweck, 1999). The collaborative environment build through DBL allows for natural conversations about strengths and abilities and how we work to improve them.

Self-Efficacy

Self-efficacy is the belief in one's ability to accomplish a task. Research has confirmed a positive relationship between self-efficacy beliefs and academic performance and persistence (Multon, Brown, & Lent, 1991). Efficacy beliefs help determine the effort, perseverance through a challenge, and resiliency.

While research on elementary students' academic self-efficacy is limited, Phan (2012) found a trajectory of increasing science self-efficacy during the school year is associated with success in science learning for fifth and sixth grade students.

Pro-Social Behaviors

The ability to get along with peers at school is important in its own right, but it also affects academic achievement and emotional adjustment (Chien et al., 2012). Building opportunities for collaboration with teacher scaffolding helps connect students and encourage pro-social behaviors. With DBL frequently using design teams, teachers have the opportunity to build an environment that values and teaches positive interactions. These behaviors then have an effect on student's academic achievement and provide a foundation for other 21st century learning skills.

I-STEM Ed. offers teachers the opportunity to engage students in a learning process that encourages growth of self as well as content knowledge. Ultimately, a "steady stream of communication between teachers and students, based on formative assessment data, encourages students' engagement, motivation, risk-taking, and achievement because it functions as part of a constructive feedback loop rather than an end point" (Buelin, Ernst, Clark, Kelly, & DeLuca, 2019, p. 23). The following section discusses formative assessment options that tailor well to hands-on STEM learning.

FORMATIVE ASSESSMENT OPTIONS IN HANDS-ON LEARNING

Formative assessment is a key tenant of quality STEM/technology education, as it acknowledges student progress (ITEA, 2004). Formative assessments are used during instruction to monitor student ability and adjust the presentation of content or instructional strategies as necessary. While there are many forms of formative assessment that can be used for quick check-ins during all types of lessons (e.g. thumbs up/thumbs down, exit tickets, journal responses, choral responses, concept maps, etc.), there are other forms of formative assessment that fit hands-on, STEM-focused lessons particularly well for more robust response opportunities. Generally, teachers prefer authentic assessments in all types of instruction that can more accurately measure the learning process, including observation, performance assessment, self-assessment, writing samples, feedback, checklists, and portfolios (McNair, Bhargava, Adams, Edgerton, & Kypros, 2003). However, the use of hands-on assessments is also an area that many teachers feel less comfortable with because it can seem more ambiguous than the true/false or multiple choice question set our society has become more accustomed with. To combat this ambiguity, the following section will share examples of current methods for infusing formative assessment specifically into hands-on instruction at the elementary level, including engineering notebooks, competency-based assessments, qualitative feedback, and portfolios. While these types of assessments are more frequently discussed as summative assessment options, they can provide rich formative assessment options with little additional effort on the teacher's part.

Figure 8. 5th Grade Engineering Notebook Page

Problem: There aren't enough rocky shore organisms surviving in your area anymore. So, you will be creating a rocky shore organism that can survive the challenges of the rocky shore, including the weight of the waves without burrowing into the sand.
Criteria and constraints: With your team, you will be creating your "critter" with only five index cards, scissors, and tape. You will have 4 minutes to brainstorm and 11 minutes to build.

Test & Evaluate

Prototype	Did it survive?	Notes
Prototype 1:		
Prototype 2:		
Prototype 3:		
Prototype 4:		

Reflection

ENGINEERING NOTEBOOKS

An engineering notebook is a tool for recording information about a design problem that mimics how engineers collect information, identify constraints, define criteria, and store information for later use, and it can also capture a student's design thinking, sketches, and reflective thoughts as the student learns (Kelley, 2011). Engineering notebooks, sometimes referred to as journals, can be used as written and visual displays of conceptual and procedural knowledge that provide insight into student thinking and ways of knowing (Hammerman, 2009). Practically, they provide a place for students to document their work and the engineering design process. They also provide an opportunity for students to explore their own processes at a metacognitive level later. Entries can be predetermined, guided, or open to aligning with instructional goals, but are constructed by students as they work through guided/open inquiries or problem-based learning (Hammerman, 2009). The amount of scaffolding provided in engineering design journals can be personalized based on student need or class developmental level. Figures 8 and 9 provide examples of the same page from an engineering journal; Figure 8 provides a generic page and Figure 9 provides more scaffolding to guide student thinking and writing. When deciding what level of scaffolding to provide, teachers should consider:

- The developmental level of their students as a whole
- How differentiation can be provided within a page structure
- Intended outcomes of the written product

Figure 9. 5th Grade Engineering Notebook Page with Scaffolding

Problem: There aren't enough rocky shore organisms surviving in your area anymore. So, you will be creating a rocky shore organism that can survive the challenges of the rocky shore, including the weight of the waves without burrowing into the sand.
Criteria and constraints: With your team, you will be creating your "critter" with only five index cards, scissors, and tape. You will have 4 minutes to brainstorm and 11 minutes to build.

Test & Evaluate

Description and/or diagram of Prototype. Describe changes to previous prototype	**Did it survive?**	**Notes** • What works? • What doesn't? • What could work better?
Prototype 1:		
Prototype 2:		
Prototype 3:		
Prototype 4:		

Always be prepared to talk about your work, prepare your answers to:

- How does your solution work?
- What changes did you make to your prototypes? Why?
- Did they improve your results? In what ways?

Some items to consider/explore when considering the use of engineering journals include:

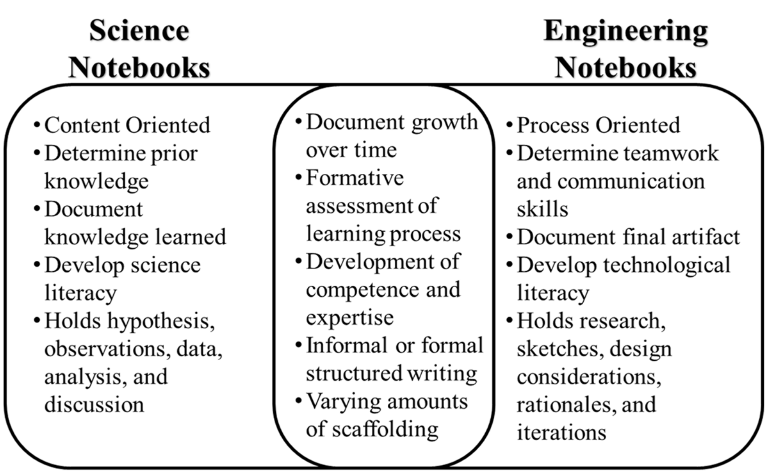
- **Organizational Structure:** Students can be provided a blank notebook (composition book, papers stapled with a folder cover, grid-based notebook, the style is about teacher preference) or guided notebook (from pre-printed headers to more structured fill-in-the-blank spacing)
- **Purpose:** teachers can use an engineering journal as a reflective space for students, learn the process of documentation, for formative assessment, summative assessment, or any combination of the three. Some questions to consider include:
  - What is gained by grading the process over the product? (e.g. Students begin to see value in the process)
  - What school policy is regarding grading of process? (Varies)

  - What is your personal preference on grading personal reflections? (Varies)
  - How would using the notebook support your objectives (Varies)
- **Time:** What amount of time can the teacher allot from the classroom for students to use their notebooks effectively, and what amount of time can the teacher give to viewing/grading each notebook?
- **Ownership**: Will journals be individual for each student, or will the journals be team-based? Questions to consider here include:
  - How do you give grades to individual students from a team product? (Answer will likely align with how grading of other projects in class is completed)
  - How will you ensure that team members are all contributing to the journal? (e.g. A daily job for team members to rotate v. providing time for team reflection where discussion is notated)
  - What is gained by having individual notebooks instead of team? And on the flipside, what is gained by having team notebooks instead of individual? And finally, which aligns best with the teachers' values and objectives?

Engineering education at the elementary level uses similar pedagogies to science education, and as such the expansive research into the value of writing in science education and literacy can be used as the theoretical basis for the use of engineering notebooks (Hertel, Cunningham, Kelley, & Lanchapelle, 2016). In other words, we can infer that the benefits attributed to writing in science education likely overlap with engineering notebooks. More specifically though, we know that, unlike some science notebook systems, engineering notebooks allow students and teachers alike to explore the thinking process while allowing teachers to continuously gather data from their students on conceptual knowledge, procedural understanding, and misconceptions to provide formative feedback on the learning process and teaching methods (Morrison, 2005; Volkmann & Abell, 2003). Further distinctions between science and engineering notebooks can be seen in Figure 10.

Research has uncovered many benefits to using engineering notebooks as a thought-organizing artifact; for instance, students are more likely to participate in group discussions if they have the support of their notebooks (Hammerman, 2009). Additionally, the use of engineering notebooks at the elementary

Figure 10. Distinction between Science and Engineering Notebooks



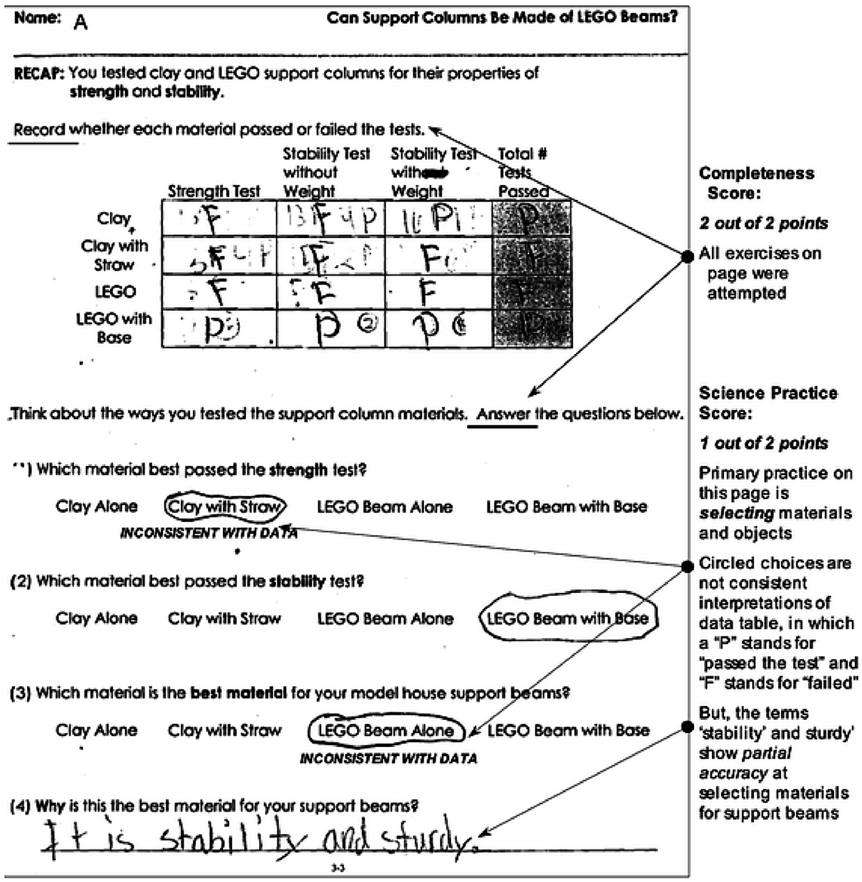
levels employ elements of literacy and comprehension to develop specific habits of mind and practice (Wilson-Lopez & Gregory, 2015). The use of engineering notebooks is a strong example of how "Students can practice writing and applying comprehension strategies in ways that help them to become more thoughtful engineers, and they can practice engineering design activities in ways that help them to become more experienced readers and writers" (Wilson-Lopez & Gregory, 2015, p. 25). Competence and even expertise are developed through active construction of knowledge that can be accomplished through writing before, during, and after hands-on learning (Chi, 2000; Aschbacher & Alonzo, 2006). These writings allow for teachers to assess both a student's literacy skills and STEM-discipline content knowledge in a formative way. Open-ended written responses reveal cognitive processes and uncover more misconceptions about complex concepts than multiple-choice items (Nicol & Macfarlane-Dick, 2007; Sugrue, Webb, & Schlackman, 1998). Additionally, the writing samples in an engineering notebook can effectively be used as a formative assessment in preparation for more traditional unit tests or benchmarks/standardized testing because they allow for a teacher to assess content knowledge, habits of mind, and writing ability in a functional way.

Disciplinary writing, like that found in an engineering notebook, includes both informal and structured writing that allow students to both reason through ideas and evaluate their designs (Wilson-Lopez & Gregory, 2015). In addition to using notebooks to explore student understanding of STEM content and writing/reasoning ability, it can be used, formatively or summatively, to assess students' ability to utilize and identify Engineering Design Model considerations and artifacts (Ernst, Bottomley, Parry, & Lavelle, 2011). Figure 11 provides an example of how an Engineering Notebook can be graded summatively. However, it can also be examined formatively. In this example, the student's circled choices are inconsistent with the data documented in the table; this can be quickly identified by the teacher and used as a tool to reteach the material. Ultimately, the use of engineering notebooks in the classroom allows for documentation of the learning process; providing a tool for students' metacognitive reflection, teacher formative and/or summative assessment, and as an experience in how work occurs outside of the school environment. This includes identifying an individual's contribution to the final product that is often designed in group work in engineering design challenges.

Another option for formative assessment of the engineering notebook includes building time for students to self-reflect on their notebook use. An effective way for doing this is to provide a set of questions that both teacher and student can refer to. Pasting this question set into the front cover (or first page) of a journal allows for easy access in a checklist form for students to assess their journal quality. It also provides a list for teachers to refer to when discussing deficiencies. For example, if a teacher is circulating during a prototype building period, he might notice a student completing work on the prototype that is contrary to the sketched plan in a journal. Referring to the question set by visually pointing and asking, "Joey, would you say your journal reflects the work you are doing right now?" allows students time to correct the error in a low-stakes way and can also lead to conversations about the importance of documenting work in the journal to be a good engineer, or for grades, or whatever else the teacher wishes to focus on. While question sets should be customized to the objectives a teacher has selected, the following are a good starting point:

- Does my journal document all phases of the engineering design process, including my research and all of my prototyping?
- Does my journal document and celebrate my failures and the lessons learned from them?

Figure 11. Sample scoring of a workbook page featuring the property of strength and the science practice of selecting materials (Wendell, & Lee, 2010).



- Does my journal demonstrate my project planning skills, including the ability to develop a plan, delegate tasks, and create a timeline with milestones?
- Does my journal demonstrate my ability to apply my abilities in math and science topics we are studying that apply to our challenge?
- Does my journal share my reflections on my design process, the proposed solution, and what I have learned during this process?

COMPETENCY-BASED ASSESSMENTS

Competency-based education is gaining visibility in the United States as a way to address systemic inequities. Competency-based education's roots are in the apprenticeship model and career and technical education. It is designed around five core elements: students advance upon mastery, measurable learning objectives empower students, assessment is a positive learning experience, differentiated support based on learning needs, and learning outcomes emphasize the creation of knowledge and development of skills (Sturgis, 2016). Assessments, both formative and summative, are used to guide learning because they define what it means to have mastery, be skilled, in that area (Bennett & Gitomer, 2009). The assessments, referred to as competency-based assessments or CBA, apply and extend student knowledge, provide flexibility, all while requiring demonstration of learning in a way that allows the student to demonstrate mastery at their own pace (Kreamer & Zimmermann, 2015). By observing students engaging in designed real-life tasks, competency is measured based on student performance of the tasks and not specifically the knowledge evoked by a question (Shavelson, 2010). For example, for a standard requiring identifying, counting, and calculating money, a first-grade teacher may set up a pretend grocery store where students shop. The shopper must keep under their budget and correctly provide money to pay the bill while the cashier must count the money provided and accurately provide change as necessary.

A vital component of CBA is a clearly defined competence; this is necessary in order to create a valid assessment. Shavelson (2010) describes seven essential parts of a competency: an intellectual ability or physical skill, the ability to perform that ability/skill, standardized assessment conditions, levels of performance, ability to improve, complexity, and grounding in a real context. When defining a competency, an educator needs to consider each of these parts. This may seem daunting at the elementary level, but when broken down, it is similar to a well-written objective as seen in Table 1. In this example, a Virginia Standard of Learning for kindergarten dealing with the ability to use scissors can be written for competency-based assessment. A sample objective of this would be, "Given a craft activity involving a task that requires the use of scissors, student will cut on a line at least (5) inches long with not more than (1) inch of the total length more than (1/4) inch from the line for (4 out of 5) crafts projects."

The next critical aspect of competency is the performance and the standardization of that performance. To test the skill that is scissor-cutting accuracy, the performance can be cut along a line, and the standardization of that performance occurs through craft activities in the classroom that require accurate cutting. Similarly, the level of performance must be predetermined to award competency in that area which usually takes the form of a cutoff score to delineate mastery from non-mastery (McClarty & Gaertner, 2015). The objective stated that accurate cutting with scissors must be performed in 4 out of 5 craft projects, in other words at 80% to determine mastery. This scale allows for continuous growth toward mastery, in comparison to a pass/fail method of observation.

Per Shavelson (2010), the performance also must contain the ability to improve. For example, in accurate cutting with scissors, each cut of more than five inches must not be more than (1/4) inch from the line itself. This gives students the minimum level that they must improve in order to correctly demonstrate the ability or skill. Complexity coincides with the idea that an appropriate cognitive demand

Table 1. Essential parts of a competency example

Essential Part of a Competency	Description for Scissor Use Competency
Intellectual ability or physical skill	Accurate use of scissors
Ability to perform that ability/skill	Cut on a line
Standardized assessment conditions	Given a craft activity involving a task that requires the use of scissors
Levels of performance	4 out of 5 times
Ability to improve	No more than (1/4) inch from the line
Complexity	Less than (1) inch of the total length more than (1/4) inch from the line
Grounding in a real context	During craft projects

must be placed on a student to successfully perform the ability or skill by activating simpler mastered abilities and skills that contribute to the assessed competency. In this example, the complexity of accurate scissor use would take into accountability to follow directions and other fine motor skills that allow for the completion of the task. As with the idea of formative assessments in general, the competency-based assessment must take place in an authentic or real context to accurate determine if mastery is met during a situation in which mastery is needed. This grounding in a real context can engage students and measure the ability or skill in a way that is authentic to students. Therefore, determining mastery in accurate scissor use would be grounded during craft projects where cutting is not the focus of the activity, but a skill that is necessary to complete the activity.

As you can see, this scissors example illustrates the connection between authentic formative assessment and competency assessment. The above competency tested for mastery is the accurate use of scissors, a physical skill, but this could also be an intellectual ability that is effectively measured through observation, such basic single-digit multiplication as seen in Table 2. The objective would be written as, "Using single digit multiplication tables, the student will successfully (90% correct) compute the products of 100 multiplication equations using the number 4 in under one minute to count large regular sets."

The emphasis in both of these examples is that the intellectual ability or physical skill is observable to determine the level of mastery. A competency-based assessment like in Table 1 can be used to measure knowledge of a topic, and therefore higher scores can equate to higher knowledge of that topic (McClarty & Gaertner, 2015). These types of assessments can either be objectively scored through multiple choice or true & false items, or performance-based through essays, group projects, or simulated environments (McClarty & Gaertner, 2015). However, the most effective form of assessment is the observation of student performance through simulated environments (Shavelson, 2010). Simulated environments pair well with I-STEM Ed. lessons, providing an opportunity for authentic performance assessment. Authentic performance assessments may be complex, undefined, require students to apply, synthesize, and evaluate problem-solving, completely structured or open-ended, and broad in scope as designed by the teacher for each competency (Slater & Ryan, 1993). For example, if a second grade teacher has students build something to hold cans at their pretend grocery store, they can role play with students as part of their presentations. If the students are carpenters, the teacher could be the client and ask students situation-based questions that allow for assessment of content, e.g. "If we increased the shelf from 5 to 8 feet, how much more wood would I have to provide?" or " What was that container they used in Ancient Greece with the handles called? I want my grain jars to look like that. Do you know its name?" This type of role play allows for authentic performance assessment.

Table 2. Single digit multiplication competency example

Essential Part of a Competency	Description for Multiplication Competency
Intellectual ability or physical skill	Computation
Ability to perform that ability/skill	Multiplication
Standardized assessment conditions	Using single digit multiplication tables
Levels of performance	90% correct
Ability to improve	In under one minute
Complexity	Using the number 4
Grounding in a real context	To count large regular sets

QUALITATIVE FEEDBACK

The use of qualitative feedback is ubiquitous in education, but the effective use of feedback can be an important formative assessment. Formative feedback, or evaluating student work through feedback, can be provided to students to shape their competence, and is arguably the simplest form of formative assessment. A rubric, when used as a formative tool, can be used to give direct qualitative feedback when designed to list all criteria and describe the levels of quality that can be used to guide the assignment through self-assessment, revision, and reflection (Andrade, 2008). For students to effectively use rubrics as a formative assessment at the elementary level, they will need direct training in how to use rubrics because of their lack of experience (Panadero & Jonsson, 2013). Traditionally, rubrics are instrumental in assessing writing, but some studies in secondary and higher education describe the use of rubrics as a way to give formative assessment that leads to increased student performance on understanding content and the growth during the learning process (Balan, 2012; Brown, Glasswell, & Harland, 2004; Mullen, 2003). The rubric, when provided to a student, provides the criteria by which the individual assignment will be judged and how that work performs on a scale in terms of what the assignment is measuring (Lombardi, 2008). Providing a rubric in advance allows the student to take ownership of the work, allowing them to assess their own level of mastery on the defined categories.

An important consideration when using a rubric as a formative assessment tool is the difference between self-assessment and self-evaluation. Self-assessment using rubrics is when students judge how their own work based on the given criteria is formative while self-evaluation, where students assess their own work and assign a grade, is summative (Andrade, 2008). As a formative assessment tool, feedback from rubrics increases student performance by letting students know what is expected of them, decreases anxiety of how assignments are scored, improves self-efficacy, and supports self-regulation (Panadero & Jonsson, 2013). These are particularly advantageous in design-based learning, where the open-ended, ill-structured problems routinely make students uncomfortable in creating a solution where there is no right answer. The presence of the feedback criteria can give students a sense of control over how the solution is presented. Rubrics can be process-driven (Figure 12) or solution focused (Figure 13). In both provided examples, the expectation is clear and allows for conversation between the student and teacher. This feedback loop enhances student learning during the process by providing access for qualitative feedback. To be used formatively, students need to be provided the rubric at the start of a design challenge to help provide structure to the student process and/or design solutions. The rubric has to be used as part of the feedback loop between student and teacher, a simple strategy to ensure this occurs is to require students to have the rubric out during each part of the unit. That way, as the teacher walks around the room, they can quickly engage the student in a feedback loop with the rubric providing a structure for the conversation.

PORTFOLIOS

In contrast, the portfolio is a larger assessment that is used to not only evaluate the individual assignments included but the entire learning process and growth over a period of time (Lombardi, 2008). When a student manages their own portfolio throughout the defined period of time, as opposed to putting it together at the end, it allows the teacher to use it more formatively, checking in on work to assess the student progression. Portfolios can utilize formative feedback to guide evaluation, self-reflection, and

Figure 12. Process-Driven Rubric for I-STEM Ed. Design Challenge

	Excellent	Good	Fair	Emerging
Problem	Excellent The problem is clearly stated (or re-stated if provided) and all constraints are clearly listed.	Good The problem and constraints can be found but are not clearly stated at the beginning or are not in own words	Fair Either the problem or the constraints are missing	Emerging Both the problem and constraints are absent
Brainstorming	Excellent Clear examples of brainstorming and research are documented. At least 5 different ideas were discussed before work started.	Good Brainstorming and research are at documented. At least 4 different ideas were discussed before work started.	Fair Brainstorming or research is limited. Less that 4 ideas are documented before work started.	Emerging Brainstorming and research cannot be clearly shown.
Design Prototype	Excellent A clear 3D model or diagram is present. Includes labels and descriptions as necessary to communicate purpose and plan to reader.	Good A drawing or flowchart is present. Includes some labels and descriptions to communicate purpose and plan to reader, but some parts need work.	Fair A drawing or description is present but the work plan and/or purpose is unclear.	Emerging Drawing or flowchart is missing.
Build Prototype	Excellent Multiple iterations of solution. Changes in design are thoroughly noted.	Good Documentation of build process is incomplete but present. Changes in design are noted but incomplete.	Fair Documentation of build process is weak but present and/or changes in design process are not clearly noted.	Emerging Build process is not documented and/or changes in design are not notated.
Test Prototype	Excellent There is collected data showing that the product works and meets all constraints. If redesign is necessary it is clearly notated and followed	Good Tests to show that the product works have been run but not clearly detailed and/or if redesign is necessary, it has not been clearly notated.	Fair There is limited evidence of product testing. Redesigns have happened without documentation.	Emerging There are no clear examples of product testing and/or redesign.
Presenting Final Product	Excellent Final product is presented in working order. The presentation clearly demonstrates the solution and process used. All team members play a part in the communication process.	Good Final product is presented in semi-working condition. The presentation addresses the solution and the process and/or all team members play a part in the communication process.	Fair Final product is presented. The presentation weakly addresses either the solution or the process and/or not all team members play a part in the communication process.	Emerging Presentation is missing solution and/or process and/or most team members do not play a part in the communication process.

Figure 13. Solution-Focused Rubric for I-STEM Ed. Design Challenge

	Emerging	Attempted	Approaching	Adequate
Design Requirements (criteria & constraints)	None of the design criteria constraints were considered	Most of the design constraints are not met	All the design constraints are attempted but 1-2 may have been misunderstood	Solution satisfies all design criteria and constraints of the challenge
Functionality	Solution rarely works	Solution malfunctions at times	Solution functions correctly and in a mostly consistent manner	Solution functions correctly and in a consistent manner every time
Construction Quality	Solution shows no attention to construction quality	Solution shows little attention to construction quality	Solution shows some attention to construction quality	Solution shows considerable attention to material selection and assembly
Creativity	Solution is a copy of another project	Solution is similar to the majority of solutions	Solution is creative, including at least one unique meaningful characteristic	Solution is creative, including many meaningful characteristics that are unique
Aesthetics	Solution is messy and unorganized. No consideration was given to appearance	Solution lacks overall neatness or organization. Little consideration given to final appearance of design	Solution is neat and organized. Some consideration given to appearance of design. Little attention paid to details	Solution is neat and organized and shows consideration for final appearance. Visually appealing with attention paid to detail.

refinement of solutions through documentation and collected artifacts as evidence of successful knowledge construction and student performance (Mintzes, Wandersee, & Novak, 2001; Ring & Ramirez, 2012). Portfolios help teachers assess individual and collective understanding of content and the learning process throughout the school year (Seitz & Bartholomew, 2008). This type of qualitative assessment can help support and scaffold the shift to a student-centered pedagogy for teachers and students by allowing them to work together to identify artifacts and other documentation that highlight where students need to improve and further develop (Seitz & Bartholomew, 2008).

Portfolios can give teachers information about how to actively adjust instruction for students, but, unlike other assessments, portfolios allow multiple opportunities for students to demonstrate their understanding of critical concepts (Laski, 2013). These opportunities give students the ability to engage in self-assessment that has been found to support the development of metacognition in younger students, which is critical for the learning process (Laski, 2013; Larkin, 2010). By facilitating conversation about student ability via a portfolio, teachers have the opportunity to discuss evidence of growth in a single content area or a combination of areas. This can be extremely helpful for students who struggle in a specific subject. One recent study examined the effects of portfolios with 8-year old students and found that the portfolio added to the learning process through parent involvement, increased student engagement, and improved self-esteem (Theodosiadou & Konstantinidis, 2015).

Portfolios serve to showcase the cumulative effect of work in multiple disciplines relating to a single theme or topic, which can help students understand how and why work outside of the classroom is interdisciplinary. The construction of an effective, formative portfolio comes in two stages, artifact collection and reflection (Smith, 2003). The first is the selection of the learning artifacts that demonstrate student understanding and growth over time through the demonstration of skills, abilities, or experiences. It can also be an expression of the students about what defines them personally, academically, and professionally. The second stage of critical reflection is just as important. This reflection extends beyond the explanation of the artifacts to describe why they were selected, make connections between learning experiences, and discuss what new learning came from the experience.

Current trends are leaning toward digital portfolios. In the elementary arena, an app called Seesaw has become very popular. Regardless of the medium selected, the portfolio process can be used as an opportunity to assess student work formatively and summatively. By examining student portfolios throughout a period of time, teachers have the opportunity to examine student work, leave written notes and/or have discussions with the student.

While some portfolio guidelines can be very content specific, there are methods that work extremely well for integrative work. One common example involves three C's. The teacher looks at each piece of work in the portfolio, assessing on three axes, confirming that the work completed correctly (mechanics), completely (information), and comprehensively (depth)? Formative scoring can be done asynchronously using a Likert scale, such as 1 (not at all) through 4 (entirely). This simple one-minute process gives clear feedback for the student to know where they can improve their work. Alternatively, teachers can sit down face-to-face with the student for a more in-depth review of the portfolio.

RECOMMENDATIONS

The examples of formative assessment provided in this chapter offer a range of opportunities for a teacher to engage students in this feedback loop during and/or after hands-on learning. Engineering notebooks, competency-based assessment, rubrics, portfolios; there is no one "right way" to use any of these tools, nor is there one form of documenting student learning that more correct for formative assessment. The best assessment is the one that a teacher chooses with intention to fit the particular situation. If the assessment needs to happen over a long period of time or multiple times during a single project, an engineering notebook may be the best formative assessment. On the other hand, if the assessment needs to cover multiple assignment types over a long period of time, a portfolio may be the right choice. However, if the outcome that needs assessment is the mastery of a skill instead of a physical or written project, then the best formative assessment would likely be a competency-based assessment. Each of these assessments use qualitative feedback, but can be the simplest formative assessment if the recommendations above are not applicable. Buelin, et al. (2019, p. 22-23) provide an excellent set of pointers for developing quality formative assessment practices in a STEM-based classroom:

- Formative assessment is most effective when teacher expectations are made very clear to students, often through using both strong and weak examples of the desired outcomes (Cauley and McMillan, 2010).
- Assessments should be specific and targeted, as should subsequent feedback to students. This allows students to concretely understand what they need to do to improve their performance and to master the content (Cauley and McMillan, 2010).
- Assessments tied to intrinsic motivation work best. Avoid making comparisons among students in feedback because this motivates them for extrinsic reasons (Cauley and McMillan, 2010). Likewise, avoid placing disproportionate emphasis on the final grade (another extrinsic motivator); instead, focus on the individual student's improvement and mastery of skills and concepts.
- Encourage a three-step process of student self-assessment in which students: (1) judge their own work, (2) identify discrepancies between their current performance and what is desired, and (3) take action to improve (Cauley and McMillan, 2010).
- Consider the social dynamics of your classroom in preparing for formative assessment strategies and delivery of teacher feedback. Students generally have three simultaneous goals—completion of their work tasks, effective learning, and social acceptance. When these goals conflict, social acceptance tends to take priority over the others (Harris, 2007). Feedback is most effective when it is constructive, grounded in the belief that students can be successful, and demonstrates sensitivity to the impact that your words can have on students' self-confidence, self-esteem, and self-efficacy.

Teachers, remember, just as you ask your students to iterate their work in design-based learning, you are iterating your teaching process. Failure is a part of the learning process. Modeling this for students and openly discussing how you are trying new types of lessons and grading options can help them feel more secure in taking risks themselves. While the open-endedness of engineering design challenges, where the solution to a problem may not be readily apparent and there are often an infinite number of potential solutions that need iteration, can be a struggle for both teacher and student alike, the data shows it is worth the struggle. Most educators and students today are more familiar with there being a single, correct answer or solution to a problem. But we know this is not how the world operates, so it is no longer how we should operate our classrooms. To provide equity and diversity of thought in the elementary classroom, we, as educators, need to seek out ways to allow all students to explore their strengths and share their ideas about how to solve real problems.

Additional Resources for Elementary Educators

The following resources are excellent starting points for teachers and administrators looking for ways to expand their STEM education programming. Many offer summative assessment options for the items they share that can be adapted or used formatively as they are. Most are free, and for those that require a small fee, they have been thoroughly vetted and are considered worth the current price.

The *Elementary STEM Journal* (formerly *Children's Technology and Engineering*) is a dynamic, practical journal for anyone interested in STEM Education via hands-on learning in Grades K-6. The journal provides hands-on activities specifically for this age group, typically with assessment recommendations, as well as articles that discuss practical issues for classroom teachers surrounding the finding of resources and application of STEM education initiatives in the classroom. Membership to the Children's Council is worth the cost; at the time of this printing, the membership includes a journal subscription. See www.iteea.org for more information.

TeachEngineering.org is a massive free digital library of K-12 engineering curricular items, including lessons, hands-on activities and maker challenges. See https://www.teachengineering.org/.

NASA provides free activity guides for educators. The Educator Guides to the Engineering Design Process are particularly helpful. See https://www.nasa.gov/audience/foreducators/best/activities.html.

STEM Teacher Learning provides professional development and continuing education for teachers via cloud-based, self-paced learning. They certify complete and there are currently 18 units researched and developed under a National Science Foundation-funded project to improve classroom instruction. See http://www.STEMteacherlearning.com.

The American Society for Engineering Education (ASEE) is a non-profit member association, dedicated to promoting and improving engineering education. While membership can be quite pricey, many papers and presentations from their conferences are posted free-of-charge on their website https://www.asee.org/.

The NSTA Learning Center provides free learning resources as well as a paid subscription option that includes an Online Professional Learning platform.The search options are well managed and you have the ability to make your own library to organize all your Learning Center and personal learning resources which can be sorted and further subdivided into smaller personalized collections that may be shared with other educators. See https://learningcenter.nsta.org/

Perhaps the best resource is your local university system. Faculty are excited to partner with local schools and teachers to help improve education efforts. Do not be afraid to reach out- often it leads to a wonderful partnership that benefits all involved!

FUTURE RESEARCH DIRECTIONS

Research in the use of formative assessments within Integrative STEM Education is in its infancy. As a field, researchers need to expand the exploration of formative assessments into STEM hands-on learning at the elementary level. Best practices for formative assessment methods in STEM education need to be identified. And finally, teacher efficacy related to using formative assessments should be examined as well.

CONCLUSION

Ultimately, formative assessment is a low-stakes feedback loop meant to enhance student learning. Formative assessment in a hands-on learning context allows for instant or near-instant correction and discussion. It provides crucial information about the level of student understanding in a classroom on an individual and collective level far beyond content knowledge. These types of formative assessment benefit both teacher and student; teachers can use formative assessments to pinpoint when further instruction is necessary and students can use them to enhance their performance by showing them their learning gaps and teaching them to be more reflective. Perhaps most importantly, formative assessment feedback loops as part of the Integrative STEM Education movement allow for personal growth. Students have the opportunity to build a future self that is ready to take on the world of tomorrow.

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KEY TERMS AND DEFINITIONS

Competency-Based Learning: An approach to teaching that focuses on developing and assessing mastery of intellectual abilities and physical skills in a real context.

Design-Based Learning: An approach that guides students in constructing their own knowledge and developing real-world problem-solving skills by engaging them in technology and engineering design.

Engineering Design Notebook: A tool for recording information in design-based learning that mimics how engineers collect information and it can also capture a student's design thinking, sketches, and reflective thoughts.

Hands-On Learning: An approach that uses authentic learning experiences and manipulatives to effectively teach content understanding and skill building.

Integrative STEM Education: The application of design-based learning that teaches scientific and mathematics content and practices with the content and practices of technology and engineering education.

Portfolio: A collection of artifacts and documentation of evidence of successful knowledge construction and student performance used to guide evaluation, self-reflection, and refinement of solutions.

Rubric: A tool that provides students with a list of criteria and describes levels of quality for an assignment that allows for qualitative feedback as a formative assessment and can be used to guide self-assessment, revision, and reflection.

Transdisciplinary learning: is an approach to explore a concept, issue, or problem from multiple disciplinary perspectives simultaneously to capture the full essence of the concept, issue, or problem.