2016

Engineering Design and Gifted Pedagogy

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CHAPTER 2

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One does not have to look far in educational literature for articles stressing the need for improvement in how science, technology, engineering, and mathematics (STEM disciplines) are taught. The White House Office of Science and Technology Policy's February 2016 white paper, *STEM for All: Ensuring High-Quality STEM Education Opportunities for All Students*, outlines policies and priorities in an effort to provide every student opportunities "to join the innovation economy, have the tools to solve our toughest challenges, and be active citizens in our increasingly technological world" (p. 1). One of the priorities is to improve STEM teaching and support active learning by engaging students in problem-solving activities, ranging from presenting problems for students to solve before receiving instruction to engaging students in original research. For those who have spent some time in gifted education, the recommendations should invoke déjà vu.

At the 18th World Conference on Gifted and Talented Children, we hosted a session entitled *Engineering Teachable Moments: Employing Engineering Design Activities*, where we shared five papers that linked engineering design activities with many of the pedagogical practices found in gifted education programs.[1] Reactions to our session were positive, but concerns were voiced about how engineering topics might align with other content and skills that need to be covered and the ability of teachers and students to undertake engineering tasks in K–8 classrooms. Since then, curriculum programs have been developed, most notably the one at the Museum of Science, Boston, that have successfully introduced accessible engineering tasks as early as kindergarten. The Next Generation Science Standards (NGSS) include engineering design as a content area throughout grades K–12 curricula. In discussing the addition of engineering design in the NGSS, the authors (NGSS Lead States, 2013) wrote, "providing students a foundation in engineering design allows them to better engage in and aspire to solve the major societal and environmental challenges they will face in the decades ahead" (p. 103). Although connections to gifted education may not be explicitly identified here, we see links to both the types of learning experiences gifted children thrive on and the development of co-cognitive factors that influence talent development (Renzulli, Kehler, & Fogarty, 2006).

PRINCIPLES OF LEARNING—DESIGNING MEANINGFUL LEARNING EXPERIENCES

In his book, *Creating Innovators*, Tony Wagner (2012) lists many of the acknowledged innovators of the era who dropped out of college to pursue their ideas. He describes them with a phrase borrowed from Henry Rutgers, "schooling was interfering with their education" (p. 56). One measure of this interference may be students' self-reported interest in mathematics and science, which drops from more than 80% in fourth grade to less than 40% just 4 years later (National Center for Educational Statistics [NCES], 2003). Although the potential reasons for this are many, the drop in interest suggests a significant loss of students with gifts and talents in the STEM disciplines as they disengage from school-based STEM tasks. In an effort to interest more individuals in engineering, the National Academy of Engineering (NAE; 2002) looked at the public's understanding of engineering. As part of that study, two prevailing messages of K–12 engineering outreach programs were identified: "Math and science are fun," and "engineers are important and contribute to the quality of life, economy, environment" (p.

1 These papers were published in Mann, Mann, Strutz, Duncan, and Yoon (2011).

2). At a time when children are beginning to consider career options, trying to interest them in exploring engineering opportunities with these messages, while their school experiences suggest otherwise, is counterintuitive.

Just as we strive to offer our students differentiated learning experiences tailored to their interests and readiness, there are several different gifted education curriculum models that provide the framework for creating challenging, meaningful learning experiences. One that incorporates the best from several models is the Parallel Curriculum Model (PCM; Tomlinson et al., 2009). Delving into the model is beyond the scope of this chapter; however, there are several points in the theory and beliefs that underpin the PCM that are particularly relevant to preparing our children for the complex, technological world in which we live. In the opening chapter, the authors (Tomlinson et al., 2009) discussed the rational and guiding principles for the model. Curriculum should . . .

- help students grapple with complex and ambiguous issues and problems;
- provide students opportunities for original, creative, and practical work in the disciplines;
- help students uncover, recognize, and apply the significant and essential concepts and principles that explain the structure and workings of the discipline, human behavior, and our physical world (added: and our engineered/technological world);
- help students develop a sense of themselves as well as of their possibilities in the world in which they live; and
- be compelling and satisfying enough to encourage student to persist despite frustration and understand the importance of effort and collaboration. (p. 3)

Within these few lines, the authors captured many of the outcome objectives we now find in the Standards for Mathematical Practice of the Common Core State Standards for Mathematics (CCSSM; National Governors Association Center for Best Practices [NGA], & Council of Chief State School Officers [CCSSO], 2010), the Science and Engineering practices in the NGSS (NGSS Lead States, 2013), and the Learning and Innovation Skills advocated by the Partnership for 21st Century Learning (2015). The four parallels in the PCM—the core curriculum, the curriculum of connections, the curriculum of identity, and the curriculum of practice—offer opportunities for students to engage in learning that is personally meaningful as they progress from novices to practicing professionals.

The Enrichment Triad Model (Renzulli, 1977) structures curriculum activities into three different but interconnected types. Type I, General Exploratory Activities, introduces children to a wide variety of topics in various disciplines designed to pique interest and generate questions from the child that lead to further, deeper investigations. Type II activities consist of both the development of creative/critical thinking and problem-solving skills as well as how-to knowledge that will provide the child with the tools needed to conduct the investigations. Type III activities engage students in seeking solutions to real-world problems they have identified.

In their September 2015 article in *Science and Children*, Tejaswini and Wendell described a process that closely follows the Enrichment Triad Model. Working with an elementary school science specialist, they identified a problem area within the school community—the care of the school's garden. The concerns were shared with the students, and the students then worked to define a specific problem they could solve—a Type I activity. Type II activities followed as students collected data; explored materials, tools, and simple machines; and learned about the needs of the plants in the garden, all leading to designing and testing of prototypes of different solutions. Selecting and implementing the best approach resulted in a solution to a meaningful, real-world problem—the culminating Type III activity.

A similar approach is employed in the Engineering is Elementary (EiE) curriculum (Museum of Science, Boston, 2016), which is based in part on the beliefs that:

- Engaging students in hands-on, real-world engineering experiences can enliven math and science and other content areas and motivate students to learn math and science concepts by illustrating relevant applications.
- Engineering fosters problem-solving skills, including problem formulation, iteration, and testing of alternative solutions.
- Engineering embraces project-based learning, encompasses hands-on construction, and sharpens children's abilities to function in three dimensions—all skills that are important for prospering in the modern world. (Hester & Cunningham, 2007, p. 3)

In EiE units, students are introduced to a problem through the eyes of a child who uses engineering to solve a real-world problem. Students are then asked to solve a similar problem. The challenge creates a "just-in-time" learning environment where students can ask questions about the knowledge and skills they need to solve the problem—an active, inquiry-driven, rather than passive, receptive learning environment.

Although middle and high school technology teachers have incorporated engineering design concepts in the classrooms for decades, conversations about pre-K–12 engineering education are relatively new. For example, the American Society for Engineering Education's Pre-College Education division was formed in 2003 with a meager budget and several dedicated individuals. Online resources such as TeachEngineering (https://www.teachengineering.org) and eGFI: Dream Up the Future (http://teachers.egfi-k12.org) provide access to growing sources of standards-based engineering lessons plans and activities to help introduce engineering and engineering design to students.

MAKING A DIFFERENCE—CO-COGNITIVE FACTORS AND TALENT DEVELOPMENT

The development of creativity, pursuit of solutions to real-world problems, generation of innovative ideas, and ability to make connections between previously unconnected ideas are necessary for the development of engineering thinking. They are also cornerstones of gifted education pedagogy. The final products within the EiE curriculum are not full Type III activities (those familiar with the Enrichment Triad Model would call them Type II 1/2) but do give students the necessary experience with the engineering design process needed to move to a Type III product. Engineering Products in Community Service (EPICS) are found in many undergraduate programs designed to give their students practice in solving ill-defined, open-ended problems, and developing real-world experiences working with clients to define, communicate, and evaluate potential solutions. Likewise, EPICS High (https://engineering.purdue.edu/EPICSHS) offers similar opportunities to high school students, and the concepts are working their way down into the elementary grades with community-based engineering projects (Edutopia, 2013; Swenson & Portsmore, 2013; Tejaswin & Wendell, 2015).

In *Light Up Your Child's Mind*, Renzulli and Reis (2009) write about creative-productive learning. This kind of learning experience changes going to school from time spent (wasted?) to time engaged in passionate, active learning. "Creative-productive learning takes place when a youngster is intent on developing an original something, a product that he hopes will have a positive impact on an audience of some kind" (p. 12). Creating something that effects positive change may be especially appealing to a gifted child who is more sensitive to values and moral issues (Davis, Rimm, & Siegle, 2011), and is often deeply committed to righting wrongs in the world. This sensitivity to human concerns is one of the six co-cognitive factors in Renzulli's Operation Houndstooth theory that forms the background for his Three-Ring Conception of Giftedness (Renzulli et al., 2006). This characteristic of giftedness involves altruism and empathy and leads to a desire to take action to help others. The misperceptions about engineers—that they do math and science and do not engage with societal or community concerns—may be a factor in discouraging gifted children from pursuing engineering as a career.

Spatial ability is a predictor of success in engineering (Humphreys, Lubinski, & Yao, 1993; Kell & Lubinski, 2013; Mann, 2014; Wai, Lubinski, & Benbow, 2009). The value schools of engineering place on spatial reasoning is highlighted by the increasing number of universities and colleges that are implementing courses for first-year students targeted at improving spatial skills (e.g., Martn-Dorta, Saorn, & Contero, 2008; Onyancha, Derov, & Kinsey, 2009; Sorby & Baartmans, 2000). Gifted students with spatial strengths excel in this area without a need for a remedial spatial reasoning course as they have a natural affinity for engineering thinking. Mann (2014) identified learning preferences of students with spatial strengths. These preferences for holistic instruction, visual ideation, and innovation align with the engineering design process. Students with spatial strengths use a holistic approach for solving problems and thrive when engaged in hands-on, real-world experiences, such as those employed in the EiE curriculum. Visual ideation is a critical skill for professionals in the engineering field as they construct mental images to determine design and functionality of products and services. Students with spatial strengths use visualization strategies as they worked to master course content. Engineering would be a stagnant field without innovation, an area in which gifted students with spatial strengths are very comfortable. They would rather generate their own problem-solving procedure than use a scripted approach. They enjoy tackling the complex and ambiguous issues and problems described in the PCM (Tomlinson et al., 2009). The inquiry-based learning situations utilized in the engineering design process closely align with the learning preferences of highly spatial students.

Unfortunately, statistics indicate that very few of our gifted spatial learners are following their areas of strengths and pursuing careers in the STEM areas such as engineering (Young & Bae, 1997). Participation in engineering design activities at the K–12 level would provide gifted students with high spatial ability the opportunity to work in their area of strength and give them experiences that may motivate them to pursue careers in the engineering field in the future. The benefit of participation in engineering design activities would not be seen solely by students who have innate ability in the area of spatial reasoning. All students would benefit, as it is possible to increase spatial problem solving performance through instruction. Sorby and Baartsman (2000) conducted a 6-year longitudinal study that compared engineering students who were randomly placed in a spatial skills course to those who did not enroll in the course. Retention, grade point average, and successful completion of a graphics course were all higher for students who were instructed in spatial reasoning strategies.

PREPARING FUTURE PROBLEM SOLVERS

The 2012 Programme for International Student Assessment (PISA) included an assessment of students' skills in tackling real-life problems. In this assessment (OECD, 2014), creative problem solving competency was defined as

> an individual's ability to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately available. It includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen. (p. 30)

An outcome of this assessment was that, on average, only 20% of students in participating countries could solve very straightforward problems if they had a familiar situation as a reference. A recommendation from the study was to empower students to solve problems within meaningful contexts. Often such contexts are messy, data is missing, assumptions need to be made, constraints exist, and promising solution paths turn out to be dead ends. Parents and teachers need the courage to support all students and especially gifted and talented learners in the pursuit of becoming practicing professionals. Encouragement to take intellectual risks, learn from mistakes, and communicate thoughts effectively is especially important when levels of frustration are high. These same skills are vital aspects of engineering design and only can be developed when we challenge beyond "textbooks [that] deliver example problems in step-by-step format—and teach students to look for the steps as opposed to thinking for themselves" (Hines, 2012, p. 41). Step-by-step instructions deny students the opportunity to explore, to make decisions, to be creative, and to engage in constructive dialogue as they work as practicing professionals to solve problems. Although many of our gifted students have perfectionist tendencies, Hines (2012), a practicing engineer and a professor at Tufts University, wrote,

> I know that a wrong answer is an inevitable result of my humanity, so I have to work according to a discipline that will allow me and my colleagues to catch my mistakes. Clear communication of my thought process is fundamental to this discipline. (p. 41)

Engineering design challenges offer the opportunity to "motivate and challenge students' fundamental understanding in context of a creative process" (Hines, 2012, p. 41), attributes that are lacking when the solution method is laid out as a sequence of steps to follow.

AN EXAMPLE ENGINEERING PROBLEM-SOLVING CHALLENGE

Access to clean, safe drinking water is taken for granted in most communities in the United States. At least that was true until recently. Lead contaminations in the water supplies for Flint, MI, and Jackson, MS, are current news stories. Health concerns for children living in those areas are discussed in multiple venues and schools, churches, and other organizations across the country are sending bottled water to help.

Although the concerns and challenges in Flint and Jackson are real and immediate, obtaining clean, safe drinking water is a global issue. The EiE curriculum has two units that have potential connections. In *Water, Water Everywhere: Designing Water Filters*, students test a variety of materials to see how well they remove contaminates from river water to provide a healthier environment for a turtle living there. In the process of designing a temporary shelter for a pet frog, students explore the properties of membranes that allow water to pass through at a controlled rate in *Just Passing Through: Designing Model Membranes.* These same kinds of systems, water filters, and use of membranes in reverse osmosis systems are also ways to reduce contaminates in drinking water. As exploratory, Type I activities these units could suggest a variety of community-based engineering projects (curriculum of practice/Type III products). Along the way, Type II activities that provide students information about the source of containments; processes, materials, risks, and associated costs involved in remediation; health risks; and a variety of other topics will be needed to provide multiple opportunities to meet the needs of the core curriculum. Students will explore connections between the various disciplines as they use their math and science knowledge and process skills to test various solutions and their language and communications skills to share the results. Connections between the communities they live in and other communities in other parts of the world are possible as they explore the differences in water sources and environmental conditions. For some, the questions they asked and the problems they find may resonate with their strengths and interests leading to future studies and potential vocations (curriculum of identity).

FINAL THOUGHTS

Gifted children are passionate about learning in their area of interest(s). For those whose strengths lie in one or more of the STEM disciplines, the opportunity to engage in engineering design activities offers a welcome change from step-by-step, problem-solving exercises that converge on one expected solution found in so many textbook- or worksheet-based curricula. Although all students should have the opportunity for inquiry-based engineering design activities, programs for gifted and talented students are especially well-suited for these types of activities, as the grade-level curriculum can be compacted by buying additional time for more in-depth explorations and iterations to improve the final products.

Seeking ways to interest more individuals in engineering, NAE (2008) commissioned a study to look at ways to "re-brand" the profession. Messages such as "must be good at math and science" and "connecting science to the real world" were the most often reported and also most often viewed as a barrier to studying engineering. Interestingly, while the same is true for medicine, there is no shortage of medical school applicants. Engineering is an optimistic and innovative profession that has a direct impact on the lives of people. Although math and science skills are needed tools, other characteristics of engineering such as creativity, collaboration, and communication are equally vital. For the child who is seeking the means to change the world, engineering offers a way.

RESOURCES

This is a brief list of curriculum programs and online resources. It is not a complete list but a starting point to explore ways to introduce students to engineering design activities.

- *Building Math for Common Core State Standards Series (Grades 6–8):* http://walch.com/Building-Math-for-Common-Core-State-Standards-3-Book-Series.html
- *Edutopia's Education Video Library:* http://www.edutopia.org/videos. A couple of our favorites are:
  - *"Wetlands Watchers: Kids Care for Their Environment":* http://www.edutopia.org/wetland-watchers-service-learning-video
  - *"How Design Thinking Can Empower Young People":* http://www.edutopia.org/is-school-enough-design-thinking-video
- *eGFI: Dream Up the Future:* http://teachers.egfi-k12.org
- *Engineering by Design, International Technology and Engineering Educators Association:* http://www.iteea.org/STEMCenter/EbD.aspx
- *Engineer Girl:* http://www.engineergirl.org
- *Engineering Education: Museum of Science Boston:* http://www.mos.org/eie

- » *Engineering is Elementary (Grades 1–5):* http://www.eie.org/eie-curriculum
- » *Engineering Adventures (Grades 3–5):* http://www.eie.org/engineering-adventures
- » *Engineering Everywhere (Grades 6–8):* http://www.eie.org/engineering-everywhere

- *National Science Digital Library:* https://nsdl.oercommons.org
- *PBS Learning Media* (search for "engineering design" and choose a grade level): http://www.pbslearningmedia.org
- *Project Lead The Way:* https://www.pltw.org
  - » *Launch (Grades K–5):* https://www.pltw.org/our-programs/pltw-launch
  - » *Gateway (Grades 6–8):* https://www.pltw.org/our-programs/pltw-gateway

- *TeachEngineering: Curriculum for K–12 Teachers:* https://www.teachengineering.org

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