Build College and Career Readiness with Early, Integrated STEM

ETA hand2mind® Research Summary

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“I have a dream. Nearly all of our youngsters will graduate high school, and nearly all will be excellent readers, manipulate numbers and estimate easily, be able to argue a point using trustworthy evidence to back it up, make decisions informed by common knowledge, solve complex problems well,... express themselves articulately, work well with others, recognize what they know and when they need to learn more, ... and appreciate the roles they might take on (and love to engage in) as productive adults.”

—Dr. Janet L. Kolodner, Georgia Institute of Technology
(in Sneider, 2015, p vii)

What is STEM? Why is early STEM Important?

An essential part of meeting the dream stated by Dr. Kolodner is integrated STEM education. Not only must students have knowledge, they must be able to apply that knowledge to solve problems and express themselves well. Integrated STEM experiences allow not only the STEM disciplines, but literacy as well, to come together in the service of solving complex problems and responding to societal needs and wants.

High-quality early education provides great long-term benefits for students in terms of future schooling (Duncan, et al, 2007) and in terms of workforce development (Strobel, 2014). Young children are natural scientists and engineers. Their exploration focuses on understanding how the world works (science) and adapting what they find to meet their wants and needs (engineering).

All too often, by the time children reach middle school, at least half of them have lost interest in STEM disciplines. (National Science Board, 2010) High-quality early STEM education can change this trajectory and lay a foundation for excellence.

What is good, integrated STEM education?

Many elementary teachers struggle to teach STEM disciplines effectively. This makes high-quality instructional materials essential for success. Moore et al (2014) provide a framework consisting of six tenets for integrated STEM curricula. High-quality learning experiences should—

- Be situated in a motivating and engaging context;
- Include engineering design challenges with relevant technologies for a compelling purpose;
- Provide opportunities to learn from failure and redesign;
- Incorporate mathematics and/or science content as main objectives;
- Focus on student-centered pedagogies; and
- Provide an emphasis on teamwork and communication.

In preschool and elementary grades, developmental appropriateness is also essential. Expectations for students should reflect their cognitive, social emotional, and physical development. For many underrepresented students (typically minorities and young
women), connecting early STEM experiences to “helping” fields makes them more relevant and engaging (Jones, Howe, & Rua, 2000). The attitudes of young women are often impacted by their perception of relevance (Clewell & Braddock, 2000) or social value (Burke, 2007).

Research also suggests that elementary teachers move through several stages as they develop confidence and competence in teaching integrated STEM education. Building on a number of studies of teacher professional development around engineering education or STEM education, Diefes-Dux (2014) suggests these stages:

Stage 1 - Overcoming the fear of engineering
Stage 2 - First-year implementation - The reality and practicality
Stage 3 - Making it engineering
Stage 4 - Second-year implementation - More of everything.


The more any curricular resource can make the implementation of engineering design tasks and STEM a straightforward task for teachers, the more effective the program will be. Providing teachers with the support to understand what engineering design is and presenting the content in developmentally appropriate ways helps overcome fear and address practical concerns around implementation. By integrating multiple disciplines (including science, mathematics, and literacy), finding time for instruction is easier because so many goals are being met through a single experience. Well-designed experiences support teachers as they experience engineering design as applications of the disciplinary experiences they are already teaching as well as rich problem-solving and team-building tasks.

The theoretical foundation for hands-on learning begins with the work of John Dewey, a powerful advocate for integrated and hands-on learning. (Dewey, 1938). The research of INSPIRE at Purdue University (http://inspire-purdue.org) and the Early Engineering Think & Make Tank at Texas A&M University (http://engineering.tamu.edu/etid/people/strobel-johannes) has most directly informed the development of the Hands-On Standards STEM in Action modules.

Precursors to these modules were used in a National Science Foundation Discovery Research K-12 project where integrated STEM modules were implemented in grades 2-4 classrooms between 2008 and 2014. (R&D: Quality Cyber-Enabled, Engineering Education Professional Development to Support Teacher Change and Student Achievement (E2PD), NSF, award # 0822261) For grades 3 and 4, student performance on a science and engineering content test increased significantly in both years. For grade 2, performance increased significantly in year 2. On average, performance increased 21 - 29% over the intervention (Yoon, Dyehouse, Lucietto, Diefes-Dux, & Capobianco, 2014). Another research project (Technology Enhanced Sustainable Aina Project, Office of Naval Research, award #N00014-11-1-0751) showed continuous student improvement over two years over their perceptions about engineers and engineering. Most groups showed significant improvement in student knowledge as well.

Research Foundation—Teachers

From research conducted on successful components of engineering education teacher professional development (PD) we have learned the following criteria for teacher buy-in: 

Excitement (viewing PD as exciting), Active Learning (hands-on and visual), Rationale provided (grasping the “why” of PD), student success (informal and formal) and efficiency (to the point) and the following desired practical strategies by teachers: Integration (either by district or PD), New Ideas & Lessons (grade appropriate and step-by-step), Observing best practice (facilitators provide walk-through) and artifacts for modeling (visualize what the teaching concretely will look like (Boots 2013).

Sun & Strobel (2013) provide a detailed description of developmental stages as teachers adopt engineering education and develop expertise in the field. Their four phases of adoption begin with Attempter and move through Adopter and Ameliorator to Advocator.
Teachers in the Attempter phase often demonstrate low levels of understanding or perceive many barriers to teaching engineering and design. As teachers move through the phases with the support of professional development, they see implementation of engineering and design as practical and valuable. By the Advocator stage, teachers are creating and implementing plans to overcome the barriers perceived by others to make this teaching sustainable in the school community.

While teachers are adopting the teaching of engineering and design in elementary grades, they are also developing expertise, moving through five phases from Mechanical Imitator to Creator. HOS STEM in Action has built on this research through embedded support for the various phases of expertise development. Videos and scripting model effective practice in integrating STEM to provide the support needed for teachers in the imitator phase. Teachers with more advanced expertise have frequent opportunities to use their Adaptor skills to adjust the teamwork requirements to meet the needs of their students, or to use their Improver skills to make additional connections to other areas of study.

Research Agenda for Hands-On Standards STEM in Action

Ongoing research for HOS STEM in Action falls into three categories: beta-testing, clinical implementation projects, and non-clinical pilot projects.

Modules are beta-tested in multiple classrooms during the development phase. This allows teachers and students to interact with prototype materials as they implement the design challenge. Members of the development team observe this implementation and interview participating teachers. Data gathered from the beta process results in meaningful changes that strengthen the modules. In spite of working with draft and prototype materials, teachers had consistently positive experiences with the modules. 93% or more of the beta test teachers agreed or strongly agreed with the following statements—

- The activities supported my curriculum and my instructional goals.
- The children were actively engaged in the activity.
- The children met the learning objectives for the activities.
- The activities helped children develop critical thinking skills.
- The benefits of the activities were worth the time investment
- I would purchase this module and others like it.

Clinical implementation projects are being conducted in two ways. First, an Investing in Innovation grant proposal has been submitted by Texas A&M University to investigate the effect on teachers and students of implementing the modules over a two-year cycle. A National Science Foundation Discovery Research K-12 grant proposal is also in development. While waiting to hear from these proposals, the research team has begun smaller clinical trials at several schools.

The first clinical trial was conducted at an elementary school in a Dallas suburb. Approximately 260 students from grades K–5 completed pre- and post-assessments. One module per grade level was implemented during a two-week period between the two rounds of assessment. The Draw an Engineer Test (DAET) (Weber et al., 2011) and Students’ Awareness and Perceptions of Learning Engineering (STAPLE) (Duncan-Wiles, 2012) were used. Paired t-tests showed significant gains for grades K, 4, and 5. Positive trends were observed for all students.

Conclusion

High-quality early STEM education experiences are essential for students to become college and career ready. Hands-On Standards STEM in Action is built on a solid research base and early studies show that it is living up to its promise. Teachers report it is easy to implement, students are engaged, and it meets instructional goals. Analysis of student learning data suggests positive trends in students’ knowledge, interest, and self-efficacy around engineering design. We expect these trends to strengthen as the modules are implemented more widely.
References


