Integrating Engineering into Middle School Curriculum: Challenges, Strategies and Impact

April 2022

Synthesis

Perceptive educators have always argued for the importance, indeed the necessity, of integrating subjects across the curriculum. The challenge for educators (such as teachers and curriculum designers) is to take advantage of the formal disciplines while not requiring the young learner to think first as a scientist, then as an engineer, and then as a mathematician (Bopardikar et al. 2020, Burkhardt and Schoenfeld 2003). The Framework (NRC 2012) made that challenge a call to action, closely connecting all the STEM disciplines within a clear articulation of science and the other disciplines as social processes. The April 2022 Theme of the Month explored this challenge through the lens of integrating engineering into to the middle school curriculum.

Marion Usselman's blog (drawing on a paper from Purzer and Quintana-Cifuentes 2019) sets a framework conversation, by talking about how engineering typically functions in the classroom. Is it used to facilitate the learning of other subjects, e.g., science or math (the pedagogical approach)? Or is the focus on the practices of engineering design, to engage students with problem posing and solving, and motivating the use of science and math practices and principles (the methodological approach)? Or is the aim actually to teach students engineering as a discipline (the epistemological approach)? Educators often find these three points of view shifting and overlapping in baffling or exciting ways as they develop and implement an innovative curriculum (Bopardikar et al. 2020)

With such a complex question, variation provides information. The panel featured three project teams and included two research scientists, a curriculum designer and two teacher leaders who have designed and implemented engineering programs in middle school classrooms. The panel was moderated by Dr. Marion Usselman, a Principal Research Scientist and Associate Director for Educational Innovation and Development at Georgia Tech's Center for Education Integrating Science, Mathematics and Computing (CEISMC).

Panelists included Dr. Meltem Alemdar, Dr. Nidaa Makki, Chelsea Nicolino, Steven Huard, and Isabel Huff. See all of their bios here.

Marion Usselman and Meltem Alemdar have collaborated on the AMP-IT-UP project in which they developed, implemented, and assessed manufacturing-focused curriculum materials that support engaging and rigorous STEM instruction, and implemented STEM-focused enrichment activities for both students and teachers.

Nidaa Makki and Chelsea Nicolino have worked together in the Zipping Towards STEM project which explored the impact of integrating engineering design on students' understanding of science and engineering concepts and practices, and also the impact on students' interest in STEM and STEM careers. The curriculum was designed to engage students in solving a real-world problem through the use of additive manufacturing. They were asked to optimize a prototype of a Soap Box Derby Car by using CAD software, virtual and physical wind tunnel testing, and 3D printing. They investigated the factors that impact the performance of a gravity racing car in order to optimize its performance, using concepts learned about forces and motion. The students also learned the basics of aerodynamics through investigating the performance of various shapes on a track and in a wind tunnel. The students then used CAD Software and virtual simulation testing to design and test a car shell.

Isabel Huff and Steven Huard shared lessons learned from the TEEMS project which developed NGSS-aligned units and six lessons -- that integrate with sixth-grade science concepts. The TEEMS curriculum applies an innovative pedagogy called Imaginative Education (IE). In IE, stories that are developmentally appropriate for middle schoolers are used to scaffold lessons, engaging students more deeply and helping them organize their knowledge productively.

Marion Usselman asked each of the panelists to focus on the aims of their curriculum, both "how they're theoretically great," and "why do we want to do this with our kids?" She probed if they are realistically implementable in the classroom, and what the impact is on the students?"

Cross-cutting themes

One theme that appeared very often in the panelists' presentations (and the videos in the playlist) was **engagement**. This is the indispensable ingredient of any lesson or curriculum - to enlist students' interest and personal connection to the learning, and to do it in such a way that students see the inquiry or design as something that matters to them, and delights them. Engineering, focused on solving interesting problems in the world, plays this pedagogical role very effectively when the problems connect with students' imaginations. As Stephen Huard said of implementing the TEEMS project: "My biggest thing with the students is just getting them interested and hooking them in....” He explained, the kids were very excited about a module on The [Boston] Molasses Disaster, because it's a local story and...”who can't get excited about molasses running down the street?" Similarly, Chelsea Nicolino from the Zipping Towards STEM project, explained that there is high student engagement as everything's hands-on and the students are a lot more responsive to engineering practices.

A closely related goal is students' vision and understanding of themselves as engineers or investigators in STEM (**identity**), and their sense of **self-efficacy**. These are known to have an important impact on students' learning now, and their possible engagement with STEM in the future. As Nidaa Makki said about Zipping towards STEM:

> "One of the design principles was to reach students in middle school before they made decisions about what they want to do in high school and what track they want to go on...we also were looking at self-efficacy in STEM and motivation towards STEM. And we found those remained stable from before to after."

Naturally, student learning of specific subject matter and practices was a central aim of all the projects, measured in both qualitative and quantitative ways. Isabel Huff explained that the TEEMS project decided to create one unit for each of the engineering standards. Then they created a number of lessons for each unit that integrate engineering with science. The general approach was a “narrative imaginative education approach” as stories are a “powerful way to engage students emotionally and therefore help them learn more deeply."

Meltem Alemdar said that AMP-IT-UP sought "to lay foundations for STEM integration, specifically engineering, science, and math. And the concepts are practiced by the learners engaging in various thinking skills that support their research by generating different ideas, principles, and knowledge. And during the application is where the concepts and practices such as manufacturing and prototyping are applied to solve a design challenge." From the classroom perspective,

Steve Huard described how the TEEMs project, addressed the classic student complaint, When are we ever going to use this stuff? When are we going to use this science or this math?

> The thing I like about the engineering is we're telling them to design these things, and then when we say to them, How do you know what materials you're going to use?" And then they have to start thinking about that. And I said, "There's your science." And how are you going to pay for these? Do you have any limitations? And that's where the math comes in. Or even the size of the things you're building."

A fourth goal the panelists mentioned is the **transfer of knowledge and skills**. A challenge for an integrated curriculum is that the problems that the students are working on can be so highly contextualized that the STEM learning is not available to the students for use in other contexts. Consequently, designing for transfer can at times be in tension with design for engagement (Kolodner et al. 2003). The teachers on our expert panel spoke of transfer as an outcome they valued. Steven Huard described how the students constructively gave feedback to each other on their projects. “And the cool thing was that they'd question each other about the science behind their ideas, the math behind their ideas." Chelsea Nicolino agreed and said in her classroom, "I would do bell ringers or some type of formative assessment to see if the students were transferring the knowledge from what we were doing with the design challenge, with what I taught with forces in motion."

In each case, panelists reported that these multiple aims were achieved: high student engagement, increased student self-efficacy in STEM, students' learning of specific STEM content and practices, and evidence of durable transfer of knowledge.

Changing the culture

Even though engineering, the E in STEM, has been seen as important to the K-12 curriculum since the standards movement in the 1990s, it still feels "new" in many schools. The development of practical and effective integrated curricula can demonstrate to teachers, to students, and to administrators that engineering can strengthen STEM education across the board, and can bring conceptual benefits as well as benefits in student engagement and meaningful connections to everyday life. As Meltem Alemdar expressed that one of the largest impacts of their project and also one of the biggest initial challenges was changing the culture around the engineering courses.

> When we started in 2012 “students and the teachers did not really expect to teach science and math. They saw engineering classes like a shop class, you come and you play with things. Actual learning was not really happening in the engineering class. And we worked really hard to change the culture around the engineering. And later on, a lot of schools continued adopting our curriculum."

There were other cultural shifts noted as well. The problem-solving frame that engineering brings to the classroom builds common ground between students and adult practitioners, which can lead to increased student engagement, STEM identity, and self-efficacy. Steve Huard spoke to this point:

> "One of the things they do is they show actual people working on the design engineering process, so kids see that adults do that as well. They're at their work sites and they're talking with each other, they're exchanging ideas, even just the idea of brainstorming. Kids are afraid to brainstorm because they don't want to get anything wrong. But when they see a group of adults tossing out ideas, discussing them, and then kindly telling each other why things may not work or that's a great idea. It just gives them an example of what type of job they could be working towards. It gives them a goal to reach towards. And I think that can be important for middle schoolers."

The projects also provided a natural context for incorporating culturally responsive teaching and racial equity. Isabel Huff described a basic strategy (which was shared across all three projects):

> "We have always done our best to try to include characters in the stories that we are using in these units and lessons from different backgrounds and to create design challenges that kids are going to be able to feel some kind of connection to. So just making sure that students get to see engineers who look something like them."

Measuring impact

Each of the projects are attempting to measure impact. Nidaa Makki describes that Zipping Towards STEM’s project was designed first with a pilot with half of the classes participating which provided an opportunity to compare those receiving the curriculum with those in a comparison group. Their research looked at how integrating engineering into the eighth-grade curriculum impacted student’s understanding in science, and specifically in force and motion.

> We found that the students increased statistically significantly from before to after the intervention in understanding of science concepts. For the engineering design, we assessed it with some multiple-choice items from the engineering concept assessment test. And then there was also an open-ended design application and a performance assessment. And we found that the students increased in those scores as well.

From qualitative data (classroom observations, teacher logs, teacher journaling, and teacher focus groups) teachers reported that students learned “soft skills.” Students reported

> "I learned so much about teamwork and how to manage my time." And one of the more interesting findings is how do I deal with failure when things don't work? That was really one of those interesting findings that I think is very productive for us that think about, as soon as we're experiencing open ended tasks where things don't go well the first time, or things crash, or the design doesn't work, or it doesn't print, how do I handle that frustration?

Last, they found that teacher’s self-efficacy increased from before the PD to after.

> And especially for teachers like Chelsea, who has been with us for so many years, after multiple years of implementation, they felt a lot more comfortable with implementing engineering design, not only for this project, but also for other projects, when other topics come up in different content areas.

Meltem Alemdar highlighted some important findings from AMP-IT-UP's research. She described that the students were selected randomly to participate in the engineering classes. Some did not take it, others for just one year and others for two or three years. They found that students' performance, measured by statewide tests, was significantly higher among those students who attended the engineering courses at least two years when compared to other students who had never has taken our engineering course or only attended one year.

In addition, their qualitative results showed "the transfer of knowledge between STEM-ID and core and math and science courses. Students reported that the internalization of the engineering design process was very similar to scientific thinking. And they also liked the math in engineering class, which was very applied, versus their regular math classes." Their survey results also showed increased student engagement and increased science interest, all statistically significant.

Teacher professional development

One key challenge for any curricular innovation is teachers' preparation and self-efficacy when adopting or adapting "project-oriented" pedagogies, new content, or new approaches to subject matter. Thus, design for teacher learning is integral to the curricular design (NRC 2012). While all three projects included teacher professional development, they also designed the curricula to be educative for teachers (Davis and Krajcik 2005), so as to support effective adaptation when teachers bring the innovation into their own setting.

Nidaa Makki describes that their project provided teachers with the opportunity to provide feedback to the design team. Based on the teacher feedback the curriculum was modified and improved. So, the teachers contributed to the evolving design.

Isabel Huff described an approach that emerged, influenced by logistical practicalities on the ground. It was difficult to provide PD due to time limitations and then because of issues related to Covid. They ended up meeting with teachers individually to make sure that they each felt empowered and understood the approach. Teachers were given access in advance to all the materials, and even the handouts so that they felt "they could just run with it."

Designing for dynamic teacher learning as well as student learning, in the context of real systems on the ground is a fascinating engineering challenge all on its own!

Recommendations for researchers

At least three major areas where research could bring value to the design and implementation of projects to integrate engineering into the middle school curriculum emerged during this theme of the month. First, more research is warranted to demonstrate when and how transfer can be the result of such integration, along several dimensions: The transfer of content and practices — and habits of mind — between subjects or into other kinds of investigations has received much research attention, but more could be explored. Second, what durable effects does integrating engineering have on students' Math or Science learning, on identity development, or on interest in pursuing STEM degrees or careers? Last, what is the effect of STEM teachers? Do they tend to integrate engineering practices into other STEM disciplines? Does it have an impact of teachers' self-efficacy may result?

Recommendations for teacher leaders

The National Academies Convocation on the role of teachers in K-12 engineering (NAS 2017 has several important recommendations for teacher leaders as "bridge-builders" across the curriculum, which seem directly relevant to this Theme:

- Teacher leaders can take on a variety of roles, including those through which they can exert an influence on education policy at levels ranging from the local to the national. They can collaborate on the development of curricula or other teaching materials, present at school board and other meetings, take on leadership roles in their schools, represent teachers outside schools, become involved in politics, engage in research experiences or fellowships and bring that new expertise back to their schools, and work with other organizations from local to national levels. They also can help other teachers recognize the value of influencing policy. (pg 5)
- Teacher leaders could be particularly helpful in identifying and sharing effective practices and in using them to help shape policies. The practices could be disseminated through a web-based hub with review, vetting, and differentiation mechanisms. (pg 10)
- Teacher leaders can help their colleagues, schools, and districts get access to the tools, knowledge, and resources they need to do much more extensive networking and be involved in policymaking. They can help differentiate between what is expected and what is needed, whether it is internships for students, a field trip to a company, or a one-time classroom visit. They can work with philanthropic and other organizations to increase the influence of and contributions by teachers to policy and decision making at the local, state, and national levels. (pg 12)

Recommendations for administrators and policy makers

- Administrators could be champions for their teacher leaders, creating environments for success by allowing teachers to raise concerns, ask questions, and come up with their own ideas. (NAS 2017 pg 11)
- Designing, implementing, and researching integrated curriculum requires teacher time for learning and collaboration, both with each other and with partners outside the school. Administrators and policy makers should encourage teachers not only to take the time to collaborate, evaluate, and plan, but also to gain skills in classroom research and design-based implementation strategies, so as to develop increasingly deep understanding of effective strategies, impacts, and outcomes within the local context.

References

Bopardikar, A., D. Bernstein, B. Drayton, and S. McKenney (2020) Work-based curriculum to broaden learners' participation in science: Insights for designers. Research in Science Education 50:1251-1279.

Burkhardt, H., & Schoenfeld, A. (2003). Improving educational research: toward a more useful, more influential, and better-funded enterprise. Educational Researcher 32(9), 3–14.

Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. Educational Researcher 34(3), 3–14. https://doi.org/10.3102/0013189X034003003.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., Ryan, M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design(tm) Into Practice. Journal of the Learning Sciences, 12(4), 495 - 547. https://doi.org/10.1207/S15327809JLS1204_2

NRC. (2012). A framework for K-12 science education: practices, cross-cutting concepts, and core ideas. Washington, DC: The National Academies Press.

National Academies of Sciences, Engineering, and Medicine (2017) Increasing the Roles and Significance of Teachers in Policymaking for K-12 Engineering Education: Proceedings of a Convocation. Washington, DC: The National Academies Press. https://doi.org/10.17226/24700.

Purzer, S., and Quintana-Cifuentes, J.P. (2019) Integrating engineering in K-12 science education: spelling out the pedagogical, epistemological, and methodological arguments. Disciplinary and Interdisciplinary Science Education Research 1:13 https://doi.org/10.1186/s43031-019-0010-0

Written by: Brian Drayton, Co-Director for the Center for School Reform at TERC.