Engaging ALL Students in STEM – Engineering as an Agent for Social Justice

Mihir Ravel and Cary Sneider

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Session Architecture

Our Flow Today: from Big Picture to Actionable Tools

• What Do We Know about What Works?
  • Insights from Two Decades of Research in Engineering Education for P-12
  • Start with Your Students: Probe Tools from new NSTA book USIE&T

• Effective & Inclusive Methods for Engaging in STEM

• Q&A

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Engineering engages youth interest because it is team-oriented, project-based, and addresses real world problems.

Students develop 21st century skills, including creativity, teamwork, communication skills, persistence, and resilience.

Engineering integrated with science can help students develop concepts and skills in science and math as well as engineering.

Students develop increased motivation and identity as a STEM learner.

**Example:** Barnett (2005) taught physics using remotely operated vehicles (ROVS) in an urban school where students often skipped class. Attendance increased for students in the ROV class as students learned physics and learned to value its importance.*

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**Insights from Research:**

**A Wide Variety of Methods Have Been Found to Be Effective**

**General methods** that can be applied to many different topics include:

- Introducing an engineering challenge early and revisiting it throughout a science unit is more effective than as a capstone activity.

- Using fiction in which the protagonist has a problem as a launching point for engineering design.

- Using drawing throughout the design process, both hand-sketching or CAD.

- Helping parents understand their essential role in encouraging their children’s interest in STEM.

- Engaging student’s interest before high school is a strong predictor of aspirations for a career in engineering and other STEM fields.
Technological Systems also provide engaging contexts for engineering:

- Robotics is the most widely researched technology used for engineering instruction. Although most robotics activities are more interesting to boys that to girls, “soft robotics” was found to be equally interesting to all genders.

- Biomedical technologies, which are equally interesting to boys and girls, include such topics as artificial lungs and hearts, prosthetic limbs, and kidney dialysis systems.

- Electromechanical systems such as burglar alarms have been found to be effective.

- Environmental projects to protect habitats, preserve endangered animals, and sustainable practices such as recycling are also highly engaging for both genders.

Buchholz et al. (2014) reported a study in which students designed puppets using LEDs and conductive thread. Girls were more comfortable with the materials than boys and took leadership in boy-girl pairs.

Effective methods include:

- Visits from role models from local universities and industries who share racial and ethnic backgrounds with youth have been very effective, as have mentors who work directly with students.

- Engaging youth in solving problems relevant to their communities is highly effective.

- Programs such as MESA that nurture youth’s interests starting in middle school and continuing through high school and into college have been very effective in meeting the needs of boys and girls of color and from low-income neighborhoods.

Ruth et al. (2016) described a study of EPICS, in which youth engineered solutions to community problems that were meaningful to them. Interviews and class observations revealed increases in engineering self-efficacy and skills, community embeddedness, and increases in resiliency and a positive response to failure.

Insights from Research
Afterschool & Summer Programs Have Great Potential To Engage Youth

• About a third of the 263 research studies we reviewed took place in afterschool or summer programs. Nearly all of these were highly successful in developing youth’s interest and engagement in STEM, as well as developing knowledge and skills.

• Programs outside of school time do not pressure students and teachers to “cover” a lot of material, and allow time for students to engage in full engineering design activities from problem definition to testing and improvement.

Example: Ancheta (2008a) surveyed 362 girls from predominantly underrepresented groups who had participated in an afterschool engineering program. 67.7% plan to take or have already taken advanced or honors math and/or science in high school and 97.5% either plan to attend college or are already attending college. The most important aspect of the program was the hands-on projects.


Image courtesy of 4-H National Council
Start From Your Students’ Current Ideas

- “Start from Where They Are” means understanding your students’ current attitudes, knowledge, and skills.

- If you map engineering experiences onto real scenarios, then students already have a starting base of knowledge and attitudes that lend power to the experience.

- Use formative assessment to understand students’ incoming conceptions about engineering and the relevant technological systems.

- Formative assessment can take the form of discussions about objects related to the technology of interest, “show & tell” in which your students share technologies they use frequently, or “probes,” for uncovering students’ ideas.
Start From Your Students’ Current Ideas

In collaboration with Page Keeley and NSTA, we developed the first set of assessment probes for discovering students’ conceptions about engineering and technology.

You can use your students’ initial ideas to build a bridge from where they are at present to where you want them to be at the end of the unit.

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Probes are aimed at ALL students*

The What, Why, Who, & How of Engineering & Technology

- Focus on students’ daily life: bicycles, birdhouses, backpacks, phones, pizzas...
- Include multi-ethnic characters in family and community.
- Uncover and activate students’ (and teachers’) ideas
- Focus on “best thinking,” not the “right answer.”
- Create a desire to “figure it out” or know more.
- Learn about research on students’ commonly held ideas
- Support ELLs (there’s a Spanish version of each probe).
- Get ideas for teaching methods and references.

Probe 10 Engineers Work in Teams

**Purpose:** Find out what your students think about the importance of teamwork in designing or improving a technology.

**Research:** Studies show that many students believe that engineering is just for those who are experts in science and math. However, engineering requires different kinds of skills, including skills involved in collaborating with others.

**Follow-up Activity:** Have students discuss the team of people needed to engineer a running shoe. What capabilities are needed? What rules should they follow to think of as many different ideas as possible and to solve resolve disagreement?

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**Team Players?**

Four friends on a soccer team were trying out a new style of soccer ball. As they tried the new ball, they wondered if the engineers that designed it also worked in teams. They each had different ideas about how engineers did their work:

- **Sarah:** When I get to college I don’t plan to study engineering because I prefer to work with a team of people. I think most engineers work alone.

- **Franz:** What makes you think engineers don’t work with other people? I think engineers work with other engineers in the same field.

- **Marvin:** I think engineers work on teams with other engineers in the same field, and engineers in other fields.

- **Seneca:** I think engineers form teams with people in all sorts of different fields—anyone who has knowledge or experience about the problem they’re working on.

Who do you think has the best description of how engineers work? _______________

Explain your thinking.
Probe 20 Importance of the Client

Purpose: Elicit your students’ ideas about who they should talk to when defining a problem. The buyer? The end-user? Both?

Research: Several studies have found fiction to provide good scenarios for problem definition.

Follow-up Activity: Ask students to identify two or more things that their family had to buy or select that needed more than one person’s approval. Was it easy or hard to agree on a decision?

Who Needs It?

Simone recently graduated from college with an engineering degree. She has just been hired by a company to design its new line of birdhouses. She knows that every product has a client. The client is usually a person or group who has a problem or need that requires a solution. Identifying clients is an important step early in an engineering design process. She asks her friends to help her identify a client for the birdhouses.

Ling: The client is the person who hired you. Just ask your employer to tell you as much as they can about what they want the new birdhouses to be like.

Annapurna: I think the client is the person who is likely to buy a birdhouse. If you meet that person’s needs, then your employer will be happy. Go to a garden shop where they sell birdhouses and ask the customers what they are looking for.

Deepali: We need to think of this from the user’s point of view. Your client is clearly the bird that will be living in the birdhouse. Go visit some gardens and parks to see which birdhouses attract the most birds!

Melvin: I think all three of you identified a client for the birdhouse.

Katrina: I disagree with all of you. The client is someone else.

Who do you agree with the most? Explain your thinking.
Engaging Students in STEM
Now Let’s Talk About the “How”

Three M’s: Models, Methods, & Materials

- Authentic Practice of STEM supports engagement
- Start from Where THEY Are
- Easy On-Ramps & Resets
- Clear Tests and Ample Iteration
- Team Records & Roles
- Examples


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STEM Engagement – E & E Go together: Authentic *Engineering* Naturally Engages ALL Students

Purpose of Science & Math: Creating New Knowledge of *Nature*

Purpose of Engineering & Technology (E&T):

Creating Solutions for *People*

E & T Starts with Society – Easy to Link with Students’ Daily Life!

For any audience: students, parents, district leaders – It’s better to start with the bigger picture of engineering

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To Engage Students in Engineering Start Where THEY Are

Motivate learning activities and design projects by starting with systems from students’ daily life

*Inclusivity Tip: pick systems familiar to everyone*

Choose Technological That are:
- Familiar
- Interesting
- Relevant
- Purposeful

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Inclusivity and Equity in Engineering Learning Experiences*

- Use narratives to develop and motivate students' understanding of the place of engineering in the world.
- Demonstrate how engineers help people, animals, the environment, or society.
- Provide role models with a range of demographic characteristics, including storybooks that depict engineers of both genders, from a variety of races and ethnicities, with different abilities/disabilities, and with a wide range of hobbies and interests.


Mae Jemison in space shuttle; image courtesy of NASA
Aim for “Real” vs “Realistic” Contexts

Self Identification - “Start from Where THEY Are”

Set an inviting, familiar context that ALL students can imagine.

REALISTIC contexts may not be familiar to ALL students.
When you go to the Aquarium, design the shark tank and calculate its volume.
You’re building a deck with your father. Design the deck and calculate its cost.
You’re flying to Disney World. Design a suitcase that fits 5 days of clothes.

REAL contexts are more likely to be recognized by ALL students.
Your bicycle’s seat was stolen. Design a replacement and make a cardboard prototype.
Winter is coming. Design gloves using these 3 types of insulating materials.
Your neighbor’s 5-year-old daughter’s birthday is coming. Design a gift toy that moves or makes fun sounds, using these materials.
Culture as Input for Engineering Design Process

“Start from Where THEY Are” – Culture connects time and space

ALL students have unique cultural backgrounds, but often in a community there are a handful of shared cultures that can serve as home bases and as bridges – between students, and between student and teacher.

Cultures are rich sources of:

**Needs** that engineering design might solve

**Ideas** for solutions that have been developed over time

**Developing Engineering Design Experiences:**
Outline a problem/need and ask students to talk to family and community about possible solutions (shelter, transportation, food sources) that have been developed in their cultural history. Then share those solutions as idea sources to seed students’ new designs.

*Research isn’t only sifting literature; it’s also dialogue with elders and peers.*

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Engaging engineering: Easy On-Ramps & Resets

• **Aim for “Easy On-Ramps and High Ceilings”**

• **On-Ramp**: start with exploring a technological object/system familiar to students – watch a video, use it, take it apart.

• **On-Ramp**: *Students vary in their construction skills and level of confidence. So:*
  - Start with a common, simple and “improvable” baseline design that all students can build to gain familiarity with tools and initial success.
  - Move to designs unique to each student/team using a formal engineering design process.

• ** Resets**: when students wander off the road, have ways to “reset” them with an on-Ramp:
  - Gather and collate class data so all students continue with good data
  - Encourage students to share ideas, borrow each others’ design concepts, and get help on ideas that are working better.

*Sadler, P.M., Coyle, H.P., & Swartz, M. (2000). Engineering Image by Andrew Brilliant, courtesy of the Museum of Science, Boston*
Methods: Effective Design Challenges – Tactics*

✓ **Testing** against nature: Designs should be evaluated using highly reliable tests against nature and not rely on complex rubrics or subjective judgment.

✓ **Multiple iterations**: Students learn from their failures as well as successes. To encourage the testing of ideas, devices should be quick to build and modify so that many tests can be performed in a short period. Aim for simpler designs to allow more iterations – much of the learning occurs in the iterative cycle.

✓ **Large dynamic range**: Start with a poorly performing device so that the students can increase performance as they modify it over several iterations.

✓ **Employ purposeful record keeping**: Student records should be formative, capturing all attempts and trials. They need to function as a resource for the resolution of claims of first ideas and for the focus of class discussions

✓ **Rotate team roles** across research, design, prototyping, documenting, and presenting.


Image courtesy of Rick Merullo

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A Note on Materials - Be Resourceful – Waste Hurts Not Only the Planet, but the Spirit

Materials - The 3 R’s – Repurpose, Reuse, Recycle

Many students’ families have incomes that make the basics of daily life precious. Consider these common activities:

- Design and test a lander that can protect an egg dropped from 10 feet.
- Design, mix, and test a water and flour paste for making paper maché puppets.
- Design and make a craftstick bridge/tower/etc. that can hold 5 textbooks.

How does a student see these when they are hungry?
How does a student see these when they are hungry?
When there is no money for home crafts?

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Engaging ALL Students in Engineering – Putting it Together

Designing for Engagement with Inclusivity and Success for ALL

- Authentic Practice of Engineering supports engagement
- Start from Where THEY Are
- Easy On-Ramps & Resets
- Clear Tests and Ample Iteration
- Team Records & Roles
- Examples

Image courtesy of Museum of Science, Boston
Video Examples - engineering a better society

- Age group: Middle school
- Approach: Purposeful and Integrated STEM
- Aimed at important needs
  - Clean water
  - Affordable/local food

Korbin Shoemaker’s Class, Walkserville Middle School
Discussion

- Consider the themes and examples we discussed today.
- Which ones do you feel are of most value to your learning community?
- What challenges might you face in introducing any ideas and methods you found useful?
Resources

**Methods for Inclusive, Engaging, and Effective Engineering Design Experiences**


**Tools for Understanding Students' Understanding of Technology and Engineering**


**Tools for Inclusivity and Equity in STEM Classrooms**


**Sources for Engineering Activities and Curricula**

Rich set of activity ideas spanning grade bands and themes: [https://www.teachengineering.org/](https://www.teachengineering.org/)

Great network of people and organizations to support engineering education: [https://www.linkengineering.org/](https://www.linkengineering.org/)

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