The Flipped Lab – an Affordable and Inclusive Approach for Expanding Student Engagement and Persistence

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Session Description:
We share approaches to science and engineering “flipped labs” that enabled students to connect STEM classes with home and families.
Session Outline: from Big Picture to Actionable Tools

• Introduction - Engaging ALL Students across Class to Home
• What Works – Insights from Two Decades of Research
• Design Guidelines for Inclusive & Engaging Flipped Labs
• Gresham High School – Air Rocket Activity & Findings
• North Clackamas High School – Elastic Car Activity & Findings
The barriers faced by girls, students of color, and all students from low-income families to pursue and succeed in STEM careers are well known.

Fortunately, many of the 263 studies we reviewed have succeeded in helping girls, students of color, and students from low-income families develop interest, knowledge, skills, and career aspirations related to engineering.
Insights from Research:
Integrating Engineering Into Science Has Important Benefits

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

- Students develop 21\textsuperscript{st} 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.

\textbf{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.*

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.
Engaging Students in Engineering—now let’s talk about the “How”

Everyone loves M&M’s: Models and Methods (and a bit about Materials)

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

Engaging Students in Engineering: Start from Where THEY Are

Inclusivity Tip: 
*pick easily recognized systems*

Choose Technological Systems that are:
- Familiar
- Interesting
- Relevant
- Purposeful

Ref: NASA


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Engaging engineering: Easy On-Ramps & Resets

• An old curriculum guideline was “Low Barriers and High Ceilings”… Today let’s 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 something apart.

• **On-Ramp**: *Students vary in their construction skills and level of confidence. Building an initial “cookbook” design, albeit a poor performer, is a necessary first step to engage students, develop rudimentary construction skills, and familiarize students with test procedures. So:
  ➢ Start with a common, simple and “improvable” Baseline Design that all students can build to gain familiarity and initial success.
  ➢ Then 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 back onto the road:
  ➢ Gather and collate class data so all students continue with good data
  ➢ Share out designs and encourage students to borrow and get help on ideas that are working better.

* Sadler, P.M., Coyle, H.P., & Swartz, M. (2000). Engineering
**Methods: effective design challenges – tactics**

- **Simpler Designs/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.

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

- **Large dynamic range**: Start with a common “Baseline Design” that all students can make but has “poor” performance so students can improve performance as they modify it.

- **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.

A final note on Materials – the 4 R’s Repurpose, Reuse, Recycle & Resourceful

• **Repurposable** to other tasks when the project is done – binder clips better than tape!

• **Reuseable** for the same task – ideally purchased materials can be saved for use in the same project again (wheels, motors, gears) Design a parachute lander that can protect an egg dropped from 10 feet.

• **Recyclable** – materials that are consumables should be environmentally friendly throughout their life cycle – paper and wood is more likely to meet these needs than plastic and metal. If metal/plastic is used better if those can be reused.

**Resourceful**: waste hurts not only the planet, but the spirit. Many students – urban and rural - are living with incomes that make the basics of daily life precious.

**Designing for Inclusivity**: Consider these common activities:

• Design a parachute lander that can protect an egg dropped from 10 feet.

• Design the strongest water and flour paste for making paper maché puppets.

  How does a student see and feel about these when their belly is hungry?
“Flipped Labs” – Students working on their own time Bridges the Classroom to Home

Why Flipped Labs? - they Expand:

- Time and Space
- Interest, Choice, and Exposure
- Valuable in “normal times” as well as remote

Designing Flipped Labs:

- Materials: Affordable, Lightweight, Compact
- Activity Design
  - Simpler “Baseline Design” that allows iteration and expansion
  - Test it yourself and with family, friends, neighbors and students
Gresham High School – Air Racer Activity

Focus: 9th Grade Physics
– Force and Motion

- 3 teachers and ~300 students participated (2020-21)

- Demographics: 1527 students; Free and Reduced Lunch: 57%, White: 45%, Hispanic/Latino: 40%, Multiracial: 6%, Black/African American: 4%, Asian 3%

Project: OnRamps > Scaffolding > Outcomes
Air Racer Activity Design Process

- **Materials:** affordable, reusable, recyclable materials
- **Phase1** - multiple trials iterating and testing various subsystems (body, propeller...) to explore “student-friendliness”
- **Phase2** – multiple trials iterating and testing various structures to integrate the parts into a working Baseline Design for a rubberband-powered AirRacer.
OnRamp: Packet sent home to ~300 students.

Students provided parts list to take inventory as a warmup to design activity.
Scaffolding: Air Racer Guide & Videos for “Baseline Design”

An air racer is a propeller-driven craft that travels along a line. Wind it up and watch it go! The tools and materials you’ll need are shown below. If possible, work with a partner.

Before starting: Check and Organize your parts

Main steps to make your air-racer

1. Measure and Cut Parts
2. Make the Body tube
3. Make the End Cap
4. Make the Fins
5. Make the Propeller Assembly
6. Connect Propeller and Body
7. Add Hanging Wires
8. Add Fins
9. Wind Up and Launch!

An air racer ready to test - color it with your own design and launch!

Mihir K. Ravel, 20201102
Science Experiment:
Measure distance traveled versus # of turns (try 10, 20, 40, 60, 80, 100)

Engineering Design
• Change fin size and number
• Change length and diameter of body
• Change type and number of rubber bands
• Change shape and number of propeller blades
• Try changing sliding friction by hanging your air-racer on to a straw that slides on the line

Design Challenge Ideas
• Most distance on 80 turns
• Fastest speed for 80 turns
• Most creative design
• Most artistic paint job
Scaffolding: Air Racer Science and Engineering Scoring Guide

Check List:

To earn 10 pts: you must complete slides 2-4 (the #Turns vs Distance experiment) AND slide 6 (Engineering Design) OR slide 7 (Science Inquiry).

8 pts: you must complete slides 2-4 (the #Turns vs Distance experiment), but slide 6 or 7 is incomplete (you started with an Engineering or Science extension).

7 pts: You must have made an Air Racer and have completed most of slides 2-4.

6 pts: You have made an Air Racer and collected data, but slides 2-4 are incomplete.

General Scoring Guide:

10 pts: All requirements met or exceeded. Excellent work
9: All requirements met, very good work
8: Most requirements met. Good work
7: Some requirements met. Progressing (+)
6: Few requirements met. Missing major components or incomplete. (Progressing -)
5: No requirements met. Poor
0: Not completed
Outcomes: Design Variations

Air racer after redesign

Flipped Lab, Ravel/Robinette/Scannell/Sneider - 28Oct2021, NSTA Portland, OR
CER Conclusion:

My graph and data show me that this a quadratic equation. We can see this by the curve of the the line and that if we input the A value for this graph 0.028 into the equation $Y=Ax^2$ we get the best fit line for the data.
### Outcomes: Completion & Survey

<table>
<thead>
<tr>
<th>% Completed</th>
<th>(\frac{86}{126} = 68%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Extension</td>
<td>(\frac{46}{126} = 36%)</td>
</tr>
<tr>
<td>Survey respondents</td>
<td>(n(62) = 65%)</td>
</tr>
</tbody>
</table>

**Overall Project Rating**

1: Great project, I highly recommend; 5: Not a good project - I don’t recommend

<table>
<thead>
<tr>
<th>Do you have a working AirRacer?</th>
<th>Have you collected some data on #Turns vs. Distance?</th>
<th>Have you collected data for at least 5 different values of the # of turns?</th>
<th>Do you have any questions on how to collect data?</th>
<th>Did you complete the #Turns vs. Distance graph prediction (if not, go to GC Classwork Page)</th>
<th>Have you graphed your data in DESMOS? (Here is a link to a formatted desmos page)</th>
<th>Did you determine a pattern between the # of turns and the distance travelled? If so, what did you find?</th>
<th>Please write any questions or comments: Next step is the Science Inquiry and/or Engineering Extension: Your choice.</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes, quadratic</td>
<td>no questions</td>
</tr>
</tbody>
</table>
"What challenges did you have...?"

"I was able to build a working AirRacer. What went well is that I was able to do it without any mistakes"

"it looked way easier than it is“
"I didn`t think it was gonna be hard to build“

"yes, what worked well was the propeller. The difficult thing was folding some of the papers.“

"I had problems with the propeller but i just played around with it and it worked eventually“

"not starting it when everyone else did then putting it off and now just not doing it“

"it was fun, it wasn't too easy but it wasn't too hard either,"

“What was unexpected or surprising?”

"I really liked how when you twisted it, it actually worked like a propeller"

“the surprising from this activity was that i didn't know you could build one out of paper."

"What was surprising is that it took a lot of detail and to be very careful to do the project"

"just the way how it was built i didnt think something like that could do something you know“

"maybe the way after building it it seemed to work i was suprised because i didnt think it would look or work alright“ .... "it could fly"

"the way it looked like a rocket because when you think racer/racing normally youd think cars or other land things not really rockets"

"I thought it was cool that out of anything in the world we got to make a plane. I’ve never had an opportunity like that"
Key Takeaways

1) Steady iteration to get a detailed procedure, troubleshoot problems, and develop instructional slides/help videos were really important.

2) Students who followed tutorials when needed were successful. It was good to have them available, but also to make them optional.

3) Having students share out with suggestions/helpful hints provided an opportunity for successful students to demonstrate leadership/expertise. Those listening saw that it was doable (and fun).

4) Troubleshooting problems paired with reflection and sharing builds deeper understanding of both concepts and the design structure and function. In this activity the most difficult thing for students was the propeller, and discussing it in class propelled the whole class forward.

The basement became my home “flipped lab” 😊
Clackamas High School – Elastic Car Activity

Focus: 9th Grade Physics – Energy and Acceleration

- 5 teachers and 500 students participated (2020-21)
- Projects implemented over different terms due to alternative quarter-by-quarter schedule last year
- Demographics: 1470 students; Free and Reduced Lunch: 29%, White: 57%, Asian: 18%, Hispanic/Latino: 12%, Black/African American: 2%

Project: OnRamps > Scaffolding > Outcomes
Project: **OnRamps > Scaffolding > Outcomes**

**Box of Parts Sent Home**

**Kit Pre-check:**
- Check list assignment
- Parts “questions”

- Anticipated Plans & Problems
  - Student preliminary concerns
  - Early student ideas for alternatives to base model
Project: OnRamps > Scaffolding > Outcomes

- “How to” Videos
  - Step-by-step build
  - Segments with safety checks
  - Hints and work-arounds

- Live Demonstration: Online class session of “show-ask-explain” the key build steps

- Ongoing Support
  - Interactive cloud journal contained structure for build questions
  - Discussion through document “chat”
Iterations & Improvements

Baseline Design

Extension Design

Elastic Car
Types of Design Iterations & Improvements

Substitutional Design

Reconfigured Design

“Outside the Box” Design

Elastic Car

Flipped Lab, Ravel/Robinette/Scannell/Sneider - 28Oct2021, NSTA Portland, OR
“I think I may add a bit of clay in the back to add weight to the car..."

“I tried to make my elastic car travel farther by using a smaller band. However, I saw no increase in the distance the vehicle traveled. Then I noticed the wheels of the car seemed like it was moving a lot but somehow couldn't get like a grip on the surface because the wheels are plastic and slippery. So I decided to tie rubber bands to the back wheels of my car, and it worked!”
Project: OnRamps > Scaffolding > Outcomes

Outcome: Project Completion

- Total Projects
- Completed Required Research and Discussion
- Completed A Build of Any Kind
- Completed Extension to Base Model
- Completed Research with Simple Car or Teacher Data
Project: OnRamps > Scaffolding > Outcomes

Outcome: Design Iterations & Improvements

- Total Photos of Cars: Highest number
- Revised: Lower number
- Substitution: Lower number
- Reconfigured: Moderate number
- Outside the Box: Lower number

Flipped Lab, Ravel/Robinette/Scannell/Sneider - 28Oct2021, NSTA Portland, OR
Students explained their system with appropriate energy concepts

“Most of the energy is used at the start because there is so much potential energy built up when the rubber band is released it uses most of its energy to start moving”

“The elastic car moves because potential energy in the rubber band is changed to kinetic energy as the elastic calms down.”
Observations & Surprises

Observations

*Based on email and journal chat messages*

- Worked in bursts on their own schedule
- Some students began before start date
- Several students used online sources for build hints and ideas
- Most students built *something, and some that were not engaged during school time*

Surprises

- Students Persisted
- Very Little one-on-one help from teacher
- Some parents/siblings participated
- Remote special-ed support was effective
Challenges

Technical/Tactical
“Not trying to poke yourself”
“Getting traction”
“The wheels kept falling off”
“I destroyed my sticks.”

Life – Stuff Happens
‘I don’t have a place to work’
‘I keep leaving my parts at the other house’
‘I never got my stuff because we moved because of the fires’
‘I have to take care of my sister and I don’t have time’
‘My mom’s helping me on this’
Activity Design Suggestions

• Build it yourself; more than once, and with friends & students

• Notice your design process - problem solving, alternatives, frustrations

• Project challenge level
  - Accessible “baseline design” that is challenging to perfect → “flexibly improvable”
  - Easy to describe, harder to do
  - Notice your use of space, time and supplies

• Budget for cost, ease of use, environmental impact and student pride in product
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/)

We sincerely appreciate the initiative and productive discussion with our teaching colleagues that piloted these flipped lab activities.

Teaching Colleagues:

**Gresham High School**
- Jennie Richard
- Shirley Tremmel

**Clackamas High School**
- Anton Clifford
- Ivana Turner
- Alexe Navarro
- Sally Howe
- Shane Monares
- Nate Munoz

We are grateful to our non-profit partner, Exceed Enterprises of Milwaukie, OR, for assembling the AirRacer kits.
Discussion

“Flipped Labs” – Students working on their own time Bridges the Classroom to Home

The themes and examples we discussed today:

• Which ones do you feel are of most value to your learning community of students and colleagues, but also families and friends?

• How would you introduce these ideas and methods into your regular teaching flow?