Using the Engineering Design Process for Student Success in Chemistry

Tyler Kinner
tyler.kinner@gcpsk12.org
Gwinnett County Public Schools
Suwanee, GA
Agenda

I. Why engineering design?

II. Classroom experiences

III. Resources and ideas

IV. Questions and Discussion
Why engineering design?
21st Century Skills
<table>
<thead>
<tr>
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<th>Knowledge Constructor</th>
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<tbody>
<tr>
<td>3</td>
<td>Students critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts and make meaningful learning experiences for themselves and others.</td>
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<thead>
<tr>
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<th>Innovative Designer</th>
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<td>4</td>
<td>Students use a variety of technologies within a design process to identify and solve problems by creating new, useful or imaginative solutions.</td>
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Engineering for higher order thinking
Engineering for higher order thinking

- Strategic thinking
- Metacognitive thinking
- Multi-modal thinking
- Empathetic thinking
Engineering for equity

- Shifts focus from traditional demonstrations of content knowledge
  - Science historically presented as monolithic ideas from culturally dominant groups
Engineering for equity

- Shifts focus from traditional demonstrations of content knowledge
  - Science historically presented as monolithic ideas from culturally dominant groups

- Ability to assess and solve problems in the immediate community
  - Water quality, air quality
  - Food and water supply issues
Engineering for equity

- Shifts focus from traditional demonstrations of content knowledge
  - Science historically presented as monolithic ideas from culturally dominant groups

- Ability to assess and solve problems in the immediate community
  - Water quality, air quality
  - Dangers in the home
  - Issues of social and environmental justice

- Access non-valued funds of knowledge
  - Access funds of knowledge associated with carpentry, welding, etc.
  - Immediate usefulness for engineering design
    - Materials selection, prototyping
The NGSS and Engineering

Science and Engineering Practices
Asking questions and defining problems
Develop and use models
Construct explanations and solutions
Use mathematical and computational thinking
Engage in argument from evidence
Plan and carry out investigations
Analyzing and interpreting data
Obtaining, evaluating, and communicating information
The NGSS and Engineering

- Engineering as both:
  Science and Engineering Practices
  AND
  Disciplinary Core Idea
The NGSS and Engineering

- Engineering as both: Science and Engineering Practices AND Core Idea (HS-ETS1 - A, B, C)
You want to incorporate engineering into your curriculum from DAY ONE, what do you do?
Issues with engineering design - an opinion

- Standards-based classrooms
  - NGSS or NGSS aligned - where does engineering actually fit into the curriculum?

- How does engineering design fit within the “phenomenon based instruction” reform?

- How do I do this while holding students accountable for learning and “keeping pace” with assessments?
<table>
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<tr>
<th>Prior Thinking About Phenomena</th>
<th>Thinking About Phenomena Through the NGSS</th>
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<tr>
<td>If it’s something fun, flashy, or involves hands-on activities, it must be engaging.</td>
<td>Authentic engagement does not have to be fun or flashy; instead, engagement is determined more by how the students generate compelling lines of inquiry that create real opportunities for learning.</td>
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<td>Anything students are interested in would make a good “engaging phenomenon”</td>
<td>Students need to be able to engage deeply with the material in order to generate an explanation of the phenomenon using target DCIs, CCCs, and SEPs.</td>
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<tr>
<td>Explanations (e.g., “electromagnetic radiation can damage cells”) are examples of phenomena</td>
<td>Phenomena (e.g., a sunburn, vision loss) are specific examples of something in the world that is happening—an event or a specific example of a general process. Phenomena are NOT the explanations or scientific terminology behind what is happening. They are what can be experienced or documented.</td>
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<td>Phenomena are just for the initial hook</td>
<td>Phenomena can drive the lesson, learning, and reflection/monitoring throughout. Using phenomena in these ways leads to deeper learning.</td>
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<td>Phenomena are good to bring in after students develop the science ideas so they can apply what they learned</td>
<td>Teaching science ideas in general (e.g., teaching about the process of photosynthesis) may work for some students, but often leads to decontextualized knowledge that students are unable to apply when relevant. Anchoring the development of general science ideas in investigations of phenomena helps students build more usable and generative knowledge.</td>
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<td>Engaging phenomena need to be questions</td>
<td>Phenomena are observable occurrences. Students need to use the occurrence to help generate the science questions or design problems that drive learning.</td>
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<td>Student engagement is a nice optional feature of instruction, but is not required</td>
<td>Engagement is a crucial access and equity issue. Students who do not have access to the material in a way that makes sense and is relevant to them are disadvantaged. Selecting phenomena that students find interesting, relevant, and consequential helps support their engagement. A good phenomenon builds on everyday or family experiences: who students are, what they do, where they came from.</td>
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https://www.nextgenscience.org
What is the quality of the water in our own backyard?
What is the quality of the water in our own backyard?
What is the quality of the water in our own backyard?
But where’s the engineering?

Usual water quality determinations:

- Procedure and materials given to students

- Students don’t have ability to measure pH, concentration of ions, etc. without expensive equipment

- Do they understand how the results are created?

Personal classroom mission:

- Equip students with knowledge and skills to identify, describe, and solve problems in their immediate community
Spectrophotometric/colorimetric determination of phosphate ions

Phosphate by molybdate assay
Student worksheet

Principle
Phosphate(V) ions react with ammonium molybdate to produce a coloured complex. The reaction is carried out in an acidic solution containing excess ascorbic acid (vitamin C) to prevent the complex from slowly oxidising.

You can use this reaction for the quantitative analysis of low concentrations of PO_4^{3-} ions in solution. You can also use simple colour matching although the results will be less precise.

Equipment and materials
- Burette
- 100 cm^3 conical flask x 7 (or use one, thoroughly washing it between samples)
- 10 cm^3 pipette
- 5 cm^3 pipette
- 1 cm^3 pipette
- Small spatula
- Bunsen burner, tripod and gauze
- Colorimeter and suitable filter (orange/red) - a solution of the complex displays maximum absorption at 650 nm
- 100 cm^3 volumetric flask x 7 (or use one, thoroughly washing it between samples)
- Ammonium molybdate solution (7 cm^3)
- Ascorbic acid (vitamin C) (7 small spatula measures)
- Potassium dihydrogenphosphate(V) solution containing 0.1 g dm^{-3} phosphorus as phosphate(V) (100 ppm) (52.5 cm^3)
- Solution of unknown phosphorus concentration (5 cm^3)
But where’s the engineering?

Personal classroom mission:

- Equip students with knowledge and skills to identify, describe, and solve problems in their immediate community
Searching the literature: a low-cost, DIY colorimeter

- Inexpensive materials provides access to the technique

- No longer a “black box”

- Students forced to better understand the context of their numerical results
But where’s the engineering?
Prototyping and discovering the concept of Beer’s Law

Ausubel’s Meaningful Learning - connections to prior experiences and knowledge makes it easier to facilitate the assimilation of new learning
Fostering cross-curricular application of learning

Showing students how they will use a wide variety of skills in their futures

Equipping them with the confidence that they have knowledge and skills to solve real problems!
Mistakes happen - often because we don’t know everything

How else can we solve the problem without additional time and resources?
Formative Assessment

Usual Suspects
Quizzes
Performance Tasks
Student Products
Formative Assessment

Usual Suspects
Quizzes
Performance Tasks
Student Products

“It is not the doing, but the thinking about the doing” - Dewey
Formative Assessment

Usual Suspects
Quizzes
Performance Tasks
Student Products

“It is not the doing, but the thinking about the doing” - Dewey

What if we formatively assess using student reflections?
Example Google Form Exit Ticket

Reflection Questions

What was your goal for the day? *
Your answer

What knowledge from chemistry did you need to use to complete your goal for the day? *
Your answer

What skills (people skills, computer skills, lab skills, etc.) did you need to use to complete your goal for the day? *
Your answer

Did you complete your goal? *
- Yes
- No
Example Google Form Exit Ticket

**Reflection Questions**

What was your goal for the day? *
Your answer

What knowledge from chemistry did you need to use to complete your goal for the day? *
Your answer

What skills (people skills, computer skills, lab skills, etc.) did you need to use to complete your goal for the day? *
Your answer

Did you complete your goal? *
- Yes
- No

If no, what prevented you? Lack of knowledge? Need more practice with a skill before you can do it in a timely manner? Be honest and specific.
Your answer

Did anything not occur the way you expected? Do you have any questions that need answered?
Your answer

Anything exciting to share?
Your answer

Upload a photo or file documenting your progress *

ADD FILE
Example Google Form Exit Ticket

Rate your group members

<table>
<thead>
<tr>
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<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
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What are we looking for?

- Declarative knowledge
  - Correct conceptions
  - Alternative conceptions
  - Lingering questions
What are we looking for?

- Declarative knowledge
  - Correct conceptions
  - Alternative conceptions
  - Lingering questions

- Procedural knowledge
  - How to use a program, system, or just how to work with others
What are we looking for?

- **Declarative knowledge**
  - Correct conceptions
  - Alternative conceptions
  - Lingering questions

- **Procedural knowledge**
  - How to use a program, system, or just *how to work with others*

- **Contextual knowledge**
  - Do students know when they need or why they need to do things
And sometimes we’ll be surprised by...

- Information about family/community resources used
  - Diverse funds of knowledge/social capital
And sometimes we’ll be surprised by...

- Information about family/community resources used
  - Diverse funds of knowledge/social capital

- Student prior knowledge
And sometimes we’ll be surprised by...

- Information about family/community resources used
  - Diverse funds of knowledge/social capital

- Student prior knowledge

- The ability of students to reflect critically on their own performance
Reflection Questions

What was your goal for the day? *

Our goal was to get an understanding of what exactly we had to do for the project. We also planned to jot down all the info for the lab report such as background knowledge, procedures, materials, etc.

What knowledge from chemistry did you need to use to complete your goal for the day? *

understanding of hat a seial dilution and Beer's Law

What skills (people skills, computer skills, lab skills, etc.) did you need to use to complete your goal for the day? *

People skills
Reflection Questions

What was your goal for the day? *
Our goal was to begin printing and finish the rest of the spreadsheets

What knowledge from chemistry did you need to use to complete your goal for the day? *
We used our knowledge about algebra 1 and computer tech (y = mx + b, inventor)

What skills (people skills, computer skills, lab skills, etc.) did you need to use to complete your goal for the day? *
We used inventor and needed to finish printing and spreadsheet
If no, what prevented you? Lack of knowledge? Need more practice with a skill before you can do it in a timely manner? Be honest and specific.

lack of knowledge prevented us from completing the second spread sheet.

Did anything not occur the way you expected? Do you have any questions that need answered?

Mr. Kinner i need you to explain this molarity thing to me again.

Anything exciting to share?

I didn't understand how to do the math for one of the worksheets.

Upload a photo or file documenting your progress *

Unknown Solution ~...
What knowledge from chemistry did you need to use to complete your goal for the day?

You needed to know the formulas

What skills (people skills, computer skills, lab skills, etc.) did you need to use to complete your goal for the day?

Computer skills

Did you complete your goal?

- Yes
- No

If no, what prevented you? Lack of knowledge? Need more practice with a skill before you can do it in a timely manner? Be honest and specific.

we really didn't get it
Assess the planning too!

**To Do**
- we need a precise plan for our video.
- we need to start filming our video

**Doing**
- we are working on the mock up for the video due friday.
- we are working on the scripts for our video.
- we are still in need up things for our product
- We are currently doing working on getting the things for the project

**Done**
- we have started to create a mock up for our video due friday.
- we have bought some of the materials needed to start building our product.
- we turned in our proposal.
- We already know the type of plants we want which are succulents
- We've planned out how we're going to prepare our terrarium.
Beyond the simple project...

- Engineering builds student capacity to solve problems
- Allows students to incorporate creativity into the content
- Foster 21st century skills
- Design is a process, not a product
Resources and ideas

- Google Scholar, Semantic Scholar, your library
  - Journal of Chemical Education
  - Chemistry Education Research and Practice

- Low-cost, DIY versions of expensive lab equipment

- Green-chemistry methodology

- Computer-based chemistry simulations
DIY Instrumentation

- DIY colorimeters
- DIY spectrophotometers & DIY fluorimeters
  - Assess beverage quality and spot counterfeit beverages
  - Design a specific product for consumers, street vendors, etc.
DIY Instrumentation

- DIY microfluidics
  - 3D printed microfluidics chambers
  - Separation of mixtures
    - Design a solution for an art supply manufacturer to do QC
Green Chemistry engineering

- Facile, green synthesis of fluorescent carbon nanoparticles
- Counterfeit detection, leak detection
- Flow-processing synthesis of chemicals
Computer-based chemistry simulations

- Use of Scratch, a free block coding platform by MIT
- Consult for a company, will a proposed reaction produce enough product to be feasible?

Using a Systems Thinking Approach and a Scratch Computer Program To Improve Students’ Understanding of the Brønsted—Lowry Acid—Base Model

Sungki Kim,1 Hee Chol,1 and Seoung-Hey Park1,2,3

1Gwangju Science Academy For the Gifted, 213 Cheomdongro-ri, Buk-gu, Gwangju 61005, Republic of Korea
2Hongmyung High School, 19 Wolmyeong-ro 22Dwae-ri, Hoonjeok-gu, Cheongju-si, Chungcheongbuk-do 28462, Republic of Korea
3Department of Chemistry Education, Korea National University of Education, 360 Taeyeongon-dong, Gwangju-si, Gwangju 61112, Republic of Korea

ABSTRACT: Numerous previous studies have reported the difficulties associated with learning the Brønsted—Lowry acid—base model. The Brønsted—Lowry acid—base model requires complex systems thinking because it considers random interactions between reactant and product particles and effective particle collisions in forward and reverse reactions. The system elements are dynamic, complex, and mutually independent. Furthermore, phenomena constantly change and interconnect with all elements of the system. Despite these difficulties, previous studies, thus far, have not reported methods that can effectively teach students the Brønsted—Lowry acid—base model, which require systems thinking. To solve this problem, we must understand the ontological attributes of science concepts, such as the Brønsted—Lowry acid—base model. In this study, we propose a Scratch program to help students understand the Brønsted—Lowry acid—base model.

KEYWORDS: High School/Introductory Chemistry, Computer-Based Learning, Aids/Bases, Systems Thinking
Summary

- Look to the literature for innovative examples, but look to your students for how the examples can apply to their lives

- Use varied tools of formative assessment to make sure students are on track and “getting it”

- Don’t be afraid to mess it up!
Questions?

Contact info
Tyler Kinner
tyler.kinner@gcpsk12.org
LinkedIn: Tyler K inner
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