ELEMENTS OF MAKING
Kyle Albernaz is a preservice chemistry teacher who wants to bring creativity and passion into his classroom. Back when he was a student himself, Kyle remembers a dichotomy between his fellow students: Those driven by logic were drawn to the sciences; the creative types, less so. Kyle wanted to blend the two worlds, and now, as a student teacher at Connally High School in Pflugerville, Texas, he has found a way, discovering that the activity known as “making” can bring creative learning experiences to his science students.

What is making?
While there is no official definition, making is generally thought of as turning ideas into products through design, invention, and building. We define making as

- an iterative process of design and fabrication that draws on a do-it-yourself (DIY) mindset;
- allows for self-expression through the creation of a personally meaningful product shared with a larger community, and, like project-based instruction;
- can help students learn content as they design solutions and build products. These products can address real-world challenges or simply be items students are inspired to create.

“Many aspects of making are universal,” Kyle says. “A lot of students enjoy creating something with their hands and seeing a finished product.”

Support is growing for integrating making into STEM education (see *The National Science Foundation and Making “On the web”). Making can help high school students explore science concepts and phenomena (Bevan 2017), yet, lacking training and experience, many science teachers are reluctant to add making to their curriculum. Blikstein and Worsley (2016) found those new to making require “a considerable amount of onboarding and facilitation” before adding making in their own teaching (p. 71).

We work to help preservice STEM teachers bring making into the classroom. These teachers need a solid understanding of what making is and how to involve their students in maker practices. To succeed at making, students need to:

- Learn to identify questions or personal interests that can lead to the creation of a product.
- Use appropriate tools safely.
- Practice elements of a maker mindset and put them into action.
- Connect their work to STEM disciplinary core ideas.
- Present their work publicly and contribute to the broader community.

This article describes six elements of making, provides a matrix to assist teachers, and offers a sample chemistry lesson for context.

Getting started with the elements of making
The six elements of making are creating original, personally meaningful products; engaging in iterative design and fabrication; developing a maker mindset; collaborating and connecting with community; sharing work; and using science and engineering. These elements are highlighted as a way to help science teachers unpack different facets of making. The section below expands on each element and provides suggestions for getting started with students.

1. Makers create original, personally meaningful products.
Making allows for self-expression and empowerment, driven by personal interests and creativity. The “What is a Maker?” video (see “On the web”) is a good introduction.

*How to start:* Maker products reflect something personal about the maker. Thus, making helps students flourish and find their passion, though drawing inspiration from their experiences can take scaffolding. As students start to make, ask them to journal about and discuss with peers connections between what they are building and their own lives or communities. Over time, students will become more comfortable identifying their own interests and using them to find inspiration.

2. Makers engage in iterative design and fabrication.
Makers select from various materials and know how to use assorted high- and low-tech tools safely, including hand and power tools, open-source programming languages, electronics, soldering, crafts, 3-D printers, laser cutters, and more. Like engineers, makers create prototypes, test their work, seek feedback from others, and continually revise and refine.

*How to start:* Building things that are tangible, useful, and complex can provide satisfaction and confidence for students. However, getting started can be challenging for those who have limited making experience. Consider collaborating with technology and engineering teachers to help establish best safety practices, teach tool skills, and manage technology-based projects. Also consult standards for using educational technology developed by the International Society for Technology in Education (see “On the web”). Start with projects and tools that you, as the teacher, are comfortable with. Review project websites,
such as instructables.com, for initial ideas. Starting with step-by-step instructions can raise student confidence with fabrication skills. As students become more comfortable with making, they can make their own decisions about the equipment, materials, and revisions needed for their design.

3. Makers demonstrate characteristics of a maker mindset.
A maker mindset promotes effort and persistence. Successful makers view failure as a chance to rethink and revise their work. Makers seek advice and feedback from others and are willing to change tack as needed. Because making is an internally motivated process, makers frequently demonstrate enjoyment in their work.

How to start: Learning persistence, flexible thinking, and a positive view of failure is a lifelong process. As a first step, have students discuss these traits and consider how they might be useful in their lives. Encourage a sense of playfulness and focus on your students’ effort, persistence, and ability to incorporate feedback more than on the products they make. Overt attention to these areas will foster a maker mindset.

4. Makers collaborate and connect with community.
The maker community is characterized by a willingness to share ideas, tools, and designs. Makers connect in person and through digital forums to form vibrant communities where they display work, share resources, and reflect on lessons learned.

How to start: Fostering community starts in the classroom. Have students work together and share ideas as they make. Next, introduce students to the broader maker community by visiting a local maker faire or connecting via social media. Visit www.makerfaire.com to browse local and national events. Follow the maker faire twitter feed, @makerfaire, or @MakerEDOrg, the feed for the maker education initiative of Make magazine. Also see these groups’ Facebook pages. Connecting to the larger maker community, students are exposed to various people and passions involved in making and may discover new ideas, role models, and personal inspiration.

5. Makers share their work publicly.
By sharing their work, makers contribute innovative ideas and products to the broader community. Without sharing, the maker community and the advances it fosters could not exist.

How to start: Some students may be more confident sharers than others. Support students with in-class sharing activities like peer feedback and gallery walks. Then, consider bringing in outside feedback or publicly sharing work by exhibiting at a school event, library, or nearby maker faire. Encourage students to upload their projects, with their parents’ permission, to sites like makershare.com or instructables.com, each of which welcomes contributions from users.

6. Makers use science and engineering.
Makers use science and engineering practices when they develop questions, make precise measurements, design solutions, test their products, and communicate information. However, for hobbyists and others making in informal settings, these practices may be more intuitive than explicit. Science teachers should bring science and engineering to the forefront.

How to start: Use the Next Generation Science Standards (NGSS Lead States 2013, see page 29) as a guide. Ask students to discuss connections to the standards throughout the project and draw attention to the science and engineering practices being employed. Explicitly link their work to the nature of science and engineering.

The Elements of Making matrix
We created the Elements of Making (EOM) matrix (Figure 1) to help science teachers engage with making at various levels. We hope this document, inspired by the National Research Council (NRC 2000), will help identify ways that making can be successfully incorporated into science teaching.

The matrix lists the six elements of making along the side. Teachers may choose to focus on one or all of these in a particular project or activity. The columns in the matrix describe varying degrees of scaffolding and a range of options to help science teachers support students. Science educators may land on different parts of the matrix, depending on their curricular goals, the nature of the project, the teacher’s comfort with making, available resources, and the students’ level of experience.
## The Elements of Making matrix

<table>
<thead>
<tr>
<th>MAKERS....</th>
<th>SUPPORTED</th>
<th>EMERGING</th>
<th>DEVELOPING</th>
<th>SOPHISTICATED</th>
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<tbody>
<tr>
<td><strong>Create original, personally meaningful product</strong></td>
<td>Makers engage in a task provided by an outside source and/or build a product from a pre-existing model or template. Personal meaning is not a relevant factor in product creation.</td>
<td>Makers refine a task provided by an outside source and offer some modification to a pre-existing design or template. The design is connected to personal interests or experience in limited ways.</td>
<td>Makers choose from a possible set of tasks or define their own task. Makers offer noticeable modification to a pre-existing design or template. The modified design is connected to personal interests or experience. Makers can articulate this connection.</td>
<td>Makers define their own tasks and create personally meaningful products that are either completely original or significantly modify pre-existing designs. The designs are deeply connected to personal interests or experiences. Makers articulate the personal connection with clarity. Personal motivation pushes the makers to exceed project expectations.</td>
</tr>
<tr>
<td><strong>Engage in iterative design and fabrication</strong></td>
<td>Makers are given step-by-step procedures for product creation. Feedback is limited. No revisions are attempted. Makers are directed to specific tools, materials, and safety procedures.</td>
<td>Makers are given general procedures for product creation. Feedback is provided and the makers are directed to make specific modifications. Makers are given a limited choice of tools. Makers begin to develop an understanding of selected tools, materials, and safety procedures.</td>
<td>Makers are given limited procedures and support as needed. Makers are given feedback at several points and use this feedback to decide on modifications and refine their designs. Makers select their own tools. Makers demonstrate an understanding of tools, materials, and safety procedures as well as some skill in fabrication.</td>
<td>Makers engage in independent problem solving and regularly ask thought-provoking questions of themselves and others. Makers solicit support and feedback as needed. Makers develop models and work through multiple iterations of the product design. Makers demonstrate a deep understanding of tools, materials, and safety procedures. Makers show improving fabrication skills, and their end products display high-quality craftsmanship.</td>
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<tr>
<td><strong>Demonstrate characteristics of a maker mindset</strong></td>
<td>Makers are introduced to characteristics of a maker mindset, including but not limited to being playful, having a growth mindset, seeing failure as instructive, and embracing collaboration.</td>
<td>Makers identify one or more characteristics of a maker mindset and reflect on those areas. Makers are given specific reflection prompts.</td>
<td>Makers display several characteristics of a maker mindset. Makers reflect on those areas throughout the project. Makers are given broad guidelines to facilitate reflection.</td>
<td>Makers display characteristics of a maker mindset. Makers show flexible thinking and a willingness to try new strategies throughout the making process. Makers demonstrate persistent effort and use missteps as opportunities for growth. Makers consistently reflect on their work.</td>
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The Elements of Making matrix (continued)

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<tr>
<th>MAKERS….</th>
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<tr>
<td><strong>Collaborate and connect with community</strong></td>
<td>Makers are directed to collaborate with others during the process of design, reflection, redesign, or presentation. Makers are given a template or prompts to facilitate discussion and idea sharing.</td>
<td>Makers are given opportunities to collaborate with others during the process of design, reflection, redesign, or presentation. Makers are given broad guidelines to facilitate discussion and idea sharing.</td>
<td>Makers solicit opportunities to collaborate with others. Evidence of collaboration is present in multiple facets of the project, including design, reflection, redesign, and/or presentation.</td>
<td>Makers solicit opportunities to collaborate with others both inside of the classroom and in the broader maker community. Evidence of collaboration is present in all facets of the project, including design, reflection, redesign, and presentation.</td>
</tr>
<tr>
<td><strong>Present their work publicly</strong></td>
<td>Makers present their work to someone else. Makers are given a template or specific prompts to support the discussion of their work and to seek feedback.</td>
<td>Makers present their work to a group. Makers are given broad presentation guidelines to support the discussion of their work and to seek feedback.</td>
<td>Makers present their work to multiple groups. Makers engage with the audience, can discuss the progression of their project, and seek feedback on their work. The presentation includes a prototype or functional product.</td>
<td>Makers present their work in multiple forums, including a presentation in a public space. Makers engage with the audience, are articulate, and can describe the making process from start to finish. Makers seek and respond to feedback. The presentation includes a high-quality product and documentation of prior iterations and designs.</td>
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<tr>
<td><strong>Use science and engineering</strong></td>
<td>Makers are given all connections to the science content and disciplinary core ideas. Makers are provided with a specific science or engineering practice to include in their work.</td>
<td>Makers are given possible connections to science content and disciplinary core ideas. Makers are directed to science and engineering practices as defined by the NGSS and asked to select a relevant practice to highlight in their work.</td>
<td>Makers are guided in forming connections to science content and disciplinary core ideas and can articulate connections. Makers demonstrate several science and engineering practices as defined by the NGSS. Makers can identify these practices in their work.</td>
<td>Makers independently draw complex connections to content, articulate ties between their work and disciplinary core ideas, and form interdisciplinary links to domains such as the arts, humanities, and mathematics. Makers demonstrate connections to multiple science and engineering practices as defined by the NGSS. Makers can describe these practices and identify them in their work.</td>
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Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

**Standards**
- HS-PS1 Matter and Its Interactions
- HS-ESS2 Earth’s Systems
- HS-ETS1 Engineering Design

**Performance Expectations**
- The chart below makes one set of connections between the instruction outlined in this article and the NGSS. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

**HS-PS1-3.** Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

**HS-ESS2-5.** Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.

**HS-ETS1-1.** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

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<tr>
<th>DIMENSIONS</th>
<th>CLASSROOM CONNECTIONS</th>
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<tr>
<td><strong>Science and Engineering Practices</strong></td>
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<tr>
<td><strong>Planning and Carrying Out Investigations</strong></td>
<td>Students designing their exhibits for the water museum project based their models on observations and data from prior experiments. The design of the exhibit may need to be refined several times because making is an iterative process. Interactive water museum exhibits can allow visitors to carry out their own investigations about the properties of water.</td>
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<td><strong>Developing and Using Models</strong></td>
<td>Students are given a real-world design challenge to construct an exhibit that models the properties of water for their water museum. In the design process students must think about the safety and reliability of an exhibit that other people may interact with. Students are given opportunities to improve upon their designs, which may include more aesthetically pleasing exhibits after their initial prototypes.</td>
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<td><strong>Disciplinary Core Ideas</strong></td>
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<td><strong>PS1.A: Structure and Properties of Matter</strong></td>
<td>Student exhibits explain various physical and chemical properties of water, such as specific heat capacity, refraction of light, expansion upon freezing, changes in density, and how these properties are essential to the role of water in Earth’s surface processes.</td>
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<tr>
<td><strong>ESS2.C: The Roles of Water in Earth’s Surface Processes</strong></td>
<td>Students can design maker exhibits that show how the interactions of a large number of water molecules result in unique properties.</td>
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<td><strong>Crosscutting Concept</strong></td>
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<tr>
<td><strong>Structure and Function</strong></td>
<td>Student exhibits can highlight the structure of water and the connection to concepts such as polarity. Exhibits can summarize observations of water’s interaction with other water molecules (cohesion) via hydrogen bonding and water’s interaction with polar and ionic compounds (adhesion).</td>
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A classroom example
In a sample lesson conducted by a preservice chemistry teacher, students are asked to build interactive exhibits for a local children’s science museum. Student teams must use their knowledge about water—its structure, polarity, and properties—to design an interactive exhibit intended to get middle schoolers excited about water chemistry. Roles within each team include a materials manager, team lead, chemistry consultant, and design consultant. In their exhibit, students represent the property on a macroscopic and molecular level, ensure the product requires interaction from the user, and make an informative plaque so potential visitors can read information as well as interact with the exhibit.

The complete sample lesson plan (see “On the web”) gives a general overview of the lesson, describes what students made, and shows how the activity aligns with disciplinary core ideas, science and engineering practices, and crosscutting concepts. The example also discusses how the EOM Matrix can be applied when analyzing this lesson. In addition, next steps are provided as suggestions for how the lesson could be modified to move toward more sophisticated making.

Advice
For this article we received advice from preservice teachers, mentors, and educators involved in making. They advise teachers not to be intimidated. While making may seem daunting, project options range from those taking a semester to complete to others that take only 45 minutes. Some projects use high-tech equipment, while others use common materials. Find what works best for you, jump in, make mistakes, and learn alongside students. Also remember that making is an excellent avenue for building useful products that support your community. By considering the needs of others, students can build empathy and develop confidence in their ability to create and contribute. In this way, making can reach beyond the walls of the science classroom to benefit the broader society.

Conclusion
The elements of making and the accompanying matrix are intended to provide scaffolding to support making in the science classroom. Making is built on a foundation of collaboration, shared resources, and community. In that spirit, we are sharing our experiences with making in STEM classrooms in the hopes of empowering other science teachers and their students with these practices.

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ON THE WEB
Makershare: https://makershare.com
Instructables: www.instructables.com
International Society for Technology in Education (ISTE): www.iste.org
Sample lesson plan: https://sites.google.com/view/livelongandmake/maker-ed/lessons
UTeach Maker: https://maker.uteach.utexas.edu
UTeach Maker Lesson Bank: https://maker.uteach.utexas.edu/lessonbank
What is a Maker (video): www.youtube.com/watch?v=rUoZwu5DiK

REFERENCES

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