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Commentary

An Outreach/Learning Activity for STEAM Education via the Design and 3D Printing of an Accessible Periodic Table

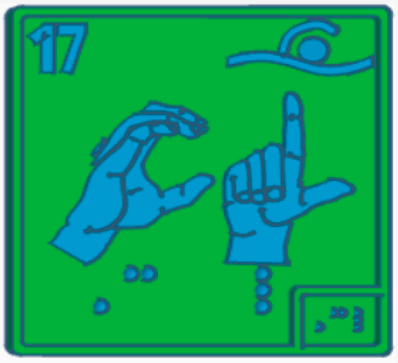
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ABSTRACT: Through K-12 student workshops in 3D-printing technology at the Michigan State St. Andrews 3D-printing lab, a collaborative STEAM outreach project was initiated with the Committee on Chemists with Disabilities of the American Chemical Society to design and build an accessible Periodic Table of the Elements to celebrate the 2019 International Year of the Periodic Table. This project supported the education of students in 3D-printing technology and promoted their interests in learning about science while bringing awareness to the obstacles faced by individuals with disabilities. The project lessons, which included tile designs using CAD software, conformed to both the Common Core State Standards and the Next Generation Science Standards by defining problems, developing models, carrying out investigations, and designing solutions. Students acquired basic skills in 3D modeling and broad general knowledge of the Periodic Table. In Fall 2019, this Periodic Table, which included ASL hand-signing and Braille on each element tile, was displayed at the National American Chemical Society Meeting in San Diego.



KEYWORDS: *Periodicity/Periodic Table, Student-Centered Learning, General Public, Elementary/Middle School Science, Interdisciplinary/Multidisciplinary, Computer-Based Learning, Hands-On Learning/Manipulatives*

INTRODUCTION

The Common Core is a set of K-12 curriculum standards focusing on mathematics and English language arts/literacy (ELA), while the Next Generation Science Standards (NGSS) are standards designed to promote a conceptual understanding of scientific knowledge, including engineering and design processes.[1] The framework for students, which starts with implementing the engineering process of designing and constructing prototypes, followed by testing and optimizing the resulting designs, often has not been explicitly included in science standards and is not widely practiced by many science teachers.[2] In November 2015, the Michigan State Board of Education adopted NGSS for K-12 students,[2] bringing attention to educators of better methods in presenting STEAM courses. One recommended method is the utilization of 3D printing together with model design that allows students to obtain real-world experience through hands-on engineering design processes.[3] 3D printing has become a valuable tool for STEAM education as it provides opportunities for students to design and create 3D objects while integrating lessons in science, engineering, art, and math, and cultivating students' creativity, collaboration, problem-solving skills, and scientific and digital literacy. A review on the utility of 3D printing to enrich chemistry education has been published.[4] The 3D-printed objects can help to facilitate conceptual learning, including the teaching of Periodic Table trends and concepts.[5] Among the many practical uses of 3D printing is the increase in accessibility for students with disabilities, particularly those with visual impairments.

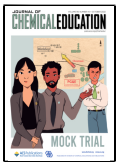
3D Printing

Individual element tiles were produced using established 3D-printing technology,[6−18] including CAD software or a 3D-scan of a physical object. Each student was instructed on how to use the Fused Deposition Modeling (FDM) printers available in the 3D-printing lab to print element tiles. This activity helped to cultivate the students' abilities for problem-solving, cooperation, communication, and critical thinking.

3D-Printing Lab

At Michigan State University (MSU) St. Andrews, 3D-printing workshops are an important component of the various programs available to teachers, students, and families in the Great Lakes Bay area. The 3D-printing lab at MSU St. Andrews has been conducting and organizing 3D-printing workshops and activities, both in-person and online, for students and teachers from across the state of Michigan for over six years.

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3D-Printed Periodic Table

The Periodic Table of Chemical Elements contains symbols of the atomic elements arranged in rows and columns according to their atomic numbers.[19] The United Nations designated 2019 as the International Year of the Periodic Table of the Chemical Elements in recognition of its 150th year anniversary.[20] To bring to light the contributions of many scientists with disabilities in the discoveries of elements on the Periodic Table, the Committee on Chemists with Disabilities (CWD) together with the 3D-printing lab at MSU St. Andrews collaborated on the creation of an accessible three-dimensional Periodic Table.

CWD promotes education and professional opportunities in the chemical sciences and in fields requiring knowledge of chemistry for persons with disabilities.[21] One of the initiatives of CWD was to design and create an accessible 3D-printed Periodic Table to bring awareness of chemists with disabilities to the scientific community. In the fall of 2018, MSU St. Andrews was approached with a proposal to collaborate on this project. Consequently, a major program for K-12 STEAM outreach and learning was initiated.

Seven different 3D element tile models were created after some iterative designs and prototypes. Members of the CWD Periodic Table subcommittee downselected the appropriate accessible tiles from these seven prototypes, using criteria based on each tile's color contrast, Braille size and placement, and illustrations of the template. In addition, color-coding of each of the four sections of the Periodic Table (i.e., alkali and alkaline earth metals; nonmetals, halogens, and noble gases; transition metals; lanthanide and actinide series) was chosen. Once the element tile template was defined, the full project started in the spring of 2019.

■ CREATION OF A 3D-PRINTED PERIODIC TABLE

3D Printers, Materials, and Software

Flashforge Dreamer dual extruder 3D printers were purchased from Amazon and MatterHackers (Lake Forest, CA); polylactic acid (PLA) filaments were purchased from Flashforge USA (City of Industry, CA) and MatterHackers; Onshape (a free web-based software: https://www.onshape.com/en/) and Tinkercad (a free web-based software from Autodesk: https://www.tinkercad.com) were used as CAD software; and FlashPrint from Flashforge and Simplify3D (Cincinnati, OH) were used as slicing software. All activities associated with this project were conducted in the MSU St. Andrews 3D-printing lab.

3D-Printed Element Tile Prototypes

Seven different prototypes were designed and printed for evaluation by CWD. Both the parameters for the final design (Figure S1) and the details of the production of the tiles are described in the Supporting Information.

Outreach

3D printing promotes creative thinking and deep interest in students as they see the results of their efforts in creating a physical object that is initially viewed on a computer screen during the design process using a variety of computer software. The collaboration with CWD was the first time that students in the MSU 3D-printing lab were involved collectively in the completion of a single major project from which several benefits emerged. Qualitatively, there was a noticeable increase in enthusiasm by the students, teachers, mentors, and parents. The project exposed students to some of the interdisciplinary STEAM areas, including math, engineering, chemistry, material science, and English language art.

Throughout this project, students were engaged in science and engineering practices through researching, learning, analyzing, and gathering information about their selected chemical elements. They were able to express creative designs that reflected the elements' characteristics. Student ideas were incorporated into their tile designs using Tinkercad. For a chosen atomic element, their designs included ASL hand signing, Braille, and the atomic number all at the appropriate locations on each tile. Finally, the students exported a model-bundled tile to an STL file, which is a standard file format for 3D printing. With the use of slicing software, an STL model was converted to a G-code file for 3D printing.

In February 2019, staff from the MSU St. Andrews 3D-printing lab invited teachers, parents (i.e., homeschooling teachers), and students to participate in the Periodic Table project. Students included robotic team mentors in the area (most were middle school students), who had previously attended 3D-printing workshops or who had 3D-printing experience. Students with no 3D-printing experience but who expressed an interest were provided special training to be included in the project. Experienced students assisted inexperienced students in learning the necessary 3D-printing techniques. All students were readily engaged and displayed notable interest and enthusiasm throughout the process. The students were uniformly pleased to be involved in this meaningful project that helped them to understand the obstacles faced by people with disabilities.

The Process of Designing Tiles

All students acquired basic skills in generating 3D models using Tinkercad and a broad general knowledge of the Periodic Table. Each student chose between one and three elements, learned about the element(s) from online searching and standard chemistry textbooks, and created an illustration representing the properties and characteristics of each of their chosen element. Figure 1 is an example of how a student associated a particular element with their understanding of this chemical element. For example, one of the students chose the element, gold. She chose to include illustrations of a necklace and a ring on her tile to reflect that gold is a commonly used element in jewelry-making. The 3D-printing base model can be accessed through the MMC library for those students and educators who are interested in replicating these tiles for printing and remixing.

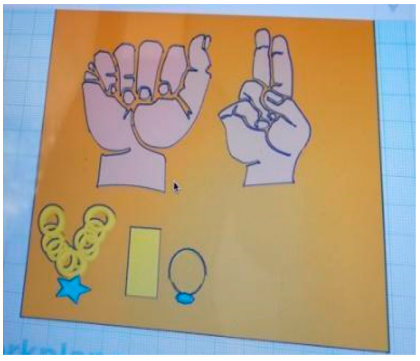


Figure 1. An example of a student's design process of the element tile for gold.

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The 3D printers are enclosed, and the filament PLA is nontoxic; therefore, there were no safety hazards to students.

Creation of the 3D-Printed Periodic Table

The finished tiles are shown in their proper arrangement in Figure 2. The Periodic Table took several months to complete with over 30 students aged 7−17 years having participated. Each student selected at least one element to research and then designed the decorative components representative of the element(s) to individual tiles that they produced. In addition to the atomic number, hand signing and Braille were added to form a complete tactile element tile for 3D printing.[22]



Figure 2. Printed tiles displayed as a complete table in the 3D-printing lab.

■ OUTCOMES AND ACCOMPLISHMENTS

This project combined multiple disciplines across STEAM, integrating math, chemistry, material science, English language art, and engineering concepts such as measurements, calculation, geometry, precision, and artistic design. Each tile was produced following the essential elements of the engineering design process, defining, developing, and optimizing, which fit the NGSS science and engineering practice and is aligned with Common Core State Standards. The project was designed and completed by engaged students with 3D-printing technology in a real-world application. The activities listed in Table 1 are aligned with the educational standards, NGSS and CCSS.

This project brought awareness to each student about disabilities that challenge an individual in accessing information about the Periodic Table and how other forms of communication, such as Braille and sign language, are integral components of how others gain equal access to information just as their sighted and hearing peers. The students became more "interested in thinking" about finding "an easy way to communicate with people with a disability." Some of the students involved in this project also experienced 3D printing for the first time and found it "a fun process" and how it is "like magic to design and create something." One student summarized the experience as helping to "understand 3D printing and being more aware of disability" and the future "use of this technology for my science project." A curated selection of students' comments and sentiments can be found in box S1 in the Supporting Information.

The accessible, tactile 3D-printed Periodic Table was assembled and presented at the ACS Central Regional Meeting in Midland, MI, on June 3−8, 2019. Figure 3 shows the Periodic Table at the American Chemical Society Fall 2019 National Meeting in San Diego, CA, on August 25−29, 2019.[25,26]

It generated great enthusiasm among the attendees. Inquisitive viewers asked questions on how the project came to fruition. They learned how the creation of the 3D-printed Periodic Table mapped onto STEAM education standards.

This project was acknowledged with an American Chemical Society ChemLuminary Award in 2020. The 3D-printed accessible Periodic Table has been featured (including all 3D-designed models as open-source) at the Web site of Maker Making Change (MMC).[28] MMC is an organization based in Canada with a vision of achieving economic and social inclusiveness for all people with disabilities.

■ CONCLUSIONS

A collaborative project in 3D printing was utilized for outreach support for students and teachers in the mid-Michigan area. Students received training in 3D printing and applied the

Table 1. Project Alignment to Education Standards: Next Generation Science Standards (NGSS) and Common Core State Standards (CCSS)

education standards	action
NGSS − MS - engineering design (MS-ETS1-1,2,3,4)[1]	participants
using disciplinary core idea	• researched an element and designed a 3D image to represent the element's connection to people/society making the Periodic Table more accessible to people with low vision and deaf and hard of hearing
• ETS1.A: define and delimit engineering problems	• gained knowledge and understanding of the properties of each atomic element
• ETS1.B: develop possible solutions	• finalized the tile design using the template (Figure S1), ASL hands, Braille, atomic number, and illustration
CCSS − English Language Arts (ELA) Standards[23]	during the process of the creation of the 3D-printed Periodic Table project, participants
• research to build and present knowledge: CCSS.ELA-LITERACY.W6.7−W6.9, W7.7−W7.9, W8.7−W8.9	• conducted research on the elements, gathered information from multiple reliable sources, and translated the information into a 3D image for their element tiles
• integration of knowledge and ideas: CCSS.ELA-LITERACY.CCRA.R7−R9	• integrated, evaluated, and analyzed the gathered information to convert the best representation visually in connecting understanding and expression
• comprehension and collaboration: CCSS.ELA-LITERACY.SL.7.1−7.2	• engaged in collaborative discussions, followed rules (template) for collegial designs, and tracked progress to meet the requirement of the individual responsibility
CCSS − Mathematical Standards[24]	• used rotations, reflections, and translations in adding geometric shapes into the designs
• geometry: CCSS.MATH.CONTENT.8.G.A.1	• recognized and represented the proportional relationship between quantities in graphs
• rations and proportional relationship: CCSS.MATH.COUNTENT.7.RP.A.1,2,3	

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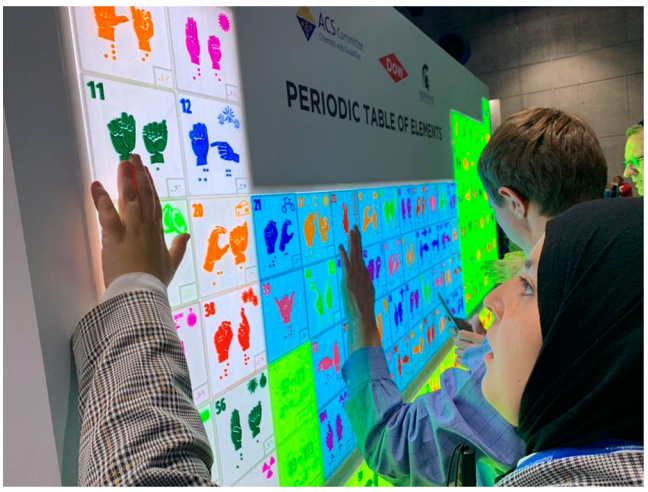


Figure 3. Prof. Mona Minkara at the completed accessible, tactile 3D-printed Periodic Table in the exhibition hall at the National ACS meeting in San Diego, CA.[27]

technique to generate individual element tiles that were assembled into an accessible, tactile 3D-printed Periodic Table. Project participants were exposed to components of STEAM education. All activities conformed to expectations of the Next Generation Science Standards and the Common Core Science Standards. The students demonstrated creativity in the design of their element tiles, and the relationship of the selected element to everyday experiences of the students was incorporated into the designs. Through this project, the students also developed an awareness of persons with disabilities. The students took pride in learning 3D-printing techniques while, at the same time, creating a product of great utility to the community of people with disabilities. Students gained an increased appreciation for learning and community involvement. Some students have subsequently utilized 3D printing in the generation of science fair projects. This collaborative project was a success that demonstrated the importance of education outreach to the local community and produced a specialized Periodic Table to bring awareness of people with vision or hearing impairments.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00186.

3D-Printed element tile prototypes and final design parameters; and outcomes and accomplishments (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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