3D Printing in Education

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Abstract
3D printing is an additive manufacturing process of producing solid 3D artifacts. Creating a 3D printed object involves designing a 3D model of the object, usually using computer-aided design (CAD) software or a scan of an existing object. The 3D model is then converted into a 3D CAD file that is used for producing the object using a 3D printer. Rooted in the maker movement, 3D printing offers real educational benefits by promoting the culture of active learning, innovation, design, and problem solving. It is holistically tied to STEM education connecting multiple STEM subject areas, particularly the areas of engineering and technology. However, just putting a 3D printer in place will not create these learning opportunities. Educators need technical and curriculum support to effectively utilize 3D printing technology for teaching and learning.

Keywords: 3D printing; Educational technology; Problem-based learning; Project-based learning

1 Definition

3D printing technology is believed to change the way things are designed, manufactured, and distributed. 3D printing, or Additive Manufacturing, was developed in the 1980s revolutionizing existing ‘subtractive’ manufacturing process. Instead of subtracting pieces of raw material to create an object, 3D printing builds layers to create the desired products. This small but important difference between adding vs. subtracting has offered a new approach for engineering design and manufacturing that has major implications for the world’s economic, geopolitical, industrial, sociocultural, and environmental landscape (Campbell, Williams, Ivanova, and Garrett 2011). 3D printers can be used to produce low-cost, customized goods that are important to modern technological societies, thus providing a more uniform access to tools and materials, enabling small-scale manufacturing, reducing waste, and supporting innovation.

Nevertheless, the 3D printer revolution only began in 2009, when 3D printing suddenly became accessible for public use. The 3D printing process involves designing a 3D model of the object, usually using computer-aided design (CAD) software or a 3D scanner, and sending the 3D CAD file to a 3D printer that creates the object by forming layers of material. A wide variety of CAD technologies are available for users with various skill sets and needs, ranging from simple applications for young or novice users to more sophisticated

DOI: 10.4324/9781138609877-REE81-1

3D sculpting and modeling software (Canessa, Fonda, and Zennaro 2013). 3D CAD files can be also downloaded from a growing number of online repositories and galleries that provide access to thousands of pre-existing 3D models.

Although new advances in research and development in 3D printing equipment and products continue to impact all industry sectors, the use of 3D printing in education is usually limited to low-cost, customer-level 3D printing equipment (Ford and Minshall 2019). 3D printing technology is being used in schools, public libraries, museums, and higher education institutions to:

- Engage students in 3D printing problem-based projects. Students design 3D printed objects in response to a design challenge or theme. Such projects involve exploring and brainstorming design ideas, creating 3D CAD files, converting them into 3D printing-ready files, and printing the object using a 3D printer.
- Educate about 3D printing technology and design practices. 3D printers are being used to introduce students to 3D printing technology and skills, as well as broader ideas associated with the impact of 3D printing technology on business and industry, economy, society, art, education, and environment (Schelly, Anzalone, Wijnen, and Pearce 2015).
- Create or use 3D printed artifacts as low-cost tools/models to support student learning, e. g., models of bones, limbs, and organs in anatomy courses (Bernhard et al. 2016); molecular and atomic structures in biology and chemistry classes (Augusto et al. 2016); art and cultural heritage resources (Maloy, Trust, Kommers, Malinowski, and LaRoche 2017); 3D maps, geometric models, and more (Educause Learning Initiative 2012).
- Produce assistive technologies for students with special needs, including visual, motor, and cognitive impairments. For instance, 3D printing technology can be used to create various tactile artifacts for visually impaired students, including braille pages (Kostakis, Niaros, and Giotitsas 2015), picture books (Dalton and Musetti 2018), geoscience terrain models (Horowitz and Schultz 2014), etc.

2 Theoretical background

3D printing is rooted in the maker movement – a social trend that emphasizes technology-based learning-through-doing, also known as a do-it-yourself movement. The theoretical framework of the maker movement and 3D printing, in particular, is social constructivism and constructionism. Both constructivism and constructionism represent key learning theories that led to the development of the maker culture that emphasizes active learning. Social constructivism and constructionism view learning as a socially situated activity where students construct their knowledge based on their experiences and prior knowledge through social interactions and collaborations (Driver, Asoko, Leach, Scott, and Mortimer 1994; Eastwell 2002). Personal experiences and interactions with the world play an important role in the process of knowledge construction (Ertmer and Newby 2013). According to social constructivism, learning is not an isolated experience, but rather a shared one. Technology, media, and tools are an essential part of constructionist theory as they play an important role in human development by facilitating the process of 'constructing a public entity, whether it's a sand castle on the beach or a theory of the universe' (Papert and Harel 1991:1).

The educational uses of 3D printing technology can be broadly classified into the active and passive integration of 3D printing into curricula (Ford and Minshall 2019). Active

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integration implies creating learning experiences that facilitate the development of 3D printing skills. Passive integration involves the use of 3D printed objects, such as assistive technology, 3D printed tools and models, for teaching and learning. For instance, 3D printing is increasingly being used in medical and biology education for device development, surgical planning, and patient education as well as development of 3D physical models of cells, human tissue, bones, and organs (Arshad, Helms, Orge, and Sayegh 2018; Augusto et al. 2016; Bernhard et al. 2016). These 3D printed, low-cost tools and models create a more equitable access to resources that are usually only available in leading institutions and research centres.

Active integration of 3D printing technology aims at creating science, technology, engineering, and mathematics (STEM)-rich learning experiences that centre on engineering and design practices. Engaging students in designing 3D printed artifacts encourages creativity, innovation, and higher-order improvisational problem solving through student-centred, problem-based learning. It presents students with real-world problems that require cross-disciplinary skills that engage students in the open-ended design of personally meaningful 3D printed objects. 3D printing has the potential to renovate the classroom by supporting more authentic design-based learning where teachers act as 'design coaches' and students become 'reflective decision makers' (Purzer 2017). Active integration of 3D printing into a curriculum creates opportunities for playful, experiential learning that promotes inquiry, team-work, communication, and critical thinking (Becker et al. 2018; Figg, Jennifer, Shannon, and Pelchat 2018).

3 3D printing in problem- and project-based learning

3D printing problem- and project-based learning (PBL) lends itself to integrative education that cuts across various disciplines by making intentional curriculum connections (Walker 1996). For example, Chien and Chu (2017) developed a 3D-Printing STEAM (Science, Technology, Engineering, Art and Mathematics) Engineering Design Curriculum to engage high school and college students in designing CO_2-cars. Schelly et al. (2015) created 3D printing cross-curriculum learning opportunities by integrating STEM education and Career and Technical education for middle and high school teachers, who participated in a three-day workshop on how to build 3D printers using Open Source technologies. Grant, MacFadden, Antonenko, and Perez (2016) designed a curricular prototype for integrated STEM learning with fossils and paleontology. Rare, delicate fossils that are usually not accessible to the public were 3D scanned and 3D printed to engage middle and high school students in research on the giant shark Megalodon. Makino et al. (2017) used 3D printing to produce different designs of police whistles and examine their sound frequency with high school students. Dalton and Musetti (2018) had students create tactile picture books for visually impaired children using 3D printing technology. 3D modeling and 3D printing learning activities were also implemented to support computing education; high school students generated 3D models through coding activities (Chytas, Diethelm, and Tsilingiris 2018). Finally, Maloy et al. (2017) integrated 3D modeling and 3D printing in middle school history/social studies classrooms, e.g., students created 3D models on water conservation, historical monuments for hidden and missing histories, and Native American dwellings. Initially sceptical about 3D printing in the history/social studies classroom, both teachers and students recognized that 3D printing could be beneficial for changing the traditional

DOI: 10.4324/9781138609877-REE81-1

instructional approaches in history/social studies education and teacher-as-expert/student-as-novice classroom dynamics.

4 Research and open questions

3D printing is an emerging educational technology that is gradually making its way into mainstream use in education. As such, relatively little research has been done on 3D printing in education. A vast majority of the existing literature on 3D printing describes how this technology was introduced to educators and students through various workshops, extracurricular activities, and informal learning (Ford and Minshall 2019). Very little research has been done on 3D printing in formal education (Novak and Wisdom 2018).

Researchers and educators agree that 3D printing can create new learning opportunities that broaden STEM participation and expose students to STEM fields. However, there are many barriers to effective integration of 3D printing technology in education, including lack of systematic teacher preparation for using 3D printing in the classroom (Dalton and Musetti 2018; Novak and Wisdom 2018), lack of careful integration of 3D printing into the curriculum (Chamberlain and Meyers 2015), lack of continued teacher proficient development (Irwin 2015), and inequitable access to 3D printing technology. Many details of how to design, implement, and evaluate meaningful 3D printing learning experiences that lead to desired learning outcomes remain unexplored. Equally important is to develop a better understanding of how to enhance educators' knowledge, skills, and motivation to use 3D printing technology. It can be expected that future research will examine what foundational knowledge and skills students gain from 3D printing learning and how to create 3D printing learning experiences to engage underrepresented populations in STEM.

References and further reading.

Arshad, J., Helms, R. W., Orge, F. H., and Sayegh, R. R. (2018). Educational Value of a 3D Printer in Ophthalmology Training. *Journal of Academic Ophthalmology*, 10(1), e69–e71.

Augusto, I., Monteiro, D., Girard-Dias, W., dos Santos, T. O., Rosa Belmonte, S. L., Pinto de Oliveira, J., … Guimarães, M. C. C. (2016). Virtual Reconstruction and Three-Dimensional Printing of Blood Cells as a Tool in Cell Biology Education. *PLoS ONE*, 11(8), e0161184.

Becker, S. A., Brown, M., Dahlstrom, E., Davis, A., DePaul, K., Diaz, V., and Pomerantz, J. (2018). *NMC Horizon Report: 2018 Higher Education Edition*. Louisville, CO: EDUCAUSE.

Bernhard, J.-C., Isotani, S., Matsugasumi, T., Duddalwar, V., Hung, A. J., Suer, E., … Gill, I. S. (2016). Personalized 3D Printed Model of Kidney and Tumor Anatomy: A Useful Tool for Patient Education. *World Journal of Urology*, 34(3), 337–345.

Campbell, T., Williams, C., Ivanova, O., and Garrett, B. (2011). *Could 3D Printing Change the World? Technologies, Potential, and Implications of Additive Manufacturing*. Strategic Foresight Report. Washington, DC: Atlantic Council.

Canessa, E., Fonda, C., and Zennaro, M. (2013). *Low-cost 3D Printing for Science, Education and Sustainable Development*. Trieste, Italy: The Abdus Salam International Centre for Theoretical Physics (ICTP).

Chamberlain, S., and Meyers, M. (2015). Incorporation of 3D Printing in STEM Curricula. Worcester, MA: Worcester Polytechnic Institute.

Chien, Y.-H., and Chu, P.-Y. (2017). The Different Learning Outcomes of High School and College Students on a 3D-Printing STEAM Engineering Design Curriculum. *International Journal of Science and Mathematics Education*, 16(6), 1047–1064.

Chytas, C., Diethelm, I., and Tsilingiris, A. (2018, 17–20 April 2018). Learning Programming Through Design: An Analysis of Parametric Design Projects in Digital Fabrication Labs and an Online Makerspace. Paper presented at the 2018 IEEE Global Engineering Education Conference (EDUCON).

DOI: 10.4324/9781138609877-REE81-1

Dalton, B., and Musetti, K. (2018). Tactile Picture Book Making and Multimodal Composition: Students Design for Equity in English Language Arts. In E. Ortlieb, E. H. J. Cheek, and P. Semingson (eds.), *Best Practices for Teaching Digital Literacies* (pp. 195–213). London, UK: Emerald Publishing.

Driver, R., Asoko, H., Leach, J., Scott, P., and Mortimer, E. (1994). Constructing Scientific Knowledge in the Classroom. *Educational Researcher*, 23(7), 5–12.

Eastwell, P. (2002). Social Constructivism. *The Science Education Review*, 1(3), 82–86.

Educause Learning Initiative (2012, July). *7 Things You Should Know About 3D Printing*. Retrieved from https://library.educause.edu/resources/2012/7/7-things-you-should-know-about-3d-printing.

Ertmer, P. A., and Newby, T. J. (2013). Behaviorism, Cognitivism, Constructivism: Comparing Critical Features from an Instructional Design Perspective. *Performance Improvement Quarterly*, 26(2), 43–71.

Figg, C., Jennifer, R., Shannon, W., and Pelchat, K. (2018). Using Informal Learning of Makerspaces to Enhance Technological Pedagogical and Content Knowledge (TPACK). Paper presented at the Society for Information Technology and Teacher Education International Conference 2018, Washington, DC. https://www.learntechlib.org/p/182808.

Ford, S., and Minshall, T. (2019). Invited Review Article: Where and How 3D Printing is Used in Teaching and Education. *Additive Manufacturing*, 25, 131–150. doi:10.1016/j.addma.2018.10.028.

Grant, C. A., MacFadden, B. J., Antonenko, P., and Perez, V. J. (2016). 3-D Fossils for K–12 Education: A Case Example Using the Giant Extinct Shark *Carcharocles Megalodon* . *The Paleontological Society Papers*, 22, 197–209. doi:10.1017/scs.2017.15.

Horowitz, S. S., and Schultz, P. H. (2014). Printing Space: Using 3D Printing of Digital Terrain Models in Geosciences Education and Research. *Journal of Geoscience Education*, 62(1), 138–145.

Irwin, J. L. (2015). Evaluation of Reprap 3D Printer Workshops in K-12 STEM. *age*, 26(1).

Kostakis, V., Niaros, V., and Giotitsas, C. (2015). Open Source 3D Printing as a Means of Learning: An Educational Experiment in Two High Schools in Greece. *Telematics and Informatics*, 32, 118–128.

Makino, M., Suzuki, K., Takamatsu, K., Shiratori, A., Saito, A., Sakai, K., and Furukawa, H. (2017). 3D Printing of Police Whistles for STEM Education. *Microsystem Technologies*, 1–4 [online first].

Maloy, R., Trust, T., Kommers, S., Malinowski, A., and LaRoche, I. (2017). 3D Modeling and Printing in History/Social Studies Classrooms: Initial Lessons and Insights. *Contemporary Issues in Technology and Teacher Education*, 17(*2*).

Novak, E., and Wisdom, S. (2018). Effects of 3D Printing Project-Based Learning on Preservice Elementary Teachers' Science Attitudes, Science Content Knowledge, and Anxiety About Teaching Science. *Journal of Technology and Science Education*, 27(5), 412–432.

Papert, S., and Harel, I. (1991). *Constructionism*. Norwood, NJ: Ablex Publishing Corporation.

Purzer, Ş. (2017). Engineering Approaches to Problem Solving and Design in Secondary School Science: Teachers as Design Coaches. A Paper Commissioned by the National Academies of Sciences, Engineering, and Medicine Science Investigations and Engineering Design for Grades 6–12. Retrieved from https://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_189503.pdf.

Schelly, C., Anzalone, G., Wijnen, B., and Pearce, J. M. (2015). Open-Source 3-D Printing Technologies for Education: Bringing Additive Manufacturing to the Classroom. *Journal of Visual Languages and Computing*, 28, 226–237. doi:10.1016/j.jvlc.2015.01.004.

Walker, D. (1996). *Integrative Education: Empowering Students to Learn*. Eugene, OR: Oregon Study School Council.

DOI: 10.4324/9781138609877-REE81-1