Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45482

# Implementation and Evaluation of an Engineering Design Process Course for High School Preservice Teachers based on 3D Printer Component Analysis

**Prof. Weihang Zhu, University of Houston - COE**

Weihang Zhu is a Professor of Mechanical Engineering Technology, University of Houston, USA since 2018. He was a Professor of Industrial Engineering at Lamar University from 2005 to 2018. He received his Ph.D. in Industrial Engineering from North Carolina State University (2003), USA and his M.S. and B.S. in Mechanical and Energy Engineering.

**Prof. Mariam Manuel, University of Houston - COE**

Dr. Mariam Manuel is a Clinical Assistant Professor specializing in engineering design education for teachHOUSTON, a secondary STEM teacher preparation program in the Department of Mathematics at University of Houston. In addition to preservice STEM teacher education courses, Dr. Manuel teaches Physics for Middle School Teachers and has authored/taught graduate level coursework in Engineering Design Education, for the UH STEM Master's program. Dr. Manuel serves on multiple grants and actively publishes and presents at national research conferences. Her research interests include STEM teacher preparation, engineering design education, and culturally responsive pedagogy.

**Dr. Paige Evans, University of Houston**

Dr. Paige K. Evans is a Clinical Professor in the department of Mathematics at the University of Houston (UH) and the Associate Director of the teachHOUSTON program where she works with preservice secondary STEM teachers to teach innovative lessons as wel

**Peter Weber, University of Houston, College of Technology (MERGED MEMBERSHIP WITH COE)**

# Implementation and Evaluation of an Engineering Design Process Course for High School Preservice Teachers based on 3D Printer Component Analysis


## Abstract

3D printing (3DP) has been becoming pervasive in the K-16 education system. However, in many schools, new 3D printers arrive, work for a certain period, and before long break down due to lack of maintenance and support. It is therefore imperative for teachers to develop a deeper understanding of 3D printing in order to fully release its potential in engineering design. In this project, the course of engineering design for preservice teachers (PST, current undergraduate students) is developed and implemented with mechanical components from dissected 3D printers. The approach is to dissect a 3D printer's hardware, explain each component's function, introduce each component's manufacturing methods, describe possible defects, and elucidate what works and what does not. This allows the PSTs to develop a better understanding of 3D printing process, have a better idea on how to fix a 3D printer when it breaks down, and design components that are compatible with 3D printing. The evaluation results show that the course was well received by the PSTs who have improved their knowledge in 3D printing. In the future course offering, both knowledge gain and efficacy will be evaluated to help us better understand the impact of the course.



**Keywords**: Preservice teacher education, engineering design process, 3D printing


## 1. Introduction

Engineering Design Process (EDP) is an integral component of what engineers do and how they approach societal problems. 3D Printing (3DP) has been becoming more and more popular throughout the education system including high schools. The recent years have seen more investment and availability of 3DP in high schools, especially Career and Technical Education (CTE) programs. However, mere availability of 3DP is not enough for teachers to fully utilize its potential in their classrooms.

This project develops an EDP course tightly integrated with 3DP for preservice teachers (PST) who are going to enter the workforce in high schools. The approach is to dissect a 3D printer's hardware, explain each component's function, introduce each component's manufacturing methods, describe possible defects, and elucidate what works and what does not. This allows the PSTs to develop a better understanding of 3D printing process, have a better idea on how to fix a 3D printer when it breaks down, and design components that are compatible with 3D printing. The 3D printing is also tightly integrated with the engineering design methodology as a prototype fabrication tool.

The rest of the paper is organized as follows. Section 2 is the literature review. Section 3 elaborates the course structure, example course contents, and pedagogy. Section 4 describes the implementation and evaluation results. Section 5 is the conclusion and future work.

## 2. Literature Review

3DP is becoming rapidly available and accessible to the public due to the cheaper desktop 3DP and availability of CAD applications designed for users with various 3D modeling skills. 3DP can provide critical and timely prototype needs in EDP, offering "the greatest potential for applying science knowledge in the classroom and engaging in engineering practices" ( (National Research Council, 2012), pp. 201–202). Research shows that the 3DP project intervention significantly decreased participants' science teaching anxiety and improved their science teaching efficacy, science interest, and perceived competence in K-3 technological and engineering design science standards (Novak & Wisdom, 2018).

3DP has been used in various disciplines to visualize the science concepts (Papavlasopoulou, Giannakos, & Jaccheri, 2017), most notably in the maker movement. However, out of the selected 43 peer-reviewed articles on the maker movement, only two studies investigated educational benefits of 3DP (Leduc-Mills & Eisenberg, 2011; Mellis & Buechley, 2012). Smith et al. (2015) conducted observational studies in the Danish school system and reported that teachers had "a critical lack of understanding and knowledge relating to framing the design challenge, the use of technology and the scaffolding of the creative and reflective design process" ( (Smith, Iversen, & Hjorth, 2015), p. 22). Kostakis et al. (2015) conducted a pilot qualitative study that examined educational benefits of 3DP and design with 33 high school students in Greece (Kostakis, Niaros, & Giotitsas, 2015). They stressed the importance of preparing teachers for such projects and the need of possessing technological skills and in-depth understanding of 3DP and EDP.

Several studies in East Asia introduced 3DP to PSTs and developed a TPACK-based curriculum (Sullivan & McCartney, 2017; Yi, Park, & Lee, 2016; Song, 2018). TPACK means Technological Pedagogical and Content Knowledge (Figure 1). The TPACK framework transcends the three individual components of *content*, *pedagogy*, and *technology* (Mishra & Koehler, 2006). Through different combinations of T (technological), P (pedagogical), and C (content), TPACK has **seven components**: TK, PK, CK, TPK, TCK, PCK, and TPCK. The TPACK framework advocates '*learning by design*' and suggests when teachers are aware of how to use 3DP and how to effectively integrate such technology into the curriculum, students can actively learn through their use. Chai and Koh (2017) proposed the Scaffolded TPACK Lesson Design Model (STLDM) to change teachers' TPACK and design beliefs (Chai & Koh, 2017).

Empirical research on 3DP integration in teacher preparation programs is scarce (Maloy, Trust, Kommers, Malinowski, & LoRoche, 2017; Verner & Merksamer, 2015). Its potential has been explored in various educational contexts, including history/social studies classrooms (Maloy, Trust, Kommers, Malinowski, & LoRoche, 2017), special education (Buehler, Comrie, Hofmann, McDonald, & Hurst, 2016), anatomy education (Vaccarezza & Papa, 2015; Smithsonian X 3D - Education), high school technology education (Chien, 2017), and biotechnology and the chemical sciences (Gross, Erkal, Lockwood, Chen, & Spence, 2014). Novak and Wisdom engaged 42 preservice elementary teachers in a 3DP Science Project in the elementary classroom (Novak & Wisdom, 2018).

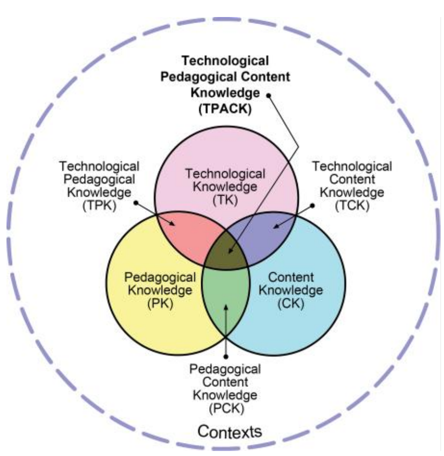


Figure 1. TPACK Model

## 3. Course Design and Pedagogy

Engineering design process (EDP) has become an essential component for preservice teachers (PSTs), especially in high school STEM education. The integration of 3D printing (3DP) into EDP has brought transformative change, enhancing the iterative process through virtual and physical prototyping. This innovative PST course on EDP purposefully integrates 3DP to offer an in-depth exploration of engineering concepts. For the purposes of this paper, the content focus is centered on 3D printing; however, the course also includes a unit on data literacy in STEM.

Our approach leverages the TPACK framework to balance technological, pedagogical, and content knowledge. **Table 1** outlines the four course modules in this course and how they are mapped to TPACK model.

**Table 1** CUIN 4397 TPACK-based Course Module Development Summary

| # | Hrs | Contents | Key Information | TPACK |
|---|---|---|---|---|
| **I** | 6 | Engineering design process | Reverse Engineering of a product; customer needs matrix; sketch; functional models; activity diagrams | CK;PCK, TK |
| **II** | 9 | Part 1: 3DP dissection and reverse engineering | Disassemble a 3D printer and identify components, materials, and their manufacturing methods | TCK |
| | 3 | Part 2: 3DP operation | 3D printing process, G code, STL, slicer | TK |
| | 6 | Part 2: 3D modeling | SolidWorks Apps for Kids; open source models | TK,CK |
| | 3 | Part 2: 3DP troubleshooting | Print quality, calibration, post-processing, maintenance | TK |
| **III** | 6 | Invention design challenge | Each group prototype an innovation using 3D printed parts and standard components that can be purchased | PK,PCK TPK |
| **IV** | 12 | Curricular development | Preservice teachers' own lesson plans | TPCK |

The course is structured into four modules, as summarized below:

**Module Overview:**

I. **Introduction to the Engineering Design Process**:
- Activities included reverse engineering of consumer products, functional modeling, and customer needs analysis.
- PSTs worked in teams to conduct interviews and surveys, generating customer needs matrices for selected consumer products.
- Lessons emphasized critical thinking, real-world problem-solving, and iterative design processes.

II. **3D Printing Fundamentals**:

- **Part 1:** PSTs disassembled 3D printers, exploring components such as heated beds, nozzles, and belts. Discussions included component functions, manufacturing methods, and troubleshooting.
- We identified the major machine elements of a FDM 3DP (**Table 2**) and developed course materials for these elements.

**Table 2** Machine Elements from the 3D Printer Hardware

| No | Components | Materials and/or Machine Elements | Manufacturing Processes |
|---|---|---|---|
| **1** | Plastic filament | Polymer materials | Plastics extrusion |
| **2** | Aluminum frame | Aluminum bar | Bulk deformation |
| **3** | Heated bed | Aluminum sheet metal | Sheet metal working |
| **4** | Belt and pulley | Belt and pulley standard | Rubber, casting / machining |
| **5** | Spring | Spring standard | Winding |
| **6** | Bearing | Bearing standard | Heat treatment, sheet metal |
| **7** | Leadscrew rod | Screw standard | Rolling |
| **8** | Bolt and nut | Bolt and nut standard | Cutting, forging, heat treatment |
| **9** | Nozzle | Rotational part | Machining |

- **Part 2:** Students gained hands-on experience assembling, operating, and troubleshooting 3D printers. They utilized step-by-step instructions they created for smooth operation.
- **Part 3:** CAD modeling was introduced with TinkerCAD and Fusion 360, focusing on designing 3D components tied to lesson objectives and classroom applications. Demonstrations and guided questions encouraged active learning.

III. **Design Challenge**:

As part of the design challenge, students developed and printed various prototypes to explore engineering concepts. One example was the ‘Sink or Swim’ project, where students designed and 3D printed small model boats to analyze buoyancy principles. They tested different hull designs to optimize weight distribution and maximize buoyancy, refining their designs through multiple iterations. Beyond buoyancy, students explored geometric volume calculations by designing and printing composite figures—such as cylinders, cones, and hexagonal prisms. Using these models, they calculated total volume and investigated real-world applications, such as optimizing container shapes for efficient packaging.

Another example involved rotational motion, where students engineered custom-designed toy car wheels to optimize speed and acceleration on a ramp. They examined how mass distribution, radius, and material properties influenced rotational inertia, refining their 3D-printed prototypes based on test results. This hands-on activity demonstrated how engineering principles apply in automotive design and mechanical systems. Additionally, teams prototyped innovative solutions using 3D-printed parts and standard components. For example, some students designed water filtration systems or other culturally relevant prototypes, incorporating community-driven problem-solving into their engineering projects.

The course materials were not directly shared with the 15 preservice teachers over the summer; rather, they were exposed to 3DP and manufacturing content that informed the course curriculum and enriched their learning experience.

IV. **Lesson Plan Development and Reflection**:

- A core focus of the course is equipping PSTs to develop and refine lesson plans that integrate the engineering design process into math and science content.
- PSTs crafted hands-on, inquiry-based lesson plans aligned with Texas Essential Knowledge and Skills (TEKS) standards, focusing on fostering critical thinking and problem-solving in their future classrooms.
- Students engaged in iterative feedback cycles, including peer and instructor evaluations, to refine their lessons.
- Reflections on their teaching strategies and feedback sessions provided opportunities for PSTs to consider how to adapt engineering design concepts to meet diverse learners' needs effectively.

While the summer research program provided 8 preservice teachers and 15 in-service teachers with exposure to 3DP and manufacturing content, this experience served only as a foundation. The comprehensive course extends beyond these foundational elements, integrating advanced engineering design principles, CAD modeling, curriculum development, and culturally responsive pedagogy (CRP) to prepare PSTs for K-12 classrooms.

**Culturally Responsive Pedagogy (CRP) in Lesson Design**

A critical feature of the course was the emphasis on culturally responsive pedagogy (CRP), ensuring that design challenges were rooted in contexts relevant to students' lived experiences. For instance, in a unit on geometric dilations and scale, students created scaled prototypes of technology-based products that addressed community needs. They explored how different populations interact with technology and brainstormed product designs that could improve accessibility, particularly for communities with limited access to emerging tech.

Additionally, in the rotational motion unit, students analyzed how tire design varies across different terrains and cultures. They discussed how communities in arid, icy, or mountainous regions adapt vehicle design to their environments, considering cultural and economic factors in engineering. These projects encouraged students to think critically about the intersections of engineering, accessibility, and global challenges, ensuring that their learning extended beyond theoretical concepts.

Through an iterative feedback cycle, students were encouraged to incorporate culturally relevant examples into their lesson plans. Some designed lessons that addressed real-world challenges, such as water purification systems used in different global communities, or explored how various cultures have developed mathematical and engineering techniques to solve everyday problems. By integrating CRP into their teaching strategies, PSTs developed a deeper understanding of how engineering design can be contextualized to make STEM learning more inclusive and meaningful. Despite challenges such as extended printing times, PSTs demonstrated strong engagement and enthusiasm throughout the course. By integrating theory with practice, the course successfully prepared future STEM educators to incorporate EDP and 3DP into K-12 classrooms.

Through an iterative feedback cycle, students were encouraged to incorporate culturally relevant examples into their lesson plans. Some designed lessons that addressed real-world challenges, such as water purification systems used in different global communities, or explored how various cultures have developed mathematical and engineering techniques to solve everyday problems. By integrating CRP into their teaching strategies, PSTs developed a deeper understanding of how engineering design can be contextualized to make STEM learning more inclusive and meaningful.

## 4. Teaching and Evaluation Results

The 3D printer and manufacturing processes course materials were first developed and disseminated to 8 PSTs in the Noyce Summer Research program and 15 in-service teachers in the Research Experience for Teachers program in summer 2023. After receiving feedback, the course materials were revised and used in the formal course in the spring 2024 semester. Only six PSTs enrolled in this offering. The evaluation includes three parts:

- Instructor teaching log
- Pre- and post- course quizzes on knowledge gain in 3D printing
- Course evaluation and student feedback

According to the instructor teaching log, most of the students were unfamiliar with the engineering design process. Two activities, parachute and bridge-building effectively introduced students to the steps of the engineering process. The hands-on nature of these projects captured students' interest. They were highly engaged during both the bridge and parachute competitions. Next, the students went through a reverse engineering exercise: disassemble a hair dryer using tools. Some are using a screwdriver for the first time. The reverse engineering project allowed students to break down consumer mechanical products, leading to enthusiastic presentations. The students then selected low-cost mechanical products for further exploration.

Most of the students have no prior experience with 3D printing. With assistance from the teaching assistant, students were able to assemble 3D printers. They learned parts through diagrams and labels. Students were asked to write step-by-step instructions for using the 3D printer which helped themselves identify gaps in their understanding. Before printing, students researched and designed presentations on various types of filaments, discussing their applications in different contexts. When the time for 3D part modeling came, students began with TinkerCAD, a user-friendly design software widely used in K-12 educational settings. They successfully created and printed their first models, integrating their designs with their reverse engineering projects. After mastering TinkerCAD, students advanced to Autodesk Fusion 360, a more sophisticated Computer Aided Design software. While more complex, students found value in using both tools, though extra instructional time was needed for Autodesk Fusion 360. The 3D printing process took longer than anticipated due to the need for students to use printers in the teachHOUSTON office area. However, despite minor setbacks, all students successfully completed three prints each. This extended printing time did cut into time originally set aside for other content.

After the 3D printing modules, the students started to work on design challenge and curricular development as follows:

- **First Project**: Students undertook a reverse engineering task for a previously developed lesson plan from another field-based course. This required them to reimagine the lesson using the engineering design process while incorporating potential 3D printing elements.
- **Final Project**: For the final project, students created new lesson plans aligned with Texas Education Standards (TEKS) and integrated the engineering design process. These lessons were tailored to their future teaching content areas, such as chemistry or biology, with optional 3D printing elements included.

A common concern among the students was the practicality of using 3D printers in future classrooms due to time constraints, cost, and lack of equipment availability in schools. The availability issue can be addressed duo to the low cost of 3D printers. The time constraints can be addressed partially with high-speed 3D printers that become more prevalent recently. Several 3D printer vendors have invented new printers at six to ten times faster than the previous generation. Future students will be able to finish printing in the classroom period. Despite the challenges, students embraced the engineering design process as a robust framework for inquiry-based teaching and felt confident in their ability to apply it in future educational settings.

The evaluation of the course included instructor observations, pre- and post-course quizzes, and qualitative feedback from students. These methods provided a comprehensive assessment of the course’s impact on student learning and engagement.

**Pre- and Post-Course Survey Analysis:**

The pre- and post-course surveys demonstrated a clear improvement in students' understanding of 3D printing concepts. The table below illustrates the question-by-question comparison of average pre- and post-course correct percentages:

| # | Question | Average Pre-Course Correct Percentage | Average Post-Course Correct Percentage |
|---|---|---|---|
| 1 | A common 3D printer uses plastic filament as the raw material. During printing, it melts the filament and deposits it onto a print bed through a nozzle. What term is used to describe this type of 3D printer? | 80.0% | 100.0% |
| 2 | What is the most common plastic filament used in consumer 3D printers? | 80.0% | 100.0% |
| 3 | Which of the following machine element can be used to transfer rotary motion into linear motion? | 20.0% | 100.0% |
| 4 | In ANSI standard, for 1/4-20H bolt, 20 means | 20.0% | 75.0% |

| | | | |
|---|---|---|---|
| 5 | The most common material for the nozzle on a consumer 3D printer is | 60.0% | 100.0% |
| 6 | How does the nozzle size affect the extrusion process in 3D printing? | 100.0% | 100.0% |
| 7 | The three Boolean operations in Constructive Solid Geometry are (three correct answers): | 0.0% | 25.0% |
| 8 | The most commonly used file format for 3D printing models is | 100.0% | 100.0% |
| 9 | The software that converts a 3D model into layers is called: | 100.0% | 100.0% |
| 10 | What does it mean when we say the infill parameter for a print is 20%? | 80.0% | 75.0% |

On average, the overall pre-course correct percentage was **64.0%**, which increased to **87.5%** post-course. This substantial improvement underscores the effectiveness of the course in enhancing students' understanding of 3D printing concepts.

The most significant improvements were observed in questions 3, 4, and 5. For question 3, focused on machine elements and their functions, the correct percentage increased from **20.0%** to **100.0%**. Question 4, which addressed standards for bolts, saw an improvement from **20.0%** to **75.0%**. Additionally, question 5, which focused on the materials used for 3D printer nozzles, demonstrated growth from **60.0%** to **100.0%**. These gains highlight the effectiveness of targeted instructional strategies in addressing challenging content areas.

The improvement highlights the effectiveness of the course's hands-on and integrative approach, which allowed students to deepen their conceptual knowledge and practical skills. The surveys also indicated specific areas for further clarification, providing valuable guidance for refining future course iterations.

At the end of the course, students were satisfied with the course as 100% of the students replied 'Strongly Agree' or 'Agree' to all course evaluation questions. In addition, two student comments are quoted as below.

- "I really enjoyed this course, i wish it was a little bit more organized, however since this was the first time the course was offered there will be kinks here and there. Dr. (Instructor) is one of the most caring professors I have ever had (and this is including the other courses I have taken with her) she genuinely wants students to succeed and here she wants students to be able to take what they learned and apply it in their future classrooms, something I will be doing as soon as I graduate!"
- "Dr. (Instructor) is one of the most compassionate and welcoming professors I have had. She demonstrates great care for her students and works to make all students feel comfortable and appreciated in her classroom. I recommend her to all my friends and I am grateful to have had her as my professor."
- "I think this was an excellent class taught by an excellent professor! I think that the information is very valuable, and it is well taught."

**Key Takeaways:**

The course demonstrated several key strengths. Students experienced significant knowledge gains in 3D printing and the engineering design process, as evidenced by their improved quiz scores and the confidence they expressed in applying these concepts. Engaging hands-on activities, such as prototyping and reverse engineering, fostered collaboration and critical thinking. Moreover, high levels of satisfaction among students highlighted the course's success in creating a meaningful and impactful learning environment.

However, the evaluation also revealed areas for improvement. Organizational challenges, such as the sequencing of activities and time management during the semester, were noted by both the instructor and students. Additionally, the extended time required for 3D printing limited opportunities to cover other content areas as planned. These insights provide valuable guidance for refining the course to enhance its effectiveness in future iterations. Overall, the course evaluation underscores its success in equipping students with valuable skills and knowledge while identifying areas for growth to further enhance its impact.

## 5. Conclusion

This project developed an Engineering Design and Technology course integrating 3D printing components for preservice teachers. During the summer research program, 8 preservice teachers and 15 in-service teachers were exposed to 3DP and manufacturing content that served as a foundation for the course. However, the 15-week semester-long course offered a much broader and more comprehensive curriculum, encompassing advanced engineering design, CAD modeling, and culturally responsive teaching practices. This course was positively received by the six students who enrolled during its initial offering. Over the next two years, we aim to refine the curriculum further, expand its reach to more preservice teachers, and evaluate its impact to improve STEM education outcomes.


## Acknowledgment

All authors and faculty participating in this project are sponsored by the National Science Foundation grant #2141674. Their support is greatly appreciated. W. Zhu acknowledges the funding from the University of Houston Advanced Manufacturing Institute, University of Houston Division of Research, the support from National Science Foundation grant #1855147, #1950036, #2141674, US Department of Education grant P116S230007, and US Department of Agriculture grant #13111855, #13424031, and National Academy of Science grant #200011064 to the University of Houston.


## References


Buehler, E., Comrie, N., Hofmann, M., McDonald, S., & Hurst, A. (2016). Investigating the implications of 3D printing in special education. *ACM Transactions on Accessible Computing, 8*(3), 1-28.

Chai, C., & Koh, J. (2017). Changing teachers' TPACK and design beliefs through the Scaffolded TPACK Lesson Design Model (STLDM). *Learning: Research and Practice*. doi:10.1080/23735082.2017.1360506

Chien, Y.-H. (2017). Developing a pre-engineering curriculum for 3D printing skills for high school technology education. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(7), 2941-2958.

Groover, M. (2011). *Introduction to Manufacturing Processes* (1st ed.). Wiley.

Groover, M. (2015). *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems* (6th ed.). Wiley.

Gross, B., Erkal, J., Lockwood, S., Chen, C., & Spence, D. (2014). Evaluation of 3D printing and its potential impact on biotechnology and the chemical sciences. *Analytical Chemistry, 86*(7), 3240–3253.

Kostakis, V., Niaros, V., & Giotitsas, C. (2015). Open source 3D printingas a means of learning: an educational experiment in two high schools in Greece. *Telematics and Informatics, 32*(1), 118-128.

Leduc-Mills, B., & Eisenberg, M. (2011). The UCube: a child-friendly device for introductory three-dimensional design. *Proceedings of the 10th international conference on interaction design and children.* New York.

Maloy, R., Trust, T., Kommers, S., Malinowski, A., & LoRoche, I. (2017). 3D modeling and printing in history/social studies classrooms: initial lessons and insights. *Contemporary Issues in Technology and Teacher Education, 17*(2).

Mellis, D., & Buechley, L. (2012). Case studies in the personal fabrication of electronic products. *Proceedings of the designing interactive systems conference.* New York.

Mishra, P., & Koehler, M. (2006). Technological pedagogical content knowledge: A framework for teacher. *Teachers College Record, 108*(6), 1017-1054.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (Board on science education, division of behavioral and social sciences and education ed. ed.). Washington, DC: The National Academies Press.

Novak, E., & 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 Science Education and Technology, 27*, 412-432.

Papavlasopoulou, S., Giannakos, M., & Jaccheri, L. (2017). Empirical studies on the maker movement, a promising approach to learning: a literature review. *Entertainment Computing, 18*, 57-78.

Smith, R., Iversen, O., & Hjorth, M. (2015). Design thinking for digital fabrication in education. *International Journal of Child-Computer Interaction, 5*, 20-28.

*Smithsonian X 3D - Education.* (n.d.). Retrieved 2020, from Smithsonian: https://3d.si.edu/article/educators

Song, M. (2018). Learning to teach 3D printing in schools: how do teachers in Korea prepare to integrate 3D printing technology into classrooms? *Educational Media International*. doi:10.1080/09523987.2018.1512448

Sullivan, P., & McCartney, H. (2017). Integrating 3D printing into an early childhood teacher preparation course: Reflections on practice. *Journal of Early Childhood Teacher Education, 38*(1), 39-51.

Vaccarezza, M., & Papa, V. (2015). 3D printing: a valuable resource in human anatomy education. *Anatomical Science International, 90*(1), 64-65.

Verner, I., & Merksamer, A. (2015). Digital Design and 3D Printing in Technology Teacher Education. *Procedia CIRP, 36*(Supplement C), 182-186.

Yi, S., Park, H., & Lee, Y. (2016). Development of the TPACK-Based Curriculum with 3D Printer for Pre-service Teachers. *The E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education.* Washington, DC. Retrieved from https://www.learntechlib.org/p/173978