

Professional Development Informing Teachers' Intention to Teach Additive Manufacturing in K-12 Classrooms

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ABSTRACT

Additive Manufacturing (AM), also known as 3D printing, is a process of creating physical objects from digital models by adding materials layer by layer. The adoption of AM is part of a larger technological shift characterized by digital manufacturing technologies. With technological change comes the need for new skills in the STEM workforce. The professional development (PD) was aimed at training and educating teachers who can teach students and help to meet these new STEM workforce demands. The research question for this study was “To what extent does the professional development on additive manufacturing influence teachers' intention to teach AM in the K-12 classrooms?” This research was guided by the Technology Acceptance Model (TAM) framework and employed a qualitative approach to generate a comprehensive understanding of the phenomenon under study. Ten New Mexico secondary school teachers participated in the AM professional development. The data collection tools included pre- and post-PD surveys completed by the teachers. Results show 80% of teachers confirmed their intention to teach AM in the subsequent school year. Key findings that influenced teachers in adopting AM for teaching and learning included 1) perceived relevance and value, and 2) sustained support through professional preparation and resource availability. Significant gains in content knowledge and preparation of instructional materials during the PD were critical in impacting teachers' intention to integrate AM into teaching and learning.

KEYWORDS: Additive manufacturing (AM), K-12 teachers, professional development (PD), STEM workforce development, Technology Acceptance Model (TAM)

1 INTRODUCTION

Additive manufacturing (AM), commonly known as 3D printing, has emerged as one of the most transformative technologies in education, offering opportunities to revolutionize teaching and learning across K-12 classrooms. The increasing popularity and promising potential of AM technologies and their expected influence on product design and industrial manufacturing require the development of innovative educational programs and teaching strategies (Stern et al., 2019). In K–12, college classrooms, and trade schools around the world, 3D printing is a valued tool for learning and skills development in science, technology, engineering, and math (STEM) fields (Novak, 2022; Ramdhani and Mulyanti, 2020). As digital fabrication technologies become increas-

ingly accessible and affordable, educators are recognizing their potential to bridge the gap between theoretical concepts and hands-on applications, creating immersive learning environments that prepare students for the demands of Industry 4.0 and the modern workforce (Chen and Cheng, 2021; Chun, 2021).

The integration of AM in K-12 education serves multiple pedagogical purposes, from enhancing student engagement to developing critical 21st-century skills. 3D printing technology helps engineers to construct buildings, allows manufacturers to produce products quickly and efficiently, and even enables scientists to print organs and tissue for transplants in fields of medicine (Ford and Minshall, 2019). With recent advances in information and communication technologies (ICT) and greater access to ICT in the 21st century, technology has been increasingly employed to improve student engagement in learning and to promote students' motivation specifically for STEM (Lin et al., 2023). Research indicates that bringing ideas and designs to life can be a key motivator for children in school (Wisdom and Novak, 2019). As students transition from passive consumers of information to active creators and makers, developing spatial reasoning, design thinking (Chatterjee and Mahajan, 2025), and problem-solving capabilities become critical for their future success (Ali and Khine, 2020; Khurma et al., 2023; Ng et al., 2022).

Despite its educational potential, the implementation of AM in K-12 settings faces significant challenges that educators and administrators must navigate carefully. One challenge is the cost of 3D printers and materials, which can be prohibitive for some educational institutions, particularly those with limited resources (Evans and McComb, 2023). Additionally, there may be technical barriers, such as the need for training educators on how to use 3D printing technology effectively and integrate it into the curriculum (Waqar et al., 2024). AM integration could enhance skill development, hands-on experience, and participant engagement but may encounter challenges associated with resource availability, time constraints, and school integration (Tejera et al., 2025). Furthermore, adoption rates are low, and the technology's visible effects on teaching and learning are minor (Branko et al., 2023), suggesting that successful implementation requires more than just acquiring the technology, but it demands comprehensive professional development, curriculum redesign, and sustained institutional support (Asempapa and Love, 2021; Thyssen and Meier, 2023).

The path forward for AM in K-12 education lies in addressing these implementation barriers while capitalizing on the technology's transformative potential. Collaboration between the university and K-12 schools can open possibilities for systematic integration (Go and Hart, 2016; Pantazis and Priavolou, 2017). A standards-aligned, STEM-based curriculum integrating AM facilitates hands-on STEM learning (Khurma et al., 2023). Scaffolding and modeling helps effectively integrate AM technology with pedagogical practices needed for implementation (Chatterjee and Warr, 2024). As educational institutions continue to recognize that training and education are key drivers for the broader adoption of additive manufacturing (Simpson et al., 2017), the focus must shift toward developing comprehensive frameworks that encompass teacher preparation, curriculum development, resource allocation, and ongoing support systems to ensure that additive manufacturing realizes its promise as a catalyst for transformative K-12 education and STEM workforce development (Cheng et al., 2024).

Theoretical Framework

This study is informed by the principles of usefulness and usability, which underpin the theoret-

ical foundation of the Technology Acceptance Model (TAM). TAM was initially conceptualized as a theoretical framework designed to evaluate the extent to which users accept and adopt particular information systems or technologies (Brock and Khan, 2017; Zhong and Xiao, 2015). TAM is based on the Theory of Reasoned Action (TRA), developed by Fishbein and Ajzen (1975) to explain behavior through personal beliefs, attitudes, and the influence of others (Szajna, 1996). TRA suggests that people choose a behavior if they expect it to lead to positive results (Compeau and Higgins, 1995). TAM proposes that two primary factors determine a user's acceptance of technology (Davis, 1989, 1993): 1) perceived usefulness, the degree to which a person believes that using a particular system would enhance their job performance and 2) perceived ease of use, the degree to which a person believes that using the technology would be free of efforts that includes factors like user-friendliness and technical complexity. According to TAM, these two perceptions directly influence a user's attitude toward the technology, which in turn affects their behavioral intention to use it, and ultimately their actual usage behavior. TAM explains predictors of human behavior towards potential acceptance or rejection of new technology (Granić and Marangunić, 2019). The model also suggests that perceived ease of use can influence perceived usefulness, when technology is easier to use, people are more likely to find it useful.

TAM has been widely applied in educational technology research to understand factors that promote or hinder teachers' adoption of new technologies in their classrooms. The fundamental constructs of the TAM, perceived ease of use and perceived usefulness, have been established as preceding determinants that influence the adoption of technology-enhanced learning approaches (Granić and Marangunić, 2019). The TAM framework has been extended to include external variables including self-efficacy, subjective norms, and facilitating conditions (Scherer et al., 2019). In educational contexts, the TAM variables explained 39.2% of the variance in teachers' intentions to use technology (Scherer et al., 2019), making it particularly relevant for understanding teachers' adoption of AM technologies. The model's application to PD allows for examination of how training experiences shape teachers' responses to emerging technologies, influencing their classroom implementation behavior.

This investigation examines how the AM PD influences teachers' acceptance and their implementation of AM technologies. We integrated use and ease of usefulness throughout both the program structure and our approach. Throughout the program structure, participants engaged in hands-on projects that directly connected AM technologies to their teaching objectives and practices, demonstrating pedagogical value and student learning outcomes. The program emphasized real-world problem-solving scenarios where teachers could envision immediate classroom applications, from creating geometric models for mathematics instruction to producing characters for their English Language and Arts lessons. Using case studies, the PD provided examples to teachers to develop their own AM-integrated lesson plans.

Our instructional approach deliberately addressed perceived ease of use by implementing a scaffolded learning progression that aimed to gradually build technical confidence and competency. This approach provided a critical foundation for teachers and continuously evaluated teachers' needs (Chatterjee and Parra, 2020). The program began with simplified, user-friendly AM software and equipment, allowing teachers to experience early successes before progressing to more complex applications. Technical support was embedded throughout all sessions with step-by-step hands-on practice from design to print. Additionally, the program provided extensive post-training resources and ongoing technical assistance during their planning, preparation, and implementation.

2 METHODOLOGY

2.1. Purpose Statement

The purpose of this study is to examine how participation in a hybrid professional development program influences K-12 teachers' acceptance and intention to integrate additive manufacturing technologies into their classroom instruction.

2.2. Additive Manufacturing Professional Development

The PD was designed to support a cohort of 10 middle and high school teachers to enhance their additive manufacturing content knowledge and develop technical skills [Computer-aided design (CAD), material selection, 3D printing operation], pedagogical skills (integrating AM into curriculum, assessment strategies), and professional skills (collaboration, problem solving, and implementation).

We provided a hybrid PD for 35 hours of instruction, including online and in-person instruction and practice. The instruction was composed of a combination of 10 hours of online sessions on AM lectures with PowerPoint presentations, instructions on downloading software, question and answer sessions, discussions and reflections, and plenary lectures. In-person sessions consisted of 10 hours of hands-on learning in the university laboratory space. Lesson planning for teaching AM in the classroom, discussions, networking and socialization consisted of 15 hours.

2.3. Participants

Our research participants were K-12 teachers who voluntarily registered for the AM PD. A call with a flyer, a promo video, and an open registration link was issued to teachers through the school district. The program specifically targeted middle and high school teachers. In total, 10 teachers participated in the first hybrid AM PD for 35 hours. Five male and five female teachers participated, and the average teaching experience was around 15 years. Six teachers teach at the middle school and four teachers at the high school. Teachers teach the following subject areas: Behavioral Skills, Chemistry, Computer Science, Core Subjects, English Language Arts (including English as a Second Language, English Language Development, and Creative Writing), Mathematics, and Science. One participant works at the library.

2.4. Data Collection

A qualitative approach was used to collect data to provide a more holistic understanding. The primary data source for this study consists of survey responses collected from participants in the AM PD. Participants were recruited through an application which included 10 questions. The participant application form collected comprehensive demographic and professional information from prospective participants in the PD AM program. Basic demographic data included participants' names, email addresses, and gender identification. The form gathered commitment-related information through confirmatory questions regarding teaching K-12 students during the 2025-2026 school year, availability to attend all virtual and in-person PD sessions and follow-up meetings, and ability to implement additive manufacturing instruction during summer or fall term. Professional background data encompassed the specific subjects and grade levels participants would teach during the 2025-2026 academic year, along with detailed descriptions of their teaching experience including years of service and school contexts. The application also collected goal-oriented information through questions about participants' objectives for joining the project, their current use of AM or 3D-printing in classroom instruction, and their expectations regarding student

benefits from their participation in the PD program.

Prior to the PD, the teachers participated in a pre-PD meeting and completed a pre-PD survey. Teachers completed a post-PD survey on the last day of the PD. Teachers used a self-selected same five-digit unique identifier for both the pre- and post-PD surveys. All participants completed the survey, yielding a 100% (n=10) response rate. Three members of the research team met in Zoom several times to discuss this study and collaboratively develop the survey. Two researchers developed the survey in Microsoft Forms, and the other two researchers pilot tested it. Items were a mix of multiple-choice, Likert-scale ratings, and open-ended text boxes enabling both descriptive trend data and narrative elaboration. Pre-PD consisted of 19 questions and post-PD consisted of 33 questions. The survey instrument comprised four distinct sections designed to comprehensively assess teachers' perspectives and experiences. Section 1 included the unique identifier Section 2 focused on understanding of AM and PD experience, and contained 7 questions (same in both pre and post-PD). Section 3 examined teaching practices related to routine teaching in school and intention to integrate AM through 8 questions (same in both pre- and post-PD). Section 4 addressed PD structure, including format and delivery considerations, with 15 questions (2 in pre-PD and 15 in post-PD). Finally, Section 5 explored future considerations through 3 questions (2 in pre-PD and 3 in post-PD), providing insights into teachers' anticipated needs and directions for continued professional growth in AM education.

2.5. Data Analysis

Analysis of the open-ended survey responses employed a hybrid deductive-inductive coding approach (Saldaña, 2011). The analytical process began with deductive coding grounded in TAM (Davis, 1989), applying predetermined codes aligned with the workshop's theoretical foundation. These deductive codes included: Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). Under PU constructs were PU_Student Learning: Perceived benefits of AM for student educational outcomes, PU_Professional Development: AM's value for teacher professional growth. Under Perceived Ease of Use (PEOU) constructs included PEOU_Technical Operation and User Interface: Comfort with operating 3D printers and software, along with ease of using AM design and control software, PEOU_Teaching Integration: Ease of incorporating AM into current teaching areas. Following the initial deductive analysis, we conducted inductive coding to capture emergent themes and patterns that arose organically from participants' responses. This two-phase approach ensured both theoretical grounding and empirical richness, capturing themes that emerged directly from participant responses while remaining anchored to the TAM framework.

3 RESULTS

3.1. Perceived Usefulness (PU)

a) Student Learning: Perceived benefits for student educational outcomes. Participants demonstrated strong anticipation for AM's educational benefits for their students. All respondents provided detailed responses about expected student learning benefits focusing on two primary areas: 1) engagement through the hands-on designing process and 2) career pathway exposure.

Engagement through hands-on designing process: Participants indicated the potential of AM to foster student engagement through meaningful, hands-on learning that deepens understanding of the design process. Several participants emphasized that AM can significantly enhance students' interest by shifting classroom activities from passive tasks to active learning and problem-solv-

ing. One response in this direction was “the kids might be a lot more interested in creating something than just paperwork.” The tangible nature of AM was particularly valued, as the opportunity to design and produce physical artifacts reinforcing learning through direct experience as was evidenced from the comment, “Teaching them and having them hold something physical through the hands-on sessions will be a moment of joy and pride.” Moreover, participants highlighted the importance of guiding students through the full engineering design cycle from conceptualization to prototyping, underscoring how AM can serve as a powerful pedagogical tool for cultivating creativity, critical thinking, and iterative problem-solving skills. In this regard, one respondent specifically noted the value of “Helping students go through the entire engineering design process from idea to prototype will be critical.” These insights suggest that AM’s unique capacity to integrate engagement, experiential learning, and process-oriented understanding makes it an effective approach for supporting both student motivation and deeper conceptual development.

Career Pathway Exposure: Participants consistently emphasized the potential of AM to broaden students’ awareness of future career opportunities. Teachers noted that engaging with AM not only introduces students to emerging technologies, but also cultivates new ways of thinking that are directly applicable to a variety of professional fields. One participant reflected, “It can open up doorways to new forms of thinking and give students options for careers,” highlighting the role of AM in fostering both creativity and strategic problem-solving skills that are valued in contemporary workplaces. By providing early exposure to engineering processes and technological tools, AM experiences can help students explore potential career pathways in engineering, design, innovation, and related STEM fields, thereby aligning classroom learning with real-world applications and professional trajectories

The post-survey revealed unanimously positive results for explanatory confidence, with 100% of participants (n=10) responding “Yes” when asked if they could now explain AM more clearly than before the PD. This represents a complete consensus on improved capability that 100% of the participants gained confidence in explaining AM concepts to students after the PD.

b) **Professional Development: AM's Value for Teacher Professional Growth.** In the pre-survey for the professional growth expectations the participants articulated diverse professional benefits they anticipated from AM learning.

Expanding Instructional Toolkit by Developing a New Skill: A unifying theme emerging from participants’ responses was that acquiring new skills contributes to professional growth by keeping teachers current with emerging educational technologies and pedagogical practices, ultimately improving both teaching effectiveness and student outcomes. Learning a new skill provides fresh strategies to engage and motivate students. Findings highlighted that the PD helped teachers build confidence in promoting innovative approaches such as integrating AM in content areas and supporting more effective differentiation for diverse learners. One special education teacher noted potential benefits for diverse learners “I think AM can be very beneficial to aid my bilingual students.” Teachers highlighted how using AM into classroom instruction can invigorate teaching practices, providing novel opportunities to excite and motivate students. Multiple responses focused on improving classroom instruction, e.g., “I feel this will help in my teaching and get my students excited about learning.” Several participants noted AM’s potential to align with existing curricula, and expressed interest in content integration, particularly in STEM subjects, enabling students to apply concepts through hands-on design experience. One comment towards subject integration was, “Learning how to design and 3D print will immensely help me in my chemistry

classroom.” Additionally, integrating AM in teaching has the potential to promote student engagement, interdisciplinary learning, and inclusive education all of which makes students’ learning meaningful and effective. Teachers connected their professional growth and success with students’ motivation, learning, and accomplishments. A teacher enthusiastically expressed, “I look forward to integrating it into my classroom one way or another! The bottom line for students is to be engaged and thrive.” Professional growth was closely linked to student engagement, with teachers expressing enthusiasm for adopting AM to help learners thrive academically and remain actively involved in classroom activities. Moreover, participants recognized the inclusive potential of AM, particularly for diverse learners, such as bilingual or special education students, by offering accessible, interactive, and tangible learning experiences. Collectively, these insights suggest that AM serves as a multifaceted educational tool, supporting teacher development, fostering subject integration, enhancing engagement, and addressing diverse learner needs.

Post-Survey professional development results for relevance of the workshop for teachers’ professional growth showed strong positive outcomes as 60% of respondents reported “Highly Relevant,” and 40% reported “Moderately Relevant.” Since none of the participants rated the PD as having low relevance to their professional growth, it can be inferred that all participants recognized and valued its importance for their own professional development.

3.2. Perceived Ease of Use (PEOU)

a) Technical Operation and Interface Use: Comfort with 3D Printers and Software. The finding revealed that despite 80% of participants reported having no prior experience with AM, all participants successfully completed hands-on printing activities. The results demonstrated that previous exposure to 3D printing technology is not a prerequisite for successful technical engagement, as all participants regardless of their lack of experience were able to navigate the operational demands of both the hardware and software components during the workshop. From a TAM perspective, this outcome has important implications for PEOU. The 100% success rate suggests that when appropriate instructional scaffolding and support are provided, the learning curve for AM technology may be less steep than anticipated. Some participants in the pre-PD discussions expressed uncertainty about their success, noting their lack of prior AM experience and assuming it required extensive technical knowledge and skill. The participants' ability to move from novice status (80% with no experience) to successful completion of hands-on activities within the workshop timeframe, combined with their responses in the post PD survey, indicated that the technological interface and operational requirements were successfully acquired within a short period. This finding also suggests that facilitating conditions, such as structured hands-on activities, guided instruction, and immediate technical support during the workshop played a critical role in enabling participants to overcome initial barriers related to unfamiliarity with the technology and to achieve basic operational competency.

b) Teaching Integration: Ease of Incorporating AM into Current Classroom. In the post PD survey regarding teachers’ comfort level to integrate AM in the classroom, 50% reported “fully prepared” while 50% reported “somewhat prepared.” This finding demonstrates a positive behavioral intention toward AM integration based on the comfort level to use the technology in classroom settings. This indicates that the PD successfully built participants' confidence in their ability to translate workshop learning into classroom practice. The complete absence of participants reporting feeling unprepared suggests that during the PD participants gained knowledge and experience which would enable them to integrate AM in their current classroom. Participants’ responses highlighted

that the PD provided opportunities to the participants to address questions related to barriers to technology adoption and provided practical strategies to envision AM implementation within their existing instructional contexts. From a TAM perspective, this result reflects favorable attitudes toward using additive manufacturing technology in educational settings. The fact that half of the participants felt fully prepared indicates that the workshop went beyond basic technical training to address the pedagogical dimensions of AM integration, such as curriculum alignment, lesson planning, and instructional strategies that are essential for classroom implementation. The remaining 50% who felt “somewhat prepared” likely recognized the complexity of translating PD experiences into diverse classroom environments. This distribution also suggests realistic self-assessment among participants. Those reporting feeling “somewhat prepared” acknowledged practical constraints such as facilitating conditions, including access to equipment, materials, technical support that influence their readiness to implement AM. This nuanced response pattern indicates that while participants gained confidence in their technical abilities and pedagogical understanding, they also recognize that successful classroom integration depends on factors beyond individual capability. The 50% full preparedness to integrate AM into teaching is particularly significant when contextualized with the finding that 80% had no prior AM experience. This dramatic shift from novice to prepared practitioner within the workshop timeframe speaks to the effectiveness of the PD design in building both technical competence and pedagogical confidence.

4 DISCUSSION

Based on the survey results, several key factors pertaining to the professional development design and facilitation likely influenced teachers’ intentions to implement AM in their classrooms. The progression from initial discomfort in incorporating AM to post-PD confidence in teaching AM concepts suggests that hands-on experience and knowledge building directly impacted implementation intentions. Confidence building appears to be a primary driver, as the program addressed participants’ comfort levels with AM technology and measured their preparedness to integrate it into the curriculum after the PD. Resource availability represents another critical factor, with the post-survey specifically examining whether participants received adequate resources from the PD for classroom implementation and what additional support they needed, indicating that practical readiness significantly influences teachers’ willingness to adopt new technologies.

Successfully completing the PD, despite limited prior experience, likely enhanced participants’ self-efficacy and strengthened their intention to integrate AM into their teaching, as they proved to themselves that they could operate the technology effectively. Furthermore, this result has practical implications for PD design, suggests that educators without prior AM experience should not be discouraged from adopting the technology, and that well-designed, hands-on training can effectively bridge the experience gap, potentially accelerating AM adoption in K-12 educational contexts.

Contextual fit within existing practice appears to influence intentions significantly, with the surveys examining how well AM content aligned with participants’ current teaching practices and whether they could identify specific grade levels or subject areas for integration. Finally, sustained institutional support emerged as a factor, reflected in questions about continued PD interests and participation in follow-up phases where teachers would implement AM with their students. The high retention rate (100% completed the PD), 50% expressed feeling fully prepared to implement, and 80% teachers implementing it in their teaching suggests that comprehensive support and ongo-

ing engagement opportunities strengthened teachers' commitment to classroom integration of additive manufacturing technologies.

Perceived relevance and value for student learning emerged as a central influence factor, with both surveys examining how teachers viewed AM's benefits for their students and the appropriateness of content for their specific student populations. This suggests that teachers' implementation intentions were strongly tied to their belief in AM's educational value and associated future career pathways rather than just technical interest. Professional preparation and support also played a crucial role, as evidenced by participants' responses regarding the adequacy of hands-on practice opportunities, the availability of expert guidance during technical activities, access to resources and materials for classroom implementation, and opportunities for collaborative learning with fellow educators. Teachers who felt adequately prepared through the PD were more likely to commit to implementation.

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