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2.1 Mapping the state-of-the-art

Leading organization: Johannes Kepler University Linz

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3D modelling and printing as a part of teacher education: Mapping the state-of-the-art

This document is a partial result of the project *Accelerating STEAM-related Knowledge and Skills via 3D Modelling and 3D Printing (acronym: 3D STEAM)*

The project has been co-founded by the European Union within its program *ERASMUS+ KA220-HED - Cooperation partnerships in higher education*

This particular work package was led by Johannes Kepler University, Linz, Austria

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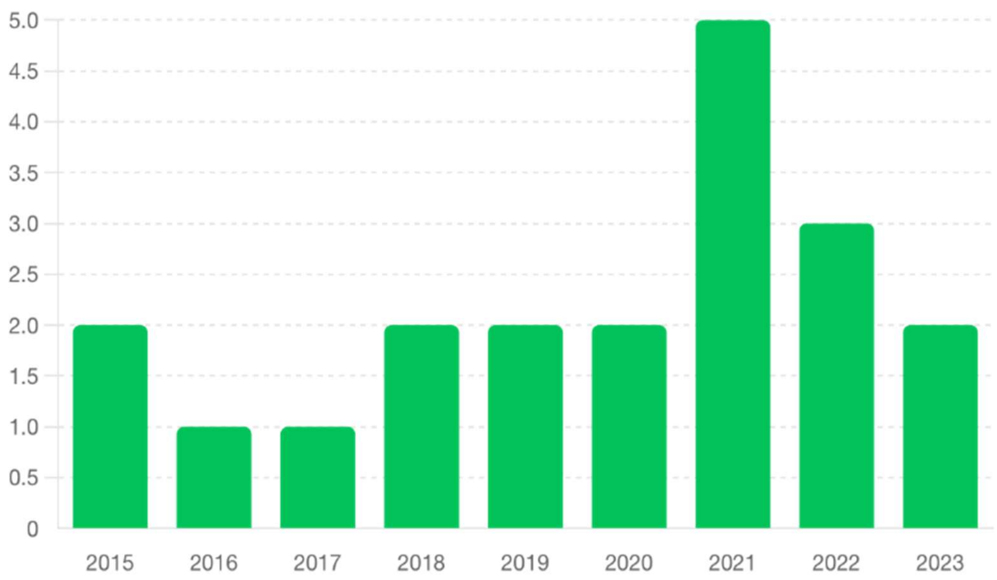
Context and Overview of the Studies

The project *Accelerating STEAM-related Knowledge and Skills via 3D Modelling and 3D Printing* intends to assist future (pre-service) teachers to plan and carry out teaching activities with 3D modelling through a STEAM-based transdisciplinary approach. The project is done by universities in five countries of the European Union. Our principal aim is to design and develop university teacher training courses fostering 3D modelling skills of pre-service teachers with a variety of technologies as well as to reach a wider audience and students through such approaches. In addition, the gained knowledge and experiences will support in-service teacher training in the participating countries and beyond.

Not "to invent the wheel", the projects like our one have to start with mapping the state-of-the-art. Its main aim is to learn what has been done, whether there are lessons to be learned, to collect ideas for optimal expansion of current knowledge and to adapt gained knowledge to the local conditions of the project partners.

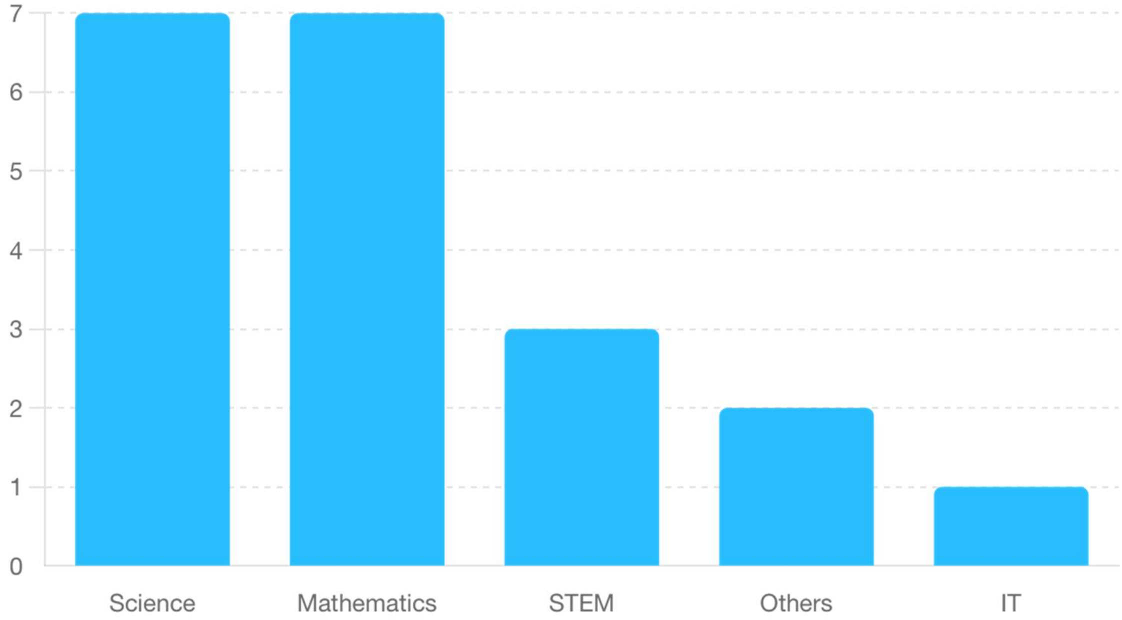
This report analyses 21 studies examining the integration of 3D technologies, specifically 3D modelling and printing, in teacher training. The goal is to understand how these technologies are utilised, identify the challenges and enablers, and derive key findings and recommendations for developing effective teacher training programs.

Number of publications per year:



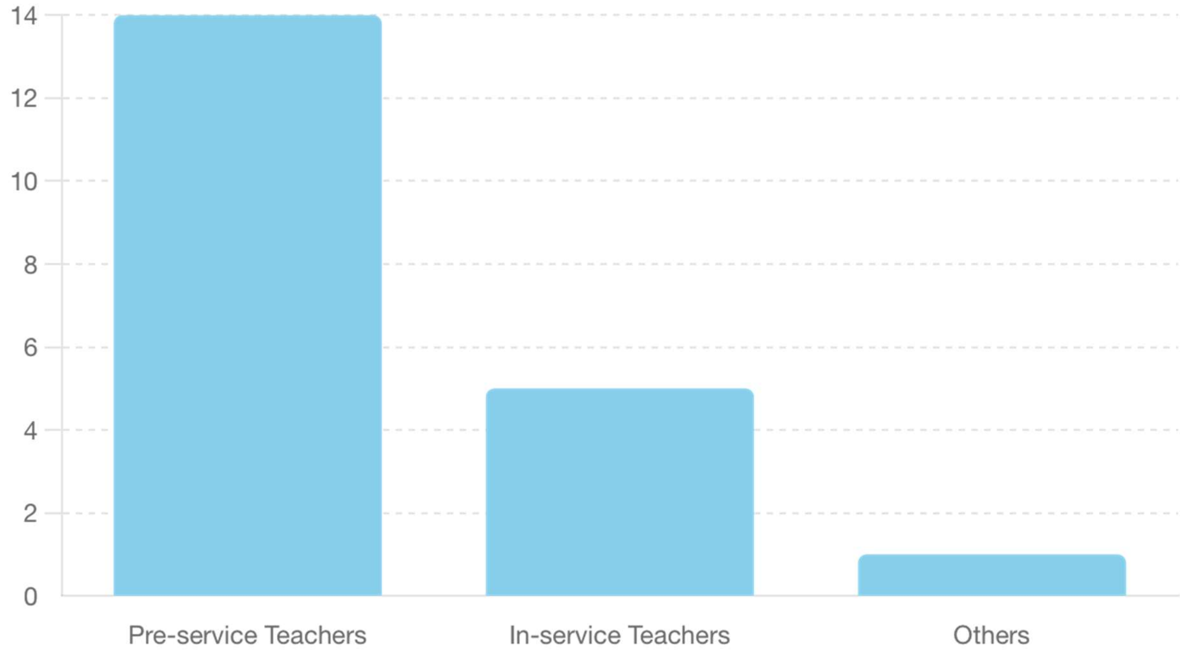
The studies span several years, with Publications ranging from 2015 to 2021. They originate from multiple countries and regions, reflecting diverse educational contexts and approaches. For instance, studies have been conducted in Greece, Turkey, and the USA, among other countries. The types of publications include journal articles and conference papers, indicating the academic rigour and widespread interest in this area of research.

Number of publications per discipline focus:

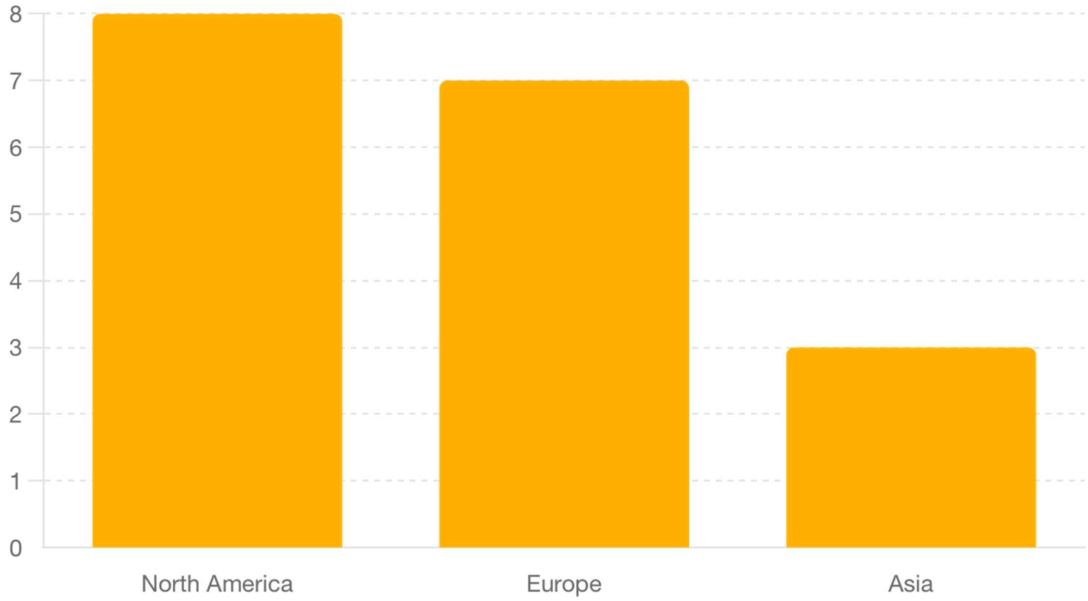


The graphs show the distribution of these studies across different years, countries, educational levels, and disciplines. For example, most studies focus on pre-service and in-service teachers, and the disciplines include STEM (Science, Technology, Engineering, and Mathematics), Arts, and Information Technology (IT). The data also reveals that many studies are centred in Europe and North America, highlighting regional trends in adopting 3D technologies in education.

Number of publications by educational level:



Number of publications by continent:



Application of 3D Technologies in Education

3D technologies are employed in various ways to enhance educational experiences. One prominent method is integrating 3DMP into an existing course. For example, in a course entitled "Teaching Social Sciences Through the Arts," pre-service teachers engage in 3D printing projects to create artefacts representing their responses to literature. This approach enriches the curriculum and allows teachers to explore social issues creatively and collaboratively. Similarly, in secondary mathematics methods courses, 3D printing is introduced to enhance pre-service teachers' Technological Pedagogical Content Knowledge (TPACK), equipping them with the skills needed to integrate digital fabrication tools into their teaching practices.

Curriculum enhancement through 3D technologies provides hands-on learning opportunities that make abstract concepts more tangible. In STEM education, for instance, 3D printing is used to construct models of complex structures, such as molecular models in chemistry or prototypes in engineering. This hands-on approach helps students visualise and better understand the material, fostering a more engaging and effective learning environment.

Collaborative design projects using 3D modelling and printing are another significant application. These projects often involve students working together to design and print artefacts that reflect their collective understanding of a topic. For instance, pre-service teachers might collaborate on creating a 3D-printed model that represents a theme from a children's book, facilitating discussions on how their designs enhance or challenge their interpretations of the text. Such projects promote teamwork, creativity, and deeper engagement with the subject matter.

Specific applications of 3D technologies are tailored to different educational contexts. For example, pre-service teachers use 3D modelling and printing in one program to develop teaching aids that can be directly applied in classrooms. This includes creating custom manipulatives for mathematics lessons or designing interactive models for science experiments. These applications demonstrate the versatility of 3D technologies in addressing diverse educational needs and enhancing instructional methods.

Teacher training programs frequently incorporate 3D technologies to prepare educators for modern classroom environments. These programs provide theoretical knowledge and practical 3D modelling and printing skills. For example, pre-service teachers might receive training on how to operate 3D printers, design 3D models using computer-aided design (CAD) software, and integrate these technologies into their lesson plans. Such comprehensive training ensures that future teachers are well-equipped to utilise 3D technologies effectively, fostering innovation in their teaching practices.

The use of 3D technologies spans across different disciplines, including mathematics, science, social sciences, and arts. This interdisciplinary approach broadens the scope of 3D printing applications in education. In STEM education, 3D printing creates models that illustrate complex concepts, such as geometric shapes in mathematics or engineering prototypes. In social sciences, 3D printing projects can facilitate discussions on historical artefacts or cultural representations. This versatility makes 3D technologies valuable for enhancing educational experiences across different subjects.

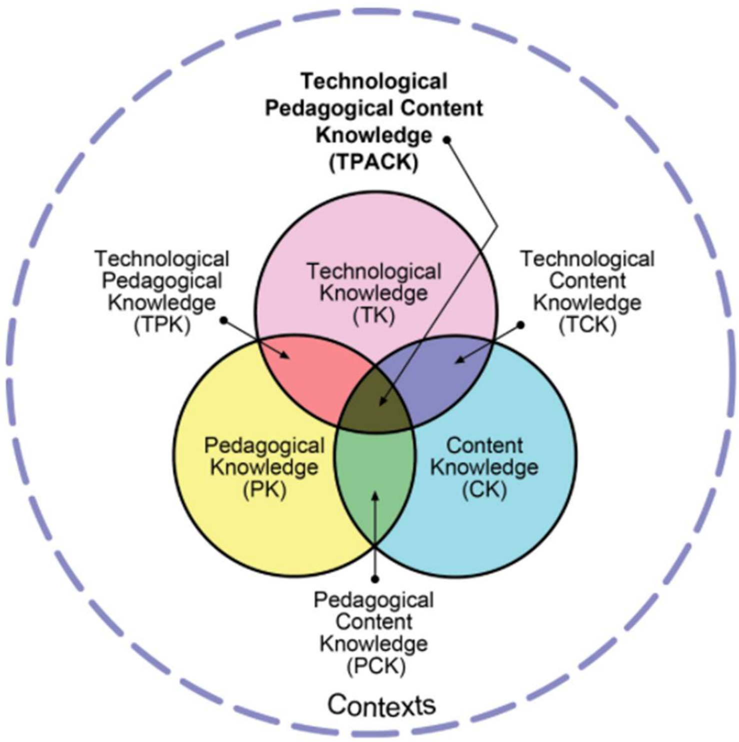
Organisation

The time and organisation of these interventions are crucial for their success. Effective training programs include structured modules that cover various aspects of 3D printing, from basic skills to advanced applications. Real-time demonstrations and live sessions are particularly beneficial, allowing participants to observe the printing process, from design to final output. Practical projects where participants design and print their own educational materials are also a key component, providing hands-on experience and fostering creativity and problem-solving skills.

Workshops played a significant role in the practical application of these technologies. For example, one study involved teachers building 3D printers using open-source technologies to bring back to their schools. Another study adopted the CDIO (Conceive-Design-Implement-Operate) approach, balancing pedagogical fundamentals, technological skills, and teaching practice. Additionally, the TPACK Developmental Model was highlighted for considering teacher knowledge specific to mathematics teaching tools. Furthermore, a detailed framework involving discovery learning, opportunities for practice, collaboration, and technology resource development was used to prepare pre-service teachers for the future integration of emerging technologies. These varied approaches underscore the importance of structured, hands-on, and collaborative learning experiences in effectively integrating 3D printing into educational practices.

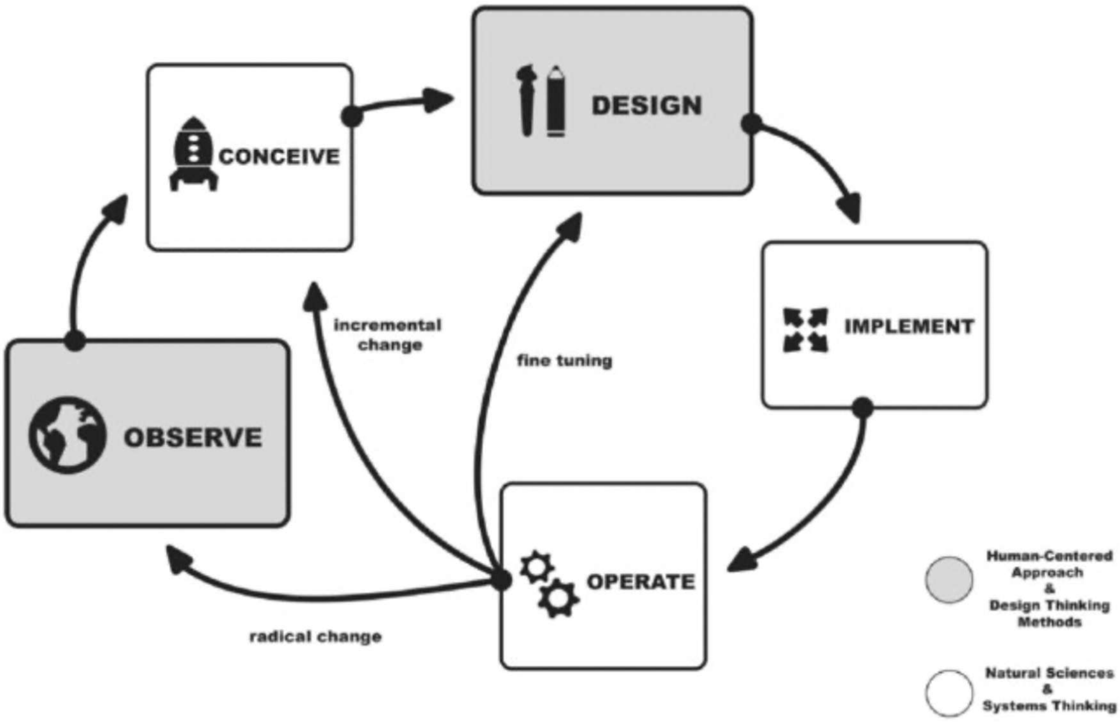
Models

The Technological Pedagogical Content Knowledge (**TPACK**) framework is essential for integrating technology effectively into teaching practices. TPACK combines teachers' knowledge of content, pedagogy, and technology, enabling them to design lessons incorporating advanced tools like 3D modelling and printing. By understanding how these three domains intersect, teachers can create more engaging and interactive learning experiences. For example, in science classes, 3D models can help explain complex structures, while in mathematics, students can design and print geometric shapes to better grasp abstract concepts. This holistic approach ensures that technology is not used in isolation but as a seamless part of the educational process, enhancing overall learning outcomes. Moving from TPACK, we can see how experiential learning frameworks like Kolb's Learning Cycle further support effective 3D modelling and printing integration in education.



Kolb's Experiential Learning Cycle emphasises learning through doing, which is highly relevant for 3D modelling and printing teacher training. The cycle includes four stages: Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation. Teachers first engage in hands-on activities like creating and printing their designs. They then reflect on these experiences, considering what worked well and what challenges arose. This reflection leads to abstract conceptualisation, where teachers develop theoretical insights into using 3D printing in their teaching. Finally, they apply these insights through active experimentation to refine their instructional strategies. This cycle enhances teachers' technical skills and deepens their pedagogical understanding, making 3D printing a powerful tool in their educational toolkit. Building on experiential learning, engineering design principles offer another layer of depth to this training.

Engineering design is a systematic, iterative approach to solving problems crucial for effective 3D modelling and printing. This process involves defining problems, generating ideas, testing solutions, and optimising results. This approach can be applied in teacher training by having educators guide students through real-world projects that utilise 3D printing technology. For instance, students might be tasked with designing a prototype to address a specific need, fostering critical thinking, creativity, and problem-solving skills. This hands-on application of theoretical knowledge makes learning more engaging and demonstrates the practical utility of 3D printing in solving everyday challenges. As teachers become proficient in this approach, they can better prepare students for the demands of modern technological and engineering fields. This iterative design process naturally leads us to the CDIO framework, which provides a comprehensive structure for integrating 3D printing into education.



The **CDIO** (Conceive-Design-Implement-Operate) framework outlines a holistic approach to engineering education, emphasising the entire lifecycle of engineering projects. In the context of 3D modelling and printing teacher training, CDIO guides educators to conceive educational projects, design lesson plans, implement these plans in classrooms, and operate 3D printers to bring these projects to life. This framework ensures that teachers understand the technical aspects of 3D printing and how to effectively integrate it into their teaching practices. By experiencing the full CDIO cycle, teachers can create more dynamic and engaging learning environments, preparing students for future technological challenges. Integrating CDIO with TPACK, Kolb's Learning Cycle, and engineering design principles forms a foundation for 3D modelling and printing in education, equipping teachers with the skills and knowledge to innovate and inspire.

Barriers and Facilitators

Several challenges have been identified in integrating 3D technologies into teacher training. Technological barriers, such as hardware and software operation issues, are common. Many educators face difficulty accessing reliable equipment and receiving adequate technical support and maintenance. Resource constraints, including limited financial resources for purchasing and maintaining 3D printers and materials, pose significant hurdles.

Integrating 3D technologies into existing curricula can be challenging. Educators may struggle to find relevant and effective 3D printing projects that align with their teaching goals. Additionally, there is often resistance to change among educators accustomed to traditional teaching methods. Time constraints within existing teaching schedules further complicate the adoption of new technologies. Variability in the quality and reliability of 3D printing outputs can deter educators from fully embracing these tools.

Despite these challenges, several enablers have been identified that facilitate the successful integration of 3D technologies in education. One major enabler is the engagement and enthusiasm of participants. Teachers excited about the potential of 3D printing are more likely to invest the time and effort needed to overcome initial barriers. Structured, problem-based, and project-based learning approaches have also proven effective in engaging participants and providing them with practical skills.

Supportive professional development workshops and training programs are crucial. These workshops provide continuous support, helping educators troubleshoot technical issues and share best practices. Access to various resources and tools for 3D printing is another important enabler. Schools and educational institutions that invest in the necessary infrastructure and provide adequate resources see better outcomes.

Collaboration among educators is also key. Sharing experiences, discussing challenges, and learning from each other fosters a supportive environment that encourages innovation. Positive institutional support and encouragement for new technologies further facilitate the integration process. Flexible training schedules that accommodate teachers' availability and continuous technical support and troubleshooting assistance are vital for successful implementation.

Key Findings and Recommendations

The key findings from the studies underscore the significant benefits of integrating 3D technologies into teacher training. Participants in these programs have shown improved technological competency and enhanced TPACK. Hands-on learning experiences with 3D printing have proven effective in developing practical skills and increasing teachers' confidence in using these technologies.

3D printing helps visualise complex mathematical and scientific concepts, making them more accessible to students. This is particularly beneficial in STEM education, where abstract concepts can be challenging to grasp. Structured training programs that include comprehensive modules covering various aspects of 3D printing ensure that participants are well-equipped with the necessary skills.

A balanced approach that combines practical, hands-on experiences with theoretical knowledge is crucial. Live demonstrations and real-time learning sessions provide valuable insights into the printing process and help participants understand the practical aspects of 3D printing. Utilising existing resources such as Thingiverse and Instructables for model creation and idea generation fosters creativity and practical skills.

Collaboration and peer learning are highly beneficial. Teachers learn from each other's experiences, share best practices, and collaboratively solve problems, fostering a supportive learning environment. Engaging teachers in the same learning process their students will undergo helps them empathise with the challenges students might face, which is crucial for designing effective instructional strategies.

Based on these findings, several recommendations can be made for developing effective teacher training programs in 3D modelling and printing. First, providing teachers with a well-designed and organised set of educational resources is essential. These resources should include pre-developed simple examples for artefact construction and homework-type tasks for practice. Preparatory courses for novices in key thematic areas should also be developed.

It is crucial to allocate more time in training sessions to focus on specific tools and methodologies related to 3D technologies. Training tasks should be based on realistic scenarios to make them more meaningful and allow participants to extend these scenarios based on their interests. Identifying mentors to support, guide, and troubleshoot during training and creating links to a community of experts will provide ongoing support and learning opportunities.

Teachers must first explore 3D printers, design, and printing as learners and then integrate these technologies into their lesson design and teaching expectations. Providing online resources to support this integration can further facilitate the process. Raising awareness of 3D printers and their use in learning environments and offering digital literacy training to develop proficiency in using 3D software is also important.

It is recommended that the continued development and expansion of the making culture in education, with a focus on training teachers to embrace new pedagogical roles, be encouraged. Placing 3D printers in common areas and allowing prospective teachers to use them in their spare time will maximise accessibility and practice opportunities. Future studies should focus on analysing visual literacy skills and ways to foster their development in digital design and production environments.

By integrating these key findings and recommendations, teacher training programs can effectively prepare educators to incorporate 3D modelling and printing technologies into their teaching practices, enhancing educational outcomes and fostering innovation in the classroom.

Recommendations for designing interventions

- Provide Well-Designed Educational Resources:
    - Include pre-developed simple examples for artefact construction.
    - Incorporate homework-type tasks for practice.
- Allocate More Time for Training:
    - Focus on specific tools and methodologies related to 3D technologies.
- Use Scenario-Based Training:
    - Base training tasks on realistic scenarios.
    - Allow participants to extend these scenarios based on their interests.
- Identify and Utilize Mentors:
    - Support, guide, and troubleshoot during training.
    - Create links to a community of experts for ongoing support.
- Encourage Practical Exploration:
    - Allow teachers to explore 3D printers, design, and printing first as learners.
    - Integrate 3D technologies into lesson design and teaching expectations.
    - Provide online resources to support this integration.
- Raise Awareness and Digital Literacy:
    - Provide training to improve awareness of 3D printers and their use in learning environments.
    - Offer digital literacy training to develop proficiency in using 3D software.
- Promote Continued Development and Reflection:
    - Encourage the making culture in education.
    - Train teachers to embrace new pedagogical roles.
    - Promote reflection on different stages of 3D printing projects and the importance of sharing and discussing outcomes.
- Maximise Accessibility:
    - Place 3D printers in common areas for easy access.
    - Allow prospective teachers to use them in their spare time.