Digital Learning and 3D Printing Integration in Schools: Analyzing Teachers' Experiences

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Abstract

The decreasing cost of 3D printers has made them more accessible to schools. Digital learning with the use of 3D printing can provide engaging and interactive experiences for students, promote creativity and innovation, and help students develop problem-solving skills. However, despite the benefits, the use of 3D printing in schools is still limited. This paper explores the experiences and perspectives of teachers who have used 3D printers in their teaching to understand how the technology can become part of everyday practices and strengthen digital literacy. The article uses as an analytical framework the normalization process model (NPM) which focuses on factors that promote or inhibit routine embedding of technological interventions in existing work settings. The analysis reveals that the obstacles reported by teachers relate mostly to exogenous (organizing) factors. The findings contribute insights on how 3D printing can become part of everyday practices and of the overall school information infrastructure to facilitate learning and strengthen digital literacy from early student ages.

Keywords: Digital Learning, Normalisation Process Model, 3D printing, Work Practices, Teachers

1 Introduction

Digital learning can empower individuals and communities to access digital resources and acquire skills through the utilization of digital technologies to facilitate learning. In this context, 3D printing, as a digital technology, offers a range of learning benefits. It can provide engaging and interactive learning experiences for school students by allowing them to create and manipulate physical objects. 3D printing can aid in better understanding abstract concepts within areas such as math and science while also promoting creativity and innovation by providing students with the ability to bring their ideas to life (Ford and Minshall 2019; Novak and Wisdom 2018; Pearson and Dubé 2022). It can also help students develop problem-solving skills as they work through design and printing challenges (Hennessey and Mueller 2020). Overall, 3D printing can be a valuable tool for educators to engage students, foster creativity and innovation, and prepare them for future careers.

The combination of affordability and educational benefits makes 3D printing an important technology for digital learning. As the price of 3D printers has decreased, they have become more accessible to schools, particularly those with limited budgets. There are several 3D printers suitable for digital learning with prices similar or lower to the price for a personal computer. The availability of low-cost 3D printing equipment created the opportunity for hands-on labs in schools. These labs can relate to a wide range of courses ranging from robotics to biological sciences (e.g., using 3D printing for molecular modelling) and archaeology (using 3D printing to recreate ancient artifacts). 3D printing is a process of creating physical objects from digital designs by adding material layer by layer until the desired shape is achieved (Huang and Leu 2014; Nemorin and Selwyn 2017). Over time, the technology has matured, getting to a point where it is now feasible to work with many different types of materials, including plastic, metal and wax. The vast array of materials available for 3D printing significantly broadens its potential applications within education.

Despite the educational benefits and affordability of 3D printing, its use in schools is still limited and it has not been assimilated in teaching practices (Anđić et al. 2023; Pearson and Dubé 2022). In this study we address the following research question (RQ): *What are the factors affecting the assimilation of 3D printing technologies in teaching practices?* We investigated this research question by gathering and analysing data via a survey administered to school teachers who actively utilize 3D printers for educational purposes.

The conceptual framework for the study draws on the normalization process model (NPM) which recognizes that in order to successfully introduce novel technologies in work settings a normalization process that rebalances technologies, people, practices, and values is required (May 2006). NPM explains how new technologies can be embedded and normalised in everyday work. The underlying assumption for this paper is that what matters for regular and wide-spread appropriation of 3D printing is not only the availability of the technology per se and its functionalities, but also, the bearing of specific technologies-in-practice (how technologies are experienced within their overall context) (Feldman and Orlikowski 2011; Orlikowski 2000). Therefore, it is important to study the stances of those that have already been engaged with the particular technology in their work settings (teachers that have already experienced the use of 3D printing in schools). An inquiry into the experiences of actual users can generate insights about situated and emergent issues that cannot be captured by focusing only on the technology.

The paper contributes insights on how 3D printing can be integrated in schools to facilitate learning and strengthen digitally literacy from early student ages. The findings provide insights on factors that impact the assimilation of 3D printing in teaching and evidence on specific obstacles identified by teachers. The paper provides a nuanced perspective that highlights both teachers' contentment with immediate benefits of 3D printing and their frustration with external obstacles. Overall, our analysis reveals that the obstacles reported by teachers relate mostly to exogenous (organizing) factors. Teachers reported that they are content with the use of 3D printing in classrooms, however, they also reported exogenous obstacles related to technical support, resources including consumables and training for developing required skills. By addressing these issues, 3D printing can become a routine and valuable part of the digital learning landscape, providing students with the skills they need to succeed in a technology - driven world.

The remainder of the paper is organized in the following way. Firstly, an overview of the normalization process model is provided. Secondly, the method used to gather and analyse empirical data from schoolteachers that utilise 3D printing in their teaching is outlined. Thirdly, the study's findings are presented. Finally, the paper concludes by discussing the insights from the analysis, the implications for research and practice, the limitations of the study, and potential directions for future research.

2 Normalisation Process Model

Our study is informed by the Normalisation Process Model (NPM), which offers a lens for analysing how new technologies can be integrated into daily work (May 2006). NPM is developed explicitly for examining technologies in everyday use, the work of normalisation and the practices of embedding in work settings (May et al. 2009). It provides a framework for understanding how a new technology may or may not become a routine part of everyday practice, and for identifying factors that can facilitate or hinder its integration. The model is focused on deriving practical insights from investigating what happens in the work setting beyond deployment. Although originally designed for the introduction of information and communication technologies in healthcare (Murray et al. 2011; Vassilakopoulou and Grisot 2014), NPM has been widely used beyond healthcare, such as in the context of agile systems development (Carroll et al. 2023), big data for business analytics (Shin 2016) and online evaluations in higher education (Adam and Issah 2017).

NPM includes four categories of factors for the routine embedding of technology-based interventions: interactional workability (IW), relational integration (RI), skill-set workability (SSW), and contextual integration (CI) (May et al. 2009; Murray et al. 2011). IW refers to the impact that a new technology has on work interactions. In the case of education, this includes the interactions between teachers and students. RI refers to the impact of the new technology on relations between different groups of professionals, and the degree to which it promotes trust and accountability in inter-professional relations. SSW refers to the fit between the new technology and existing skill sets. Finally, CI refers to the fit between the new technology and the overall organizational context, including organizational goals, morale, leadership, and distribution of resources. Figure 1 provides an overview of the NPM. Both IW and RI are constructs that refer to the endogenous factors affecting technology introduction while SSW and CI refer to exogenous factors linked to the wider ecology (May et al. 2007).

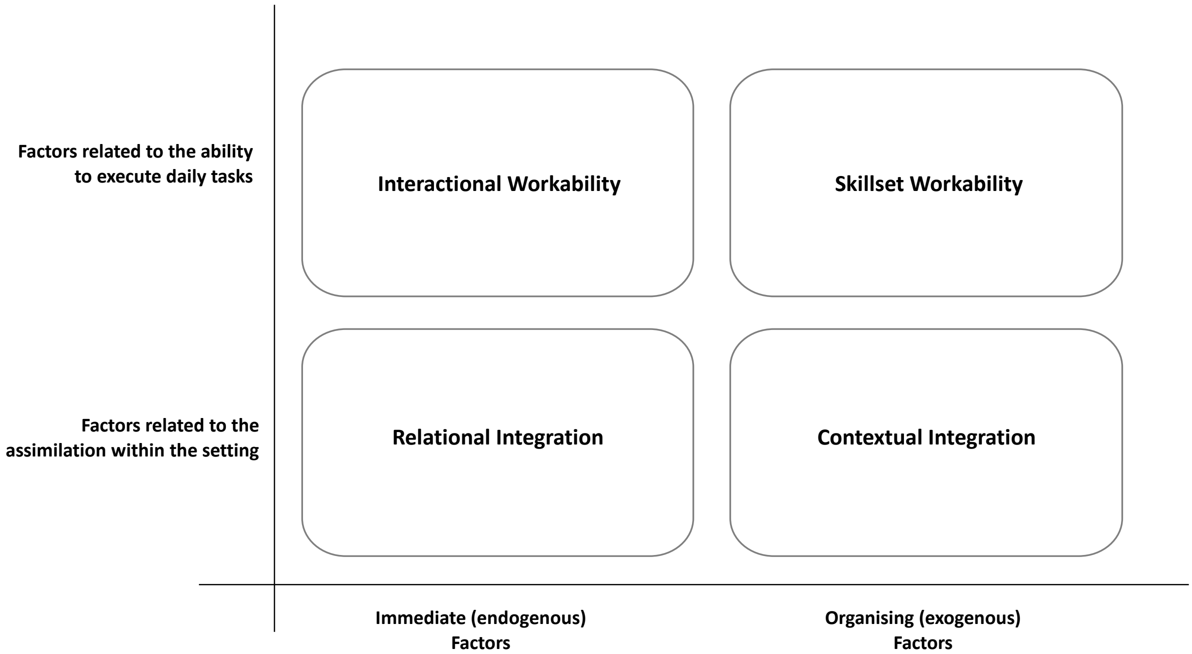

Figure 1. Overview of the Normalisation Process Model.

3 Method

To explore the factors related to embedding the use of 3D printing in school teaching we reached out to teachers that actually use 3D printing in primary and secondary education. The study was performed in Greece in the Fall of 2021. Data collection was performed in Greek language. Data were collected through closed questions about teachers´ experiences across interactional workability, relational integration, skill-set workability, contextual integration, an open question, and demographic questions. The questions were included in a broader questionnaire on teachers´ satisfaction with 3D printing adoption. In the annex, we provide an English translation of the questions used. As a second step, primary and secondary schools that have at least one 3D printer were identified. These schools were contacted by phone to investigate if 3D printing is actually used in teaching. In total, we identified 57 schools with 3D printing facilities, however, after the telephone communications it was found that in 13 of them 3D printing was not used in teaching. The remaining schools were asked to participate in the study. The school principals directed us to one teacher engaged with 3D printing per school. In total, 36 teachers participated in the study. Table 1 provides an overview of the study participants.

Participants' Age Distribution	
30-45	7
45-60	27
>60	2
Participants' Gender	
Female	11
Male	25
Participants' Location	
Athens	10
Thessaloniki	5
Remaining Greece	21

Table 1. Overview of Participants.

The majority of participants belongs to the 45-60 age group. This distribution is consistent with the overall demographics of teachers in Greece. Most of the participants are males (about 2 out of every 3 participants). Also, about 40% of the participants are located in Athens and Thessaloniki which is consistent with the overall distribution of the population in the country. Most participants have been using 3D printing for 1 to 3 years (see Table 2).

Years of experience with 3D printing			
	Less than 1	1 - 3	> 3
Participants	6	20	10

Table 2. Participants' experience with 3D printing.

It comes as no surprise that the number of schools using 3D printing is limited. Currently, the use of 3D printers in schools relies to a significant extent on teachers' initiatives. The fact that only a few schools use it underscores the need to investigate factors for normalising 3D printing in teaching.

The data analysis entailed processing answers to closed questions and assessing free text provided by teachers. So, the data analysis involved two parts. First, we processed the teachers' responses to closed questions to gain quantitative insights. The closed questions are by design directly linked to the four NPM categories of factors (interactional workability, relational integration, skill-set workability, and contextual integration) so, no coding was needed for this first part of the analysis. Second, we analysed the free-form text teachers provided to gain qualitative understandings of their experiences. The free text was analysed by two of the authors who assessed the relevance of statements to the four NPM categories. The coding process involved several iterations. Initially, both coders independently coded ten responses. They then met to identify any differences in their interpretations, discuss and resolve differences. This inter-coder discussion aimed to calibrate their understandings and promote consistent coding. After resolving their initial differences, the coders independently coded the remaining responses. Upon completing the independent coding, they met again to jointly review and finalise the analysis. This rigorous coding process involved several important elements: independent coding by two authors to mitigate potential bias, iterative coding and discussions to calibrate understandings, consensus discussion to final the analysis.

4 Findings

Our analysis examines factors that contribute to the successful assimilation of 3D printing in teaching across four categories: factors related to everyday task execution (workability both at the immediate and organizing level) and factors related to the novelty integration within the wider educational setting (integration both at the immediate and organizing level). A significant number of respondents noted that that there is a lack of proper training available, indicating issues related to the skill-set workability category. Respondents also highlighted resource limitations for 3D printing, including consumables, which are contextual integration issues. Interestingly, teachers were much more satisfied regarding immediate (endogenous) factors providing positive feedback about interactional workability and relational integration.

In the following subsections the findings for each of the four NPM categories are presented. An overview of the prominent themes emerging under each of them is provided in Figure 2.

4.1 Interactional Workability

Interactional workability refers to the extent to which 3D printing *facilitates the execution of teaching*. It focuses on how the technology performs if it is workable and acceptable. Assessing interactional workability involves evaluating how the technology is *used and valued* by teachers.

All participants found 3D printing to be a valuable aid helping them teach in a more direct manner. One of the teachers noted that 3D printing is a "necessary learning tool, must become part of the official teaching plan" while another teacher stated that "3D printing is an interdisciplinary, useful and necessary learning tool". Out of 36 respondents, 13 reported that 3D printing was significantly or very significantly helpful, while another 15 respondents found it to be moderately helpful. The remaining 8 respondents stated that it was slightly helpful. Additionally, all participants reported that 3D printing made the topics covered in class more comprehensible to students. Specifically, 21 respondents found that 3D printing improved comprehension significantly or very significantly, 11 found it to improve comprehension moderately, and 4 found it only slightly contributing to comprehension improvement. Moreover, almost all respondents, except one, reported that 3D printing had a positive impact on productivity. Among them, 15 respondents reported that they were significantly or very significantly more productive, 11 moderately more productive, and 9 slightly more productive.

4.2 Relational Integration

Relational integration focuses on how 3D printing is *integrated into existing organizational relations in schools*. Essentially, relational integration examines how a new technology fits into the organizational context in which it is being introduced. This is particularly relevant in education, as teachers typically work within organized environments where they need to relate to managers and peers. If a new technology is not well-integrated within these relationships, it may be difficult to maintain its use over time. Therefore, evaluating relational integration involves understanding how the technology is *perceived by others in the school environment and whether it is supported by them*. By identifying and addressing issues related to relational integration, successful implementation of new technologies can be facilitated.

The study participants reported that their work environment had a positive influence on their attitude towards 3D printing (26 respondents) or had no influence at all (10 respondents), with none of them indicating any negative impact. Additionally, all participants reported being satisfied with the support they received from school management, with 26 finding it significantly or very significantly helpful, 6 finding it moderately helpful, and 4 finding it slightly helpful. None of the respondents expressed any dissatisfaction with school management's support. The responses were similar when participants were asked about support in the context of other organizational relations within the school beyond the management, with 23 respondents finding it significantly or very significantly helpful, 11 finding it moderately helpful, and 2 finding it slightly helpful. Overall, these responses suggest that 3D printing is well-integrated within schools. However, some participants noted that it would have been better if 3D printing was institutionalised by being part of the syllabus. For instance, one of the teachers noted: "It has not been included in the syllabi of the courses. Also, there are no incentives such as organized competitions for students". Another teacher stated: "the course syllabus covers 3D printing quite superficially and it is up to the teacher to include it or not".

4.3 Skill-set Workability

Skill-set workability refers to the extent to which 3D printing can be made to work in practice by teachers, with *their current skills and competencies*. Assessing skill-set workability in the NPM involves evaluating whether the new technology is compatible with the current skills and competencies of the individuals who will be using it. This includes assessing whether they have the necessary knowledge, skills, and experience to use it effectively, or whether additional training or support is required. Skill-set workability is particularly important in teaching, where new interventions may require teachers to learn new skills or adapt existing ones. The lack of necessary skills or competencies create barriers to technology implementation and assimilation in every day work.

Most respondents stated that they had no training on the use of 3D printing (21 out of 36). Nevertheless, many of them found that is relatively easy to learn even without any formal training. Out of 36 respondents, 6 reported that learning how to use 3D printing was very easy, while another 18 respondents found it to be moderately easy. However, the remaining 12 respondents stated that it was not that easy to learn. So, 3D printing learnability is a challenge, and having formal training programs available can be useful. Regarding the everyday use of 3D printing, all respondents, except one, found it is easy to use. Specifically, 3 of them reported that it is very easy to use, 20 that it is moderately easy, and 12 that it is slightly easy. Overall, these responses suggest some issues related to the skill-set workability of 3D printing A significant number of respondents noted that the ease of use of 3D printing is limited, and there is a lack of proper training available. For instance, one teacher noted that "it is necessary to provide seminars for teachers on the operation of 3D printing" and another teacher explained that training is needed not only to familiarise teachers with the use of 3D printing but also for providing them guidance on "how to use 3D printing in the educational process".

4.4 Contextual Integration

Contextual integration refers to the extent to which 3D printing is compatible with the broader context in which it is being implemented. It considers the wider factors that may impact new technology introduction and use as for instance, resource constraints. Assessing contextual integration *includes examining the available infrastructure, staffing and material resources*. To ensure the successful embedding of new technologies in everyday practices it is important to assess and address issues related to contextual integration. This may involve adapting current infrastructural arrangements or securing additional resources.

All respondents stated that 3D printing is compatible with the existing school equipment and wider digital infrastructure. Specifically, 10 out of 36 respondents stated that 3D printing is sufficiently compatible while the remaining 26 respondents stated that it was very compatible. However, at the same time, the respondents expressed dissatisfaction with the resources available for technical support. Only 11 out of 36 respondents declared that these resources are sufficient, while the remaining 25 respondents pointed to inadequacies of technical support resources. Additionally, 7 out of 36 respondents pointed to deficiencies related to consumables. The remaining 29 respondents were satisfied by the availability of consumables. Overall, these responses suggest some issues related to contextual integration especially related to the availability of resources for technical support and consumables. For instance, one of the participants noted: "The Greek market has very expensive consumables and almost non-existent spare parts which I prefer to get from eBay". Another teacher stated: "The purchase of consumables requires money that do not exist at schools and there will certainly be a burden on the teacher".

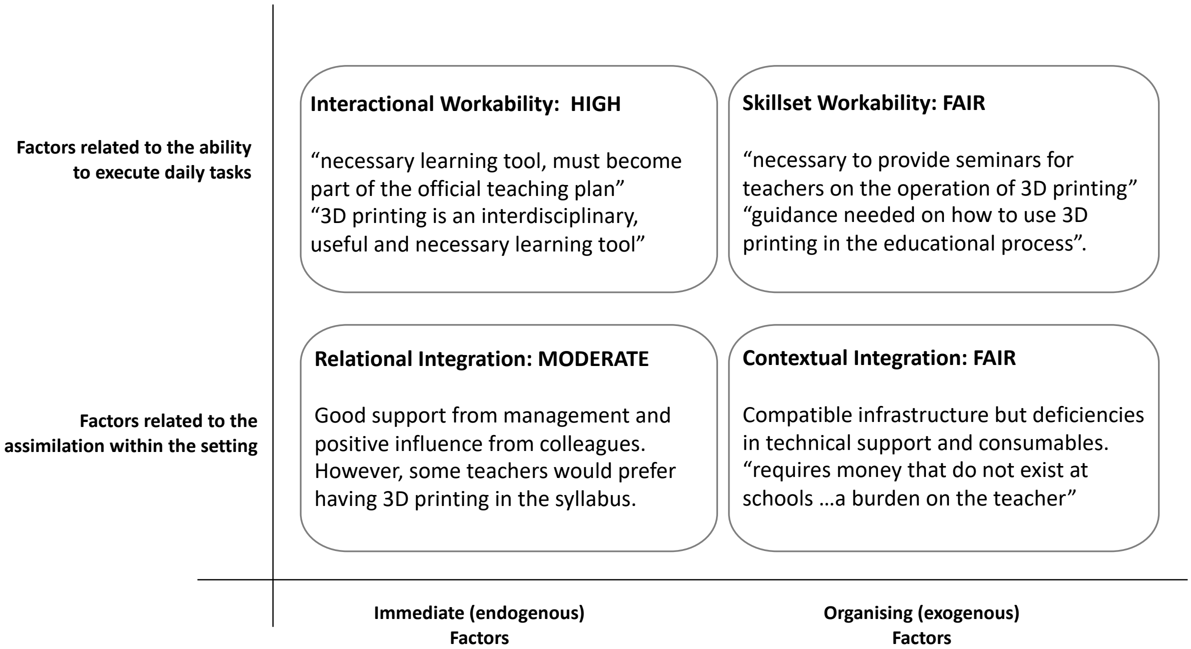

Figure 2. Overview of Empirical Findings on the Normalisation of 3D Printing at schools.

5 Discussion

Digital learning with the use of 3D printing can provide engaging and interactive experiences for students, promote creativity and innovation, and help students develop problem-solving skills strengthening digital literacy. The findings of this study indicate that teachers are satisfied with the use of 3D printing in classrooms and the impact it has on their interactions with students (interactional workability). This aligns well with similar findings in prior research (Ford and Minshall 2019; Novak and Wisdom 2018). However, it is not enough. Although 3D printing is well-received by teachers, to become a routine part of everyday practice, a number of issues must be addressed. These issues do not relate to the features of the technology itself but to exogenous factors. Teachers reported that they need training for developing required skills, technical support and resources including consumables. Insufficient training and resources present significant obstacles to the integration of instructional technologies, extending beyond 3D printing. Previous research has demonstrated that teachers often express dissatisfaction with the available resources for incorporating new technologies into their teaching practices (Reid 2014). By addressing these issues, 3D printing can become a routine and valuable part of the digital learning landscape, providing students with the skills they need to succeed in a technology-driven world.

This study makes valuable contributions to the growing body of literature on digital learning with the use of 3D printing: it provides insights on key factors that impact the assimilation of 3D printing in school teaching, it also provides evidence on specific issues teachers face and a nuanced perspective that highlights both teachers' contentment with immediate benefits of 3D printing and their frustration with external obstacles. This nuanced perspective reveals that technology features alone are insufficient for widespread use and that contextual enablers are also critical. Overall, the study provides a rich and detailed analysis of the experiences of a representative sample of teachers who have experience using 3D printing in teaching. This is particularly valuable as research examining experienced teachers´ perceptions, opinions, and conceptions about using 3D printing in education is uncommon (Anđić et al. 2023). The stances of those that have already been engaged with 3D printing in their teaching provide insights to situated and emergent issues that can not be captured by focusing only on the technology. These insights have direct implications for practice and can inform both policy makers and school managers.

Furthermore, the study findings have implications for research providing directions for further studies. One key implication for Information Systems research is the need to move beyond simply examining teachers' intentions to use 3D printing and instead focus and explore the ways in which this technology is gradually assimilated into everyday work practices. This would involve more longitudinal data and data on how 3D printing is used in different teaching contexts. Extending the research across multiple contexts would allow the investigation of the impact of cultural and other contextual factors. Finally, further research could also include the perspectives from other stakeholders (students, parents, and administrators) that also shape technology assimilation in schools. Involving multiple perspectives could provide a holistic view.

A key limitation of this study is that it was conducted in a single country. It would be valuable to replicate this research across multiple countries to identify any differences in how this technology is perceived and used in different cultural contexts. Additionally, such a multi-country study covering many different national education systems with different levels of resources could bring insights related to the impact of funding and resource availability. Another limitation relates to the fact that the data collected reflect a single point in time. As explained when discussing the implications for research, a longitudinal study following teachers over time as they integrate 3D printing into their practices could provide deeper insights.

6 Conclusion

In conclusion, by focusing on the experiences of teachers who are using 3D printing in their work, the study provides a nuanced understanding of the challenges and opportunities involved. The study uses the Normalization Process Model (NPM) to analyse factors affecting assimilation of 3D printing in teaching practices grouped in four categories: factors related to everyday task execution (workability both at the immediate and organizing level) and factors related to novelty integration within the wider educational setting (integration both at the immediate and organizing level). Overall, the teachers participating in this study were content with immediate workability and integration but also pointed to frustrations related to organizing integration (especially related to the availability of resources for technical support and consumables) and workability (for instance, lack of proper training not only on the use of 3D printing but also on how to use it in the educational process). Moving forward, future research can build on these insights by exploring the ways in which 3D printing can be integrated in teaching practices in a more effective manner. This will require a more comprehensive understanding of the contextual factors in different cultural and educational contexts and a better understanding of the dynamics involved through longitudinal studies. Overall, this study underscores the potential of 3D printing as a tool for promoting digital learning, creativity, and innovation in schools. However, for this technology to become a routine part of everyday teaching practices, it is crucial to address the practical and contextual challenges that teachers face when introducing 3D printing in their work.

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Annex: English Translation of Questions used for Data Collection

Demographic data

Age:

Gender:

Location:

Specialty:

How long have you been working with 3D printers?

Interactional Workability
Did the use of the 3D printer increased teaching productivity?
Did the use of the 3D printer help you teach parts of the curriculum more directly?
Did the use of the 3D printer made better understood what you wanted to teach to pupils?
Overall, do you think that the use of the 3D printer has benefited your teaching work?

Relational Integration

Did your work environment influence your use of 3D printing?
Did the management of the school support the use of 3D printing?
Did the supervising school organization generally support the use of 3D printing?
Overall, are you satisfied with the support you had?

Skill-set Workability

Was it easy to learn the operation of a 3D printer?
Was there any training by qualified personnel on the operation of the 3D printer?
Do you think the 3D printer is an easy-to-use tool?
Overall, are you satisfied with the overall effort you put into learning how to use the 3D printer?

Contextual Integration
Is the 3D printer compatible with the equipment the school already has?
Is there a person or team available to support you if a problem occurs with 3D printing?
Do you have the required resources (consumables etc.) available to use the 3D printer?
Overall, are you satisfied with the 3D printer assistance and logistics?

Kindly provide in the textbox below additional details and insights you believe to be significant for the use of 3D printing.