Technological Pedagogy and Digital Competence in Sustainable Education: Public School Teachers' Perspectives on Metaverse-Based Educational Practices

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***Abstract*—In this research, the aim is to examine the views of teachers towards technological pedagogy (techno-pedagogy) and digital competence metaverse-based applications in the context of sustainable education and to reveal how teachers can be supported in this regard. A qualitative research design was adopted. The main purpose of the research is to reveal the views of teachers working in public schools on the integration of metaverse-based technologies, which is an emerging technological trend, into teaching processes. The research has been planned to analyze a need. In this direction, four sub-objectives were determined and seven qualitative questions were prepared to achieve the study objectives. A scale was developed by the researcher and before it was created, the opinions of 12 experts were obtained based on which the final version of the scale to be applied was determined accordingly. The following sub-objectives were determined: (1) to determine teachers' perceptions and attitudes towards metaverse-based education practices, (2) to reveal their experiences and suggestions on how these technologies can be integrated with sustainable education, (3) to examine the differences in digital competence between disciplines and (4) to define the difficulties faced by teachers in the technology integration process. A total of 92 public school teachers from different disciplines participated. The data were collected online via Google Forms. The obtained data were analyzed via descriptive content analysis using QDA Miner Lite software. The research findings show that teachers generally regard technological developments positively, but they do not have enough knowledge about metaverse-based applications. Additionally, although teachers with sufficient knowledge do believe that these technologies can make a positive contribution, they think there may be problems in terms of technical infrastructure, digital transformation insufficiency and pedagogical adaptation. Therefore, schools should incorporate the integration of such technologies into their education policies and ensure the transformation occurs in a fully structured manner. It has also revealed that the data obtained comply with the sustainability criteria in education and that the education of the future should be in this style.**

***Keywords*—metaverse, public school teachers, technological pedagogy, digital competence, sustainable education**

I. Introduction

Additionally, since this study was conducted specifically in the context of the Turkish Republic of Northern Cyprus (TRNC), it is also important in terms of providing data that can be used for updating, shaping and implementing regional education policies. In order for this transformation by governments and education policy developers to be more effective, the study was conducted with teachers working in the public sector. In parallel with the digital transformation process in the TRNC, it is clear that determining the digital competencies of teachers will make an important contribution in terms of teacher candidates receiving a more up-to-date education according to the opinions and suggestions determined here. In addition, the determination of digital competencies will provide concrete findings on how these competencies can be maintained and evaluated from an educational perspective. The study will also be able to address the approaches of teachers from different disciplines and enable discipline-specific effects and educational policies.

The aim of the study

Four sub-objectives have been determined in accordance with the purpose of the research. These sub-objectives are as follows;

1) To determine the perceptions, attitudes and opinions of public teachers towards metaverse-based education practices.
2) To identify the relationship between teachers' digital competencies and technological pedagogical domain knowledge.
3) To analyze teachers' views on the role of metaverse technologies in education on the axis of sustainable education.
4) To determine the technological integration experiences of teachers from different disciplines and the challenges they face based on these experiences.

In line with all these aims, this study reveals how teachers adapt or their needs in the education digitalization process, which has assumed increased importance. It also aims to discuss how this can be adapted to the sustainable education approach and its scope. The findings of the research are expected to guide policy makers, faculties of education and education-for-service programs in the education system. The opinions of public teachers are valuable in terms of shedding light on different aspects of this study.

II. Literature Review

Today, rapidly developing technologies impact all aspects of our lives. In particular, technological innovations have become an indispensable part of daily life. There are multiple factors behind this phenomenon including that such technologies make our lives easier along with applications that allow people to communicate with each other, among others. It is also clear that education is not immune to the effects of new technologies. In the 21st century, digital technologies have started to impact our lives to the extent that all social structures have undergone a digital transformation. Education is one of the domains that has been impacted most

significantly by this transformation [1]. In fact, the way in which education has been delivered has not changed since the birth of civilization, as the traditional teacher-centered learning model has been followed, where the teacher delivers knowledge and the student is a passive listener. However, this does not imply that educational materials or methods have remained static. On the contrary, the study emphasized that in new-generation learning models, the role of the teacher is evolving and emerging technologies such as the metaverse have played a significant role in facilitating this pedagogical transformation. Although this is considered the classical education model at the education level, many new education models have emerged in recent years. While classical education is losing its popularity, new education models are gaining increased importance in our lives. The reason for this is that it easily adapts to everything that makes one's life easier.

Traditional educational approaches emerge as a period in which technology transforms social structures thanks to the effects it provides to our fast-paced lives [2]. Classical education or traditional education is gradually being replaced by more flexible, accessible, and space- and time-independent education models or is being integrated into these new developments. As a result of the digital transformation, educational processes, the way individuals access information, and their learning and teaching experiences are all transforming [3]. In fact, their expectations from education undergoing a radical transformation. Exactly this is why the definition of digital transformation in our lives is absolutely in every field.

This digital transformation or change not only impacts students, but also profoundly affects teachers and education systems. All education stakeholders are actually at the center of this change [3]. The speed of development of new technologies and the rate at which they are integrated into our lives also means that teachers should be sufficiently competent to use these pedagogical technologies effectively and, accordingly, have adequate digital literacy levels. In fact, as we expect all things in our lives to be updated, there is also an expectation that teachers should also be updated [4].

In this context, the concept of "sustainable education" has also started to assume an important role in education. Although sustainability seems to be a concept more related to nature, it has a very important place in terms of the continuity, sustainability and efficiency of our lives. Education, which is one of the most important aspects of our lives, is very valuable [5]. It is not just an approach based on transferring information; by going beyond the transferal of information, it directs individuals to think critically, understand technology and use it meaningfully. Additionally, it has taken on a structure that can be used ethically and aims to raise individuals who are sensitive to nature and society. These are all among the main goals of education, which ultimately aims to raise individuals who are beneficial to society and the world [6]. In addition, transformation in education in line with sustainable development goals can only become possible with the assimilation, adoption and active participation of teachers, who are among the most important stakeholders of education.

The element that can provide the most support to sustainable education is in fact technology [7]. This is due to the fact that technology can enable energy savings, thanks to the fact that we can produce independently of space. With online transactions, it is possible to prevent waste by eliminating the need for paper. In many instances like this, it is only through technology that we can make life more sustainable. Therefore, this reveals how important sustainable education has become.

In the light of all these technological developments, one of the most relevant issues that has emerged in recent years is the concept of the metaverse. The metaverse is an interactive digital universe that is independent of space, crosses borders, and functions in an integrated manner with other new technological trends (VR, AR, Artificial trends, Blockchain, etc.) [8] where individuals can reflect a completely digital identity. Thanks to this virtual universe, individuals can participate in a structure where they can do whatever they want in the form of a digital identity by creating their virtual twins in exactly the same way through their avatars. In this universe, users can gain many experiences [9]. Through their avatars, they can socialize, exchange information, and benefit from a learning experience in a completely personalized way. In this context, the metaverse can now be used in education for everything that distance education can offer and more [10]. With the use of the metaverse in education, a learning-based environment can be offered where students can have active participant-based, personalized experiences. This environment can exist independently of time and place [11]. The innovative features of the metaverse means that it is a technology that can be encouraged to new education models within the scope of sustainable education.

However, as these techno-pedagogical education models or new paradigms in education are becoming more prevalent, it is not considered sufficient for education stakeholders to only have technical knowledge. For teachers in particular, who are the most important education stakeholders, this is completely inadequate. Teachers must also be able to use technology effectively and meaningfully, as well as incorporate it into pedagogical content [12]. In this context, the "Technological Pedagogical Content Knowledge (TPACK)" model has importance as it tries to explain how teachers can combine technological field knowledge pedagogically [13]. In particular, in terms of the use of complex and comprehensive technologies such as the metaverse in education, it is imperative for teachers to be able to effectively integrate TPACK components [13].

In order for all these developments to occur, it is imperative that education policies are updated in line with the principles of digitalization and sustainability. The importance of academic studies conducted with the aim of creating more robust foundations for this to take place is increasing [14]. In this regard, the main purpose of this study is to contribute to the education system in line with sustainable education goals by examining the views of teachers working in public schools on metaverse-based education practices in terms of both techno-pedagogical and digital competence.

III. Materials and Methods

In this section, the research model, the scope of the research, the sample group, data collection tools, statistical methods and techniques used in data collection and analysis are explained.

This research aims to reveal the views on technological pedagogy and digital competence in sustainable education: metaverse-based educational practices of public teachers by using the qualitative research technique. Qualitative research is an interpretive research method based on verbal data that aims to provide an in-depth examination of the experiences, opinions and meanings of individuals or groups [15]. It is very important that the correct design is chosen at the beginning of the research when adopting the qualitative research method [15].

This study was conducted using qualitative research methods, employing a case study design. Case studies are a qualitative approach that enables an in-depth examination of a specific phenomenon within its real-life context, providing detailed insights into participants' experiences [16]. Accordingly, this research comprehensively explored the perspectives of public-school teachers regarding metaverse-based educational practices within the framework of sustainable education. This study was conducted during the spring semester of the 2024-2025 academic year. Experts were consulted to define the study group and methodology. Using maximum variation sampling, 92 participants were selected in the qualitative phase to ensure comprehensive and rich data relevant to the research objectives. Specific inclusion criteria were established to align the sample with the study's aims and sub-objectives. The needs analysis included both expert opinions and an extensive document analysis through a systematic literature review. This review focused on scientifically accepted publications related to "metaverse," "sustainable education," "techno-pedagogy," and "digital competence." A criterion-based purposive sampling method was applied to select relevant studies, resulting in the examination of 102 publications dated between 2018 and 2025. During the needs analysis phase, opinions were taken from twelve experts from various different fields. Based on the expert opinions, a qualitative scale consisting of seven different questions was prepared by the researcher. The aim of this scale is to reveal the perceptions, attitudes and opinions of public teachers on the research subject. In this direction, 92 teachers working in the public sector in the TRNC formed the sample group as participants.

The data collection process was carried out online in April 2025. Participants were informed that they were participating in the study on a completely voluntary basis. Participants were advised inn the "Informed Consent Form" that the collected data would only be used for scientific study purposes. For the implementation of the study, permissions were obtained from both the ethics committee of the University of Kyrenia and the TRNC Ministry of National Education.

A. Ethical Approval and Informed Consent

Institutional Review Board Statement: The study was approved by the Ethics Committee of University of Kyrenia, with approval number FSBB/24.

Informed Consent Statement: In order to collect the demographic information of the participants (Table 1), an informed consent form was developed by the researcher. This form was structured on the basis of criteria such as gender, age, discipline, level of technological competence and purpose of using technology, which are believed to have effects in accordance with the purpose of the study.

Table 1. Distribution of demographic information of participants

Category		Theme	(f).	(%)
Experimental Working Group	Distribution of participants by gender	Female	54	58.70
		Male	38	41.30
	Distribution of participants by age	22-25	6	6.52
		26-35	10	10.87
		36-45	30	32.61
		45>	46	50.00
	Participant's Branch	Classroom Teacher	22	23.91
		Mathematics	14	15.22
		Foreign Language	18	19.57
		Social Sciences	10	10.87
		Quantitative Sciences	7	7.61
		Accounting-Business Administration	13	14.13
		Vocational Teacher	8	8.70
Field Experts Working Group	Level of Technological Proficiency	Old	10	10.87
		Middle	64	69.57
		High	18	19.57
	Purpose of Using Technology	Social Media	2	16.67
		Communication-Finance	7	58.33
		Game	2	16.67
		Other	1	8,33
	Specialty	Educational Sciences	3	25.00
		Computer Science	4	33.33
		Engineering	1	8.33
		Software	2	16.67
	Distribution of participants by title	Linguist	2	16.67
		Professor	8	66.67
		Assists. Prof. Dr.	2	16.67
		Instructor	2	16.67

1) Data collection tools

The data of this research were sent online to public schools via Google Forms with ethical permissions. Interview forms were administered to the sample group to obtain qualitative data.

2) Qualitative data collection tools

The interview form questions, which were prepared to collect qualitative data, were sent to public teachers online via Google Forms. Public teachers who expressed the willingness to do so on a voluntary basis and in accordance with the ethical framework participated in the study. However, although the application was made through the online platform, the researcher had the opportunity to be present and observe in two schools where data were collected during the application process.

3) Education professionals interview form

The Educational Experts Interview Form used in this research was developed to expand the needs analysis the for main topics including metaverse applications, sustainable education, techno pedagogy and digital literacy. The questions of the form are structured in line with the relevant literature review and research purpose; in order to ensure the validity of the scope, the opinions of 12 experts from different fields including Turkish Education, Measurement and Evaluation, Computer Engineering and Educational Technologies were taken. In line with the expert feedback, the questions were revised and academic competence was strengthened. The form, which consists of open-ended questions, is structured in a way that allows participants to express their opinions in depth and freely.

In this way, thanks to the form created with the contribution of experts from different disciplines, it was ensured that the questions were placed on a comprehensive scale with the aim of making a more effective contribution to the field by reducing the margin of error.

B. Analysis and Interpretation of Data

1) Document analysis

The descriptive content analysis method was used in the analysis of the data in the documents related to all scientific studies collected within the scope of this study. The most important issue in choosing this method is to reveal certain trainings on the subject. The collected data can then be systematically recorded in the digital environment and data loss is prevented.

2) Analysis of qualitative data

The fact that the qualitative data of the research were collected both face-to-face and digitally prevented data loss and ensured that suitable data were collected. In addition, the coding process was carried out on the basis of grounded theory. The obtained data were systematically divided into themes and sub-codes were created by the researcher. In this context, descriptive analysis, content analysis and continuous comparison techniques were used, and the process was recorded completely in the digital environment. QDA Miner Lite software was used in the analysis. In this way, even in the analysis process, the principle of sustainability in education was followed.

3) Validity and reliability study in qualitative analysis

The data obtained in qualitative research should be analyzed meticulously in terms of validity and reliability. Because it reflects the worldview the researcher conducting the analysis to a certain extent, they have a direct impact on the process. Therefore, the validity and reliability part should be explained in detail. The principles of validity and reliability are critical to the protection of the study both in particular and in general. The work done should eliminate all question marks in every respect. Accordingly, the table below shows that all criteria are complied with in terms of the validity and reliability of the findings and what attention is paid.

Researchers are required to act in accordance with these criteria for the robustness and reliability of the findings (See Table 2).

Table 2. Evaluation process within the scope of validity and reliability

Factor	Process
Internal Validity	Throughout the data collection process, the researcher actively participates, ensuring a lasting impact. For this reason, the data are clear and unambiguous. All data are divided into themes by the researcher and entered into the coding process. Identifying themes based on data ensures consistency.
External Validity	The findings are transferable as they are clear and unambiguous in terms of sustainability. Detailed information was given to the participants by the researcher. Participants were selected appropriately by the maximum variation sampling method.
Reliability	The two researchers conducted the analyses separately and then the joint analysis was presented in the study. All prepared findings have been examined by an impartial expert. The research method was explained in detail to all participants.
Neutrality	In the data collection, data analysis and findings sections, the researchers were completely impartial and open. It is completely free from personal comments and prejudices. This whole process was monitored by an impartial expert observer. The researchers evaluated the whole process transparently and informed the participants.

IV. Result and Discussion

A. Findings Related to the First Research Question

The first research question is "What are the perceptions, attitudes and opinions of public teachers towards metaverse-based education practices?" The findings related to this question are presented below.

Table 3. Public teachers' perceptions, attitudes, and opinions on metaverse-based educational practices

Category	Theme	*(f).*	*(%)*
Metaverse Perception	I Don't Know	12	13.04
	I Have Little Knowledge	20	21.74
	I Have Information	60	65.22
Metaverse Attitude	Makes a positive contribution to education	60	65.22
	It does not contribute to education	32	34.78
Metaverse Vision	It makes a positive contribution to education. It is important in terms of equal opportunity.	60	65.22
	It contributes negatively to education from a health, psychological, etc. point of view.	20	21.74
	I have no idea.	12	13.04

As can be seen in Table 3, public teachers were examined in three different categories. In the metaverse perception category, it can be seen that the majority of teachers have knowledge about the metaverse (n = 60, 65.22%). It is noteworthy that only a very small number of them (n = 12, 13.04%) had no information at all. In fact, this shows how much metaverse and metaverse applications have impacted our lives, at least to the extent that the teachers have a certain level of awareness of them. In addition, most of the teachers (n = 60, 65.22%) expressed the opinion that metaverse applications will contribute positively to education. The remainder (n = 32, 34.78%) did not indicate that they will make such a contribution. In the metaverse vision category, the majority (n = 60, 65.22%) stated that it will make a positive contribution, while others (n = 20, 21.74%) said it will have a negative contribution in terms of health. The rest

stated that they have no idea.

Furthermore, taking into account the comments of some participants;

Participant 13:

Demonstrated a solid understanding of the metaverse concept and perceived it as having a positive impact on education, particularly emphasizing its role in promoting educational equity.

Participant 27:

Possesses limited knowledge about the metaverse and remains cautiously neutral regarding its potential educational implications due to insufficient information.

Participant 31:

Identified as being unfamiliar with the metaverse, indicating a knowledge gap but expresses openness to learning about this emerging technology.

Participant 4:

Acknowledged the positive contributions of the metaverse to education but raised concerns about potential adverse health and psychological effects.

Participant 91:

Well-informed about the metaverse and supportive of its integration into education, highlighting its significance for fostering equal opportunities.

Participant 62:

Recognized the educational benefits of the metaverse while also maintaining awareness of its possible drawbacks, advocating for a balanced approach.

Participant 79:

Reported having minimal knowledge of the metaverse and refrained from forming a definitive opinion, indicating a need for further exposure and education on the topic.

Overall, it can be said that public teachers' perceptions of metaverse-based education are positive, but there is a significant divide in their attitude and vision. This situation reveals the necessity of restructuring education policies and teacher training in a way that increases awareness and pedagogical alignment towards such digital transformation tools

B. Findings According to the Second Research Question

The second research question is "What is the relationship between teachers' digital competencies and technological pedagogical domain knowledge?" The findings related to this question are presented below.

Table 4. The relationship between teachers' digital competencies and their Technological Pedagogical Content Knowledge (TPACK)

Category	Theme	*(f).*	*(%)*
Digital Proficiency Level	Low	10	10.87
	Middle	64	69.57
	High	18	19.57
Perception of Techno-Pedagogy	There should be technology integration in all areas of education	82	89.13
	There should be no technology integration in all areas of education	10	10.87
Relationship Between Digital Competence and Techno-Pedagogy	It's Definitely Related.	74	80.43
	It is Moderately Related.	10	10.87
	It is unrelated.	8	8.70

As can be seen in the table, in accordance with the second sub-objective, the level of digital competence has revealed the level of relationship between the level of digital competence, the perception of techno-pedagogy, digital competence and techno-pedagogy. When the results are examined in detail, it can be seen that a large proportion of the teachers have a low level of digital competence. On the other hand, it is revealed that teachers with medium and high digital proficiency levels support techno-pedagogical integration. These results reveal that the two conditions are completely positively related to each other. As seen in Table 4 a significant majority of participants (69.57%) assessed their digital competencies as being at an "intermediate" level. Also as seen in Table 4 the proportion of those who indicated they possess a "high" level of competency was 19.57%, while only 10.87% considered themselves to have a "low" level of competency. This suggests that teachers are somewhat familiar with digital technologies but require further development in areas that necessitate advanced expertise. As can be seen in Table 4 in terms of Techno-Pedagogical Perception, 89.13% of the participants believed that the integration of technology in all areas of education is essential. This high percentage reflects the positive attitudes of teachers towards the use of technology in education. However, 10.87% expressed a negative view regarding this integration. With regard to Digital Competency and Techno-Pedagogy: 80.43% of participants stated that there is a "definite relationship" between digital competency and techno-pedagogical knowledge, while 10.87% perceived this relationship as being at a "medium level," and 8.70% indicated that it is "unrelated." This finding demonstrates that teachers with high digital competency are more open to technology integration and can more effectively incorporate digital tools into their pedagogical approaches.

Furthermore, taking into account the comments of some participants;

Participant 41:

Demonstrated a moderate level of digital proficiency and strongly believed that technology integration is essential in all areas of education. This participant also perceived that a definite relationship exists between digital competence and techno-pedagogy.

Participant 72:

Exhibited a low digital proficiency level but supported the idea of comprehensive technology integration in education. This participant acknowledged a moderate correlation between digital skills and techno-pedagogical practices.

Participant 33:

Has a high level of digital proficiency and firmly advocated for the integration of technology across all educational fields. They also supported the strong connection between digital competence and techno-pedagogy.

Participant 34:

Showed a moderate digital proficiency level, preferred limited or no technology integration in certain educational areas, and was cautious about the relationship between digital

competence and techno-pedagogy, viewing it as moderately related.

In conclusion, it can be stated that as teachers' levels of digital competency increase, their belief in technology-supported pedagogical practices also strengthens; this, in turn, lays the groundwork for more effective technology integration in education.

C. Findings According to on Third Research Question

The third research question is "What are the teachers' views on the role of metaverse technologies in education on the axis of sustainable education?" The findings related to this question are presented below.

Table 5. Teachers' views on the role of metaverse technologies in education in the context of sustainable education

Category	Theme	(f).	(%)
Metaverse and Metaverse Applications Opinions	I Don't Know	12	13.04
	I Have Little Knowledge	20	21.74
	I Have Information	60	65.22
Views on Sustainable Education	The Future of Education	82	89.13
	Classical Education Is More Efficient	10	10.87

As can be seen in the Table 5, in accordance with the two sub-objectives, metaverse and metaverse-based applications and sustainable education views were examined. When the results were examined in detail, it was revealed that they had positive relationships and affected each other. As can be seen in the table, metaverse applications or metaverse-based education can have a positive effect in terms of sustainable education.

Furthermore, taking into account the comments of some participants;

Participant 14:

Demonstrated a good understanding of metaverse applications and strongly supported the view that sustainable education represents the future of education.

Participant 2:

Had limited knowledge about the metaverse and preferred classical education, expressing skepticism about the effectiveness of new educational models.

Participant 23:

Well-informed about metaverse technologies and aligned with the perspective that sustainable education will shape future learning paradigms.

Participant 34:

Possessed minimal knowledge about the metaverse and favored traditional education methods over emerging ones.

Participant 65:

Exhibited comprehensive knowledge of metaverse applications and believed in the transformative potential of sustainable education for the future.

Participant 83:

Was uncertain about metaverse technologies and remained inclined towards classical education approaches.

D. Findings According to the Fourth Research Question

The fourth research question is "What are the technological integration experiences of teachers from different disciplines and the challenges they face based on these experiences?" The findings related to this question are presented below.

Table 6. Technological integration experiences and challenges faced by teachers from different disciplines

Category	Theme	(f).	(%)
All Disciplines Have a Common Opinion	Lack of Infrastructure Lack of Technological Tools Inadequacy of Education Stakeholders	92	100

As can be seen in Table 6. almost all of the teachers from all disciplines gave the same answers. For this reason, themes were created by gathering them under three common main headings without distinguishing them. The difficulties that all teachers say in common are the same, in fact, education policy makers should focus on this issue. In addition, it is revealed that the education policies in this context should be fully integrated into national education. The fact that all teachers have the same opinion is an indication that such problems are experienced by everyone.

The qualitative data presented in Table 7 comprehensively illustrates the perspectives on the use of digital technologies in education, sustainable education, teachers' experiences with technology integration, and metaverse-based educational applications. It has been emphasized that to utilize digital technologies more effectively in education, it is necessary to address infrastructure deficiencies (78.26%) and to continuously train educational stakeholders (21.74%). In the integration of sustainable education into traditional education, advantages such as environmental conservation (21.74%), interdisciplinary learning (16.30%), critical thinking skills (27.17%), and preparation for the future (21.74%) have emerged prominently.

Among the contributions of technology to students' individual learning styles are the richness of visual materials (13.04%), the richness of auditory materials (14.13%), increased motivation (32.61%), and the ability to learn at one's own pace (10.87%). The most significant challenges faced by teachers during technology use have been identified as internet issues (56.52%), technological inadequacy (21.74%), distraction and lack of motivation (10.87%).

In general opinions regarding metaverse-based educational applications, approximately one-third of the participants (34.78%) believed that these applications enhance interaction, while 19.57% indicated that they gained experience for the first time through this study. Additionally, positive thoughts such as increasing motivation (13.04%) and the potential to be the educational model of the future (15.22%) are noteworthy. Teachers noted that metaverse tools facilitate the transition from teacher-centered to student-centered approaches in pedagogical practices (34.78%), enhance interactive and scenario-based teaching applications (21.74%), and ease the concretization of abstract concepts.

Finally, when examining the effects of metaverse applications on student motivation and the learning process, the majority of teachers (56.52%) observed a significant increase in student motivation, while 25% noted the creation of participatory and interactive learning environments, and 18.48% expressed that students' interest in the class and retention had improved. These findings indicate that metaverse-based applications are effective in transforming teachers' pedagogical approaches as well as enriching students' learning experiences.

Table 7. Qualitative data table

Dimension	Category		(f).	(%)
What kind of changes do you think need to be made in order to use digital technologies more effectively in education? Findings on the Question	Lack of infrastructure and materials must be eliminated		72	78.26
	Education stakeholders should be continuously trained		20	21.74
What do you think about sustainable education? What advantages do you see in integrating classical education? Findings on the Question	Nature Conservation		20	21.74
	Interdisciplinary Learning		15	16.30
	Critical Thinking Skills		25	27.17
	Preparing for the Future		20	21.74
	All		12	13.04
How have you observed that using technology in education contributes to students' individual learning styles? Findings on the Question	Wealth of Visual Material		12	13.04
	A Wealth of Auditory Material		13	14.13
	Motivation		30	32.61
	Self-Paced Learning		10	10.87
	Timeless and Spaceless Learning		10	10.87
	Self-Regulation Skill		5	5.43
	Cooperative Learning		6	6.52
	Equal Opportunity		6	6.52
What are the biggest challenges you face when teaching using technological tools and digital platforms? How do you deal with these challenges? Findings on the Question	Reason?		(f).	(%)
	Internet Problems		52	56.52
	Technological Inadequacy		20	21.74
	Distraction		10	10.87
	Weakness of Motivation		10	10.87
What are your general thoughts on metaverse-based education apps? Have you had any experience before? How do you plan to use these apps in education? Findings on the Question	Answer	Reason?	(f).	(%)
	Yes	Increases engagement	32	34.78
	No	My first experience with this project	18	19.57
	Yes	Virtualization Increases Motivation	12	13.04
	Yes	Future Education Model	14	15.22
	No	Lack of Technical Infrastructure-	16	17.39
How do you think metaverse-based educational tools are transforming teachers' pedagogical approaches? Findings on the Question	Reason?		(f).	(%)
	Transition from a teacher-centered structure to a student-centered approach		32	34.78
	Increase in interactive and scenario-based teaching practices		20	21.74
	Ease of concretization of abstract concepts		12	13.04
	Awareness development in digital pedagogical competencies		6	6.52
	Tendency to diversify learning environments		22	23.91
Have you had any experience with the effects of metaverse-based applications on student motivation and the learning process? Explain. Findings on the Question	Reason?		(f).	(%)
	A significant increase was observed in student motivation		52	56.52
	Participatory and interactive learning environments were created		23	25.00
	Students' interest and retention in the course increased		17	18.48

V. Discussion

In this research, the aim is to examine the views of technological pedagogy (techno-pedagogy) and digital competence metaverse-based applications among public teachers in the context of sustainable education and to reveal how they can be supported. According to the findings, it has been determined that most of the teachers have low or medium levels of digital competence. In addition, they mentioned that although they have limited knowledge of the concept of metaverse, they only have a certain level of knowledge. In fact, they information they have largely comes from social media. Most teachers stated that they did not have any experience of the metaverse universe, but wanted to have such experiences. Additionally, the teachers stated that the physical infrastructure in the institutions where education is provided, the lack of internet speed and the fact that all education stakeholders do not have sufficient training on these issues, are all aspects that are inadequate. They stated that the process can be adversely affected by this insufficient or limited knowledge, and in order for this to be positive, positive attitudes can emerge with a technological process based on practice and experience at the end of the process. Resultantly, the view that the metaverse can contribute to sustainable education through virtual interaction, gamification and scenario-based learning opportunities has emerged. In addition, in terms of equal opportunity in education, it has been argued that it can make a significant contribution to the protection of nature and sustainable life thanks to timeless and spaceless education. Certainly, in order for all this to be realized, they underlined that all education stakeholders should have the necessary levels of techno-pedagogical and digital competence and drew attention to its importance.

In the research conducted by Diaz *et al*. [17] which presented similar results to our study, it was determined that teachers were reluctant at first in terms of integrating metaverse applications into education, but they overcame this reluctance thanks to their experiences as a result of education. He also stated that metaverse environments can make a positive contribution to education through visual, auditory richness, gamification and interactive teaching opportunities. In their study, Zhu and Liu [18] revealed that teachers have difficulty in associating metaverse applications within the scope of sustainable education, but through the training provided, learning difficulties can be eliminated and they become more motivated with the integration of scenario-based learning and project-based activities. In this study in particular, it was concluded that deep learning processes are supported by the active participation of students in digital environments. The findings of

Kavanagh *et al*. [19] concur with those of our research. In the technology integration part in particular, the problems of lack of hardware and digital transformation limitations were mentioned. In this research, it is emphasized that increasing the techno-pedagogical competencies of teachers and the integration of new generation technologies into education are the most important factors. In Selwyn's study [20], findings emerged that teachers' metaverse applications transformed their pedagogical approaches. This supports the view that digital technologies will reshape teacher roles. In a study conducted by Hwang and Lee [21], it was concluded that metaverse environments or metaverse classroom design experience had positive effects on pre-service English teachers. In particular, it has been found that it enriches the learning experience and increases technological acceptance levels.

However, when the literature is reviewed in detail, opinions can be observed about the negative effects that metaverse technologies can have on educational integration. For example, in Said's study, it was revealed that metaverse-based learning environments are very distracting, as students can perceive it to be a game outside of learning and disconnect from the lesson, resulting in the teacher experiencing difficulties in terms of classroom management and lesson efficiency [22]. In addition, in the study conducted by Nyaaba *et al*. [23] it was revealed that teachers and teacher candidates with limited resources will not have access to such technologies; in particular, public schools may experience problems in terms of access, infrastructure and equipment deficiencies which may create a new equal opportunity problem.

The findings of the study reveal that public school teachers have developed positive attitudes towards metaverse technologies and that these technologies have potential, especially in terms of sustainability in education. In addition, pedagogical competence, improved infrastructure and diversification of educational materials are required. Therefore, if we consider that Generation Z, who are digital natives, are now starting to work as teachers, it is thought that such new technological trends can be the future of education or have this potential. For the sustainable continuity of the world, models that can reduce consumption should be integrated into education. Moreover, it is important to recognize that the successful integration of metaverse-based technologies in education not only depends on individual teacher competencies but also requires systemic support at institutional and policy levels. Adequate funding, ongoing professional development programs, and infrastructural improvements are critical to overcome the current barriers identified by participants. Additionally, collaboration between educators, technologists, and policymakers is essential to develop inclusive and adaptable metaverse applications that address diverse learner needs and promote equitable access. Future research should focus on longitudinal studies to assess the long-term impact of metaverse integration on teaching practices and student outcomes, as well as comparative studies across different educational contexts and regions to better understand cultural and socio-economic influences.

VI. Conclusion

The main purpose of this research is to determine the perceptions of teachers working in public schools about metaverse-based sustainable education and to contribute to the literature by revealing the needs in line with these perceptions. As a result of the research, it is predicted that there may be positive aspects. In addition, many potential problems that have arisen or may arise were also mentioned. These problems include the lack of infrastructure, lack of equipment and inadequacy of education stakeholders in terms of techno-pedagogical and digital competence. The positive aspects of the study are that there are many beneficial aspects of the integration of metaverse applications into education for a sustainable world. In addition, it is foreseen that it can provide equal opportunities and make timeless and spaceless education in the form of motivating and gamification.

It is stated that public teachers' have insufficient information on the concept of the metaverse and its association with sustainability in general, but this deficiency can be eliminated with the applied process and has the potential to make a significant contribution to education with the awareness created. They expressed the belief that the role of the teacher will change and the concept of the "new generation teacher" will be integrated into technology-oriented teaching approaches thanks to such practices. It is thought that teachers can provide education in accordance with the principles of lifelong learning, especially with scenario-based learning and project-based learning, and contribute to sustainable life.

Considering all these results, it is clear that a transformation in education can be experienced in a short time. It is unavoidable that technology, which is an important part of our lives, can now have an impact in every field. In addition, as it is noted, professional parts such as which sub-branches should be integrated are now dealt with rather than the integration of technology.

In fact, policy makers have many important roles to play in this regard, because metaverse applications should be adopted as a state policy. The physical and hardware needs of schools should be met and in-service trainings should be given to teachers. The curricula of newly trained teachers should be updated in accordance with such programs. Regardless of the challenges of integrate existing teachers, if the training of teacher candidates is done correctly, the integration process will move in a positive direction. In addition, government policies can play an important role in encouraging researchers to work in this direction and identifying problems that may occur in advance. It can even contribute to revealing needs rather than problems. Another important aspect that needs to be addressed is the interdisciplinary study part because the effects it has on each areas should be carefully observed and platforms or materials suitable for each area should be designed.

Based on these results, the potential of metaverse technologies in education shows that it is not only a technological transformation, but also a pedagogical restructuring process. A techno-pedagogical approach should no longer be discussed, but a pedagogical approach. In this context, it becomes an important requirement for teachers to have high digital competence levels. In the education of the future, the understanding of sustainable living should have an important place in the technology of the future. All areas that continue in this way, that is, in a consumer style, will cause

problems in our lives. With sustainable education, solutions to most problems can be found in the long run. Trainings that are suitable for techno-pedagogical education can make significant contributions in terms of nature protection because issues such as the cost of education stationery materials, fuel for transportation to education, expenses of educational buildings, etc. can be eliminated. With timeless and spaceless education, we can contribute to sustainable life by minimizing all these expenditures.

A. Limitations

This section discusses the limitations of the study. The research has many limitations.

- Participants participated randomly and completely on their own accord
- The sample size was only 92 people
- It is only a qualitative study and focuses on opinion
- Detailed information about any study is not given, only the opinions of the teachers are taken
- Only public-school teachers were included in the study
- Implementation was only limited to the TRNC

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Methodology, İ.S and M.O; Formal analysis, İ.S; Resources, İ.S, Data curation, İ.S; Writing—original draft, İ.S and M.O; Writing—review & editing, İ.S; Visualization, M.O; Supervision, M.O; Project administration, İ.S and M.O. All authors have read and agreed to the published version of the manuscript.

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