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Fostering digital competence in pre-service biology teachers

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ABSTRACT

Biology teachers are required to use digital technologies in their teaching practice. The issue is that biology students do not receive sufficient training or have access to enough resources to use digital technologies effectively in their studies. The solution to this problem is to develop and implement an effective strategy for enhancing the digital competence of biology teachers. This strategy involves a comprehensive approach that includes pre-test/post-test assessments and targeted training sessions focused on improving digital literacy, communication, and digital content creation. The study employed quantitative research methods, including questionnaires and interviews with students. A total of 100 pre-service biology teachers were recruited from different teacher education universities in Kazakhstan. The results show that the use of innovative teaching practices can enhance the level of digital competence of pre-service biology teachers. The students demonstrated significant improvement across five dimensions of digital competency: information and digital literacy, communication and collaboration, digital content creation, safety, and problem solving. Barriers related to the inclusion of digital technologies into teaching included the inadequate training of teachers, lack of experience, lack of resources, lack of time, and no internet access. The present findings can be used to develop new education programs for teachers and improve the effectiveness of the existing ones.

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1. INTRODUCTION

In today's information society, digital competence is becoming an integral part of teacher education [1], [2]. Digitalization in education, particularly in the teaching of biology, is a key factor in enhancing the quality of learning. The contemporary educational system, oriented towards cutting-edge technologies, aims to ensure effective and accessible instruction through information and communication technologies (ICT) [3], [4]. Competence in digital literacy for educators encompasses the ability, skills, and behaviors required to work with ICT and digital devices during instruction [5]. It is one of the eight essential competencies for lifelong learning outlined by the European Commission [3], and it plays a vital role in self-fulfillment, personal growth, active citizenship, social inclusion, and overall career advancement [2]. In science education, digitalization is crucial, as the availability and effective use of digital tools significantly enhance the quality of teaching. The development of digital literacy among young professionals is essential for

preparing competitive specialists capable of functioning effectively in the digital era [6]. Clarifying the role of technology in pedagogical education will influence future educators' attitudes toward and abilities with technology [7].

The modern education system focuses on the latest teaching practices and advanced technologies and sets itself the task of ensuring that the content of learning is not only effective but also easily digestible [1], and ICTs are instrumental in achieving this goal. An urgent task is to foster digital literacy among young people to produce competitive, highly qualified specialists capable of functioning effectively in the knowledge society [1]. Despite the growing importance of digital skills, many pre-service biology teachers are inadequately prepared to integrate digital technologies into their teaching practice [3]. This lack of preparation not only hampers the effective teaching of biology but also reduces the competitiveness of graduates in the job market. Thus, a pressing challenge in contemporary teacher education is the creation and adoption of effective strategies aimed at improving the digital competence of future biology educators. This study addresses the problem of insufficient training and resources for biology teachers and aims to identify barriers to the integration of digital technologies in the biology curriculum.

Research into digital competence development becomes a crucial step in enhancing the quality of teacher training, especially given the rapid development of technology and its influence on modern education [3], [4], [6]. Amid the constantly changing information environment, it is essential to continuously update the content of education programs as well as teaching methodologies to encourage the advancement of students' digital competence [1]. Teachers' ability to plan and conduct lessons using digital technologies largely depends on their professional competencies [4], [8]. Hence, it is vital to incorporate digital innovations into the curriculum as an instrument to stimulate the acquisition of knowledge, skills, and abilities [1]. Digital technologies are being employed to establish a distinctive environment for both living and learning, where individuals can not only access digital resources but also generate them [2]. This evolving landscape necessitates that educators adjust their teaching methods and acquire new skills to function effectively within the digital learning context [9]. This study seeks to explore the effective approaches for developing digital competence in biology teacher training and to identify the potential obstacles and challenges in the adoption of digital technologies in education. The study has developed a strategy that includes a series of targeted training sessions aimed at enhancing the digital competence of future biology teachers. The research is based on preliminary assessments and post-tests, which allow for the measurement of the effectiveness of the proposed interventions. The primary focus is on developing skills in digital literacy, communication, digital content creation, security, and problem-solving [10], [11]. The proposed methodology encompasses a comprehensive approach to training that addresses contemporary challenges and needs in pedagogical education within the context of the digital age [12], [13]. The results of this study may help universities and other education organizations develop more effective programs for pre-service teachers.

Today, digital technologies penetrate every aspect of our lives, entering the walls of our homes, schools, universities, hospitals, and firms [6], [8], [9]. The increasing digitalization of everything from the economy to culture and education leads to the widespread dissemination of digital technologies [1], [9], and the pace of such transformation is expected to speed up [10]. Previous studies indicate that pre-service teachers generally have a favorable attitude toward the use of digital technologies in education but view themselves as having limited proficiency with these tools [11].

Higher education is one area where the impact of digitalization has been particularly significant, promoting the creation of new teaching and learning methods [12]. Education is becoming more and more digital, and this requires teachers to be more prepared for the adoption of digital tools [13]. Enhancing digital competence among pre-service teachers is a pressing issue that must be tackled to ensure the production of skilled professionals who can effectively navigate the realm of digital technologies [2].

A modern biology teacher works with a constantly increasing volume of information about natural and chemical processes, their role in everyday life, new living beings, and substances [1]. As the pool of information expands, so does the number of forms in which the knowledge can be transferred. Teachers have the opportunity to leverage electronic libraries, databases, research papers, digital photographs, and videos [14], [15]. Besides working with existing information, teachers must be prepared to present it using advanced information technologies [16]. There are various approaches to achieving this competence, including engaging in online communities and conferences for educators, enrolling in professional development courses, and utilizing digital technologies to develop course materials [1], [16], [17].

Among studies devoted to examining the formation of digital competencies in pre-service teachers, most overlook the context of biology education. Nor do they consider the area of teacher's expertise, thus making it harder for educators to apply their knowledge and skills in practice. The literature review shows diversity in the theoretical approaches and tools employed [18]. Pre-service teachers frequently claim to possess various digital skills, but they are not competent enough to use these skills effectively in the educational setting [18]. These factors pose challenges in research, educational policy, and the development

of teacher training curricula. Another problem is that some educational institutions lack the equipment and ICT resources (i.e., computers, broadcasting technologies, and the internet) needed to digitally enrich the teaching and learning process [13].

Digital competence was reported to influence teaching effectiveness and students' academic achievements [8], [19]. In many countries, the education system puts an emphasis on teaching educators the skills needed to apply digital technologies in teaching [6], [9], [20]. In Australia, for example, many frameworks, methodologies, and programs have been recently proposed that support the development of digital competency [20]. At the same time, in the past 10 years, studies have been reporting the shortage of digitally literate teaching staff, highlighting the need to promote digital literacy and teacher competencies among educators [20].

Existing research shows no consensus on what skills and knowledge should comprise the digital competence of biology teachers [1], [21]–[23]. Some researchers believe that educational resources should be the main focus of teaching [22], while others emphasize the importance of developing the ability to use innovative technologies [1], such as digital microscopy and digital sensing [23]. Given the contradictions in existing literature, further research is needed to determine effective strategies for developing digital competency in biology teachers.

Today's teachers and students need to become digitally literate so that they can use technology in and outside of the classroom. The problem with this is that clear methods and programs for developing digital competence are scarce, not to mention that there are inconsistencies in the existing body of knowledge on this topic. This study aims to narrow this gap by offering a set of pedagogical tools to prepare pre-service biology teachers for the digital reality of education. Hypothetically, integrating digital technologies into the training of pre-service biology teachers leads to increased digital competence and higher quality of biology teaching in schools. This study seeks to identify effective approaches for fostering digital competency in pre-service biology teachers and obstacles one may encounter when integrating digital technologies into the teaching process. The goals of the study are: i) to redefine biology teacher teaching with innovative technologies; ii) to measure biology teacher students' digital competence pre- and post-intervention; iii) to assess the effectiveness of innovative teaching in enhancing digital competence; and iv) to explore the obstacles and challenges that biology teachers face when using digital technologies in their practice.

2. METHOD

2.1. Study design

This pre-experimental study relies on quantitative research methods. These include pre-/post-test surveys and interviews aimed to identify factors affecting digital competence development. By combining these approaches, the study aims to provide a comprehensive understanding of the influences on and outcomes of digital competence training.

2.2. Participants

The study included 100 biology teacher students from multiple teacher education institutions in Kazakhstan; 63 were female and 37 were male. The mean age of the participants was 22 years. The participant selection criteria were final-year undergraduate and graduate students from the faculty or department of Biology, as they possessed a sufficient level of pedagogical and subject-specific knowledge. Students who did not know the basics of biology were excluded.

In addition, the study involved 5 university teachers, each with a bachelor's or master's degree in Biology and a teaching background of seven years. Participating teachers were required to have the ability to use various gadgets, such as tablet computers and smartphones. These experts were asked to construct a digital competence program for future biology teachers. The proposed program lasts 2 months and consists of group sessions, held twice a week.

The sample size is adequate for achieving the research objectives, as it provides sufficient statistical power for quantitative analysis [24], [25]. A sample of 5 instructors is also acceptable for qualitative analysis and curriculum development, given their experience and qualifications [3]. Overall, the sample size was determined to ensure reliable and relevant research results.

2.3. Data collection procedure

The pre-test evaluation involved assessing students' knowledge of digital technologies and their level of digital competency. The test, previously created in Google Forms, was administered online. The time limit was 60 minutes. Students took the same test again after their training period. The administration conditions were similar to those applied during pre-intervention testing.

The proposed digital competence program centers around collective learning. It contains 12 thematic modules of biology and digital teaching resources delivered through an online format. Each

lesson lasts 90 minutes. The 12 thematic modules are: i) introduction to digital literacy in biology: basic concepts and principles; ii) the use of digital tools in biological research; iii) creating interactive educational materials for biology courses; iv) digital technologies in the teaching of microbiology and genetics; v) integration of virtual labs into biology education; vi) the use of digital resources in the teaching of ecology and environmental protection; vii) development of online biology courses and educational games; viii) virtual reality in the teaching of human anatomy and physiology; ix) digital instructional methods for teaching biodiversity and evolution; x) software programs for biological data generation and analysis; xi) digital tools for conducting biological experiments and modeling; and xii) assessing the effectiveness of digital teaching methods in biology education.

Class sessions took place within a synchronous virtual classroom created via Adobe Connect. For this, features such as YouTube-based video interactive whiteboard, and text chat were used. During class time, students were engaged in collaborative activities designed to put theoretical knowledge into practice within a digital workshop. The interactive content selected for these activities included teacher-created videos and Moodle quizzes. Teachers had the opportunity to review student responses to assess their understanding of theoretical concepts and provide feedback. After the content was presented, students were given 10 minutes to explain what they were going to do next and what digital tools they would utilize. During the online training period, students first used digital tools to learn the course material and then applied the same tools for a pedagogical purpose. After each lesson, teachers assessed students' work and gave their feedback through the lecturer-student communication forum.

2.4. Instruments

The instrument of this study is the teachers' digital competencies (TDC) questionnaire proposed by Tourón *et al.* [26]. It comprises five dimensions of digital competency [27]: information and data literacy, communication and collaboration, digital content creation, safety, and troubleshooting. The questionnaire consists of 54 items, each answered twice on a 7-point Likert scale (1=not at all to 7=completely) to determine the level of students' knowledge and how much they use it. The questionnaire was administered several times: at the beginning of each module and after completion. It was created in Google Forms and distributed among teachers through Google Meet. In addition, 5-minute interviews were conducted to identify factors hindering the digital competence development process (the list of interview questions is available in Table 1). The reliability of the TDC questionnaire was assessed using Cronbach's alpha. The Cronbach's alpha value for information literacy and digital content creation dimensions ranges from 0.89 to 0.94. The Cronbach's alpha coefficient for communication and collaboration, safety, and troubleshooting dimensions ranges from 0.87 to 0.92. The overall scale has a high internal consistency with a Cronbach's alpha of 0.98. The construct validity is good with a concordance coefficient of no less than 0.64.

Table 1. Questions for the student interview

No.	Item
1.	Could you describe challenges you faced when applying digital technologies in teaching?
2.	What digital skills do you currently possess or need to develop?
3.	What factors, in your view, hinder your progress in acquiring digital skills?
4.	What educational or professional resources would be most effective for improving digital competency?
5.	Which of the digital competencies you have are best developed and the least developed?
6.	Which digital technologies or tools do you consider most valuable for teaching, and why?
7.	How frequently do you experience a shortage of time or resources for developing digital competencies?
8.	What challenges do you face when incorporating digital technology into the curriculum?
9.	What should the university, or your colleagues, do to promote the development of digital competencies?
10.	What steps are you willing to take to improve your digital literacy?

2.5. Data analysis

The data were analyzed in SPSS 26.0. According to the findings of the Shapiro-Wilk (SW), Kolmogorov-Smirnov (KS), and Lilliefors tests, pre-test (0.911, p=0.002) and post-test (0.903, p=0.001) data are not normally distributed. Therefore, further data analysis relied on nonparametric statistical processing. Specifically, the differences between pre-intervention and post-intervention degrees of digital proficiency were analyzed using the Wilcoxon signed-rank test.

The conversations were audio-recorded and later converted into written text. The transcripts were coded and analyzed thematically. The codes were organized into categories that represent theoretical concepts, topics, and ideas presented by the participating students. The analyst examined the content of the interview transcripts to identify the repeating patterns, contradictions, and interesting observations. The results were interpreted in the setting of this study's objectives.

2.6. Limitations

In this study, the sample size is small, which limits the generalizability of the study results to a wider population. Participants' responses in the interview reflect their subjective opinions and experiences, and this subjectivity may influence data interpretation. Other limitations of this study are associated with the absence of time, funding, and necessary equipment. In addition, data errors may have occurred during the collection, analysis, and interpretation stages.

3. RESULTS

Table 2 shows the findings derived from the analysis of the TDC survey findings, i.e., the mean differences (c) between the pre-intervention and post-intervention subscale scores, levels of significance, and effect sizes (magnitudes of change in the score). A "knowledge" subscale score reflects the degree of digital proficiency when comparing the knowledge of ICT resources. A "use" subscale score indicates how much the respondent uses that knowledge.

Table 2. Pre-intervention and post-intervention scores on the TDC subscales across five digital competence areas

Competence areas	Knowledge			Use		
	c (mean diff.)	Sig.	Effect size	c	Sig.	Effect size
Information and digital literacy	-2.363	0.015	0.45	-3.051	0.001	0.35
Communication and collaboration	-3.110	0.002	0.58	-3.549	0.001	0.44
Digital content creation	-3.628	0.000	0.54	-2.228	0.020	0.43
Safety	2.427	0.012	0.43	-2.835	0.003	0.52
Troubleshooting	-4.121	0.000	0.69	-4.015	0.000	0.71

The proposed program dramatically increased the level of knowledge in the information and digital literacy area (p=0.001). The level of knowledge in the area of information and digital literacy significantly increased following the intervention, as evidenced by a mean difference of -2.363, a statistical significance level of p=0.015, and an effect size of 0.45. This indicates a notable improvement in students' understanding of ICT resources. Regarding usage, there was also a substantial improvement post-intervention, with a mean difference of -3.051, a significance level of p=0.001, and an effect size of 0.35, suggesting an increase in both the frequency and effectiveness of applying this knowledge.

The communication and collaboration score on the knowledge scale exhibited a significant improvement after the intervention (p=0.001), indicating that students became better collaborators after participating in the digital competence development program. The mean difference on the subscale "knowledge" was -3.110, with a significance level of p=0.002 and an effect size of 0.58, indicating that students improved their collaboration skills following participation in the digital competence development program. Results from the subscale "usage" also showed significant improvements, with a mean difference of -3.549, a significance level of p=0.001, and an effect size of 0.44, highlighting an increased ability of students to effectively apply their knowledge in collaborative tasks.

Following the completion of the program, there was a substantial increase in knowledge related to digital content creation, with a mean difference of -3.628, p=0.000, and an effect size of 0.54. In terms of the application of this knowledge, the mean difference was -2.228, with a significance level of p=0.020 and an effect size of 0.43, indicating that students became more confident in creating digital content after the program. Knowledge about security significantly improved, with a mean difference of 2.427, p=0.012, and an effect size of 0.43, reflecting increased awareness among students regarding the protection of personal data and devices. The application of knowledge in this area also saw a notable increase post-intervention, with a mean difference of -2.835, p=0.003, and an effect size of 0.52, demonstrating heightened attention to digital security.

The area of troubleshooting exhibited the most substantial change, with a mean difference of -4.121 on the "knowledge" subscale, a significance level of p=0.000, and an effect size of 0.69. On the "usage" subscale, the mean difference was -4.015, p=0.000, and an effect size of 0.71, indicating that students significantly improved their ability to resolve technical issues following the program. These findings show that the proposed collaborative digital training program for biology teachers was effective in improving different aspects of digital competency proposed in the common digital competence framework for teachers (INTEF). University students are rather anxious about the prospect of integrating ICTs into the classroom, as suggested by the results of the student interview depicted in Figure 1. When implementing new ICT-based teaching methodologies, biology teachers may face a number of obstacles and challenges.

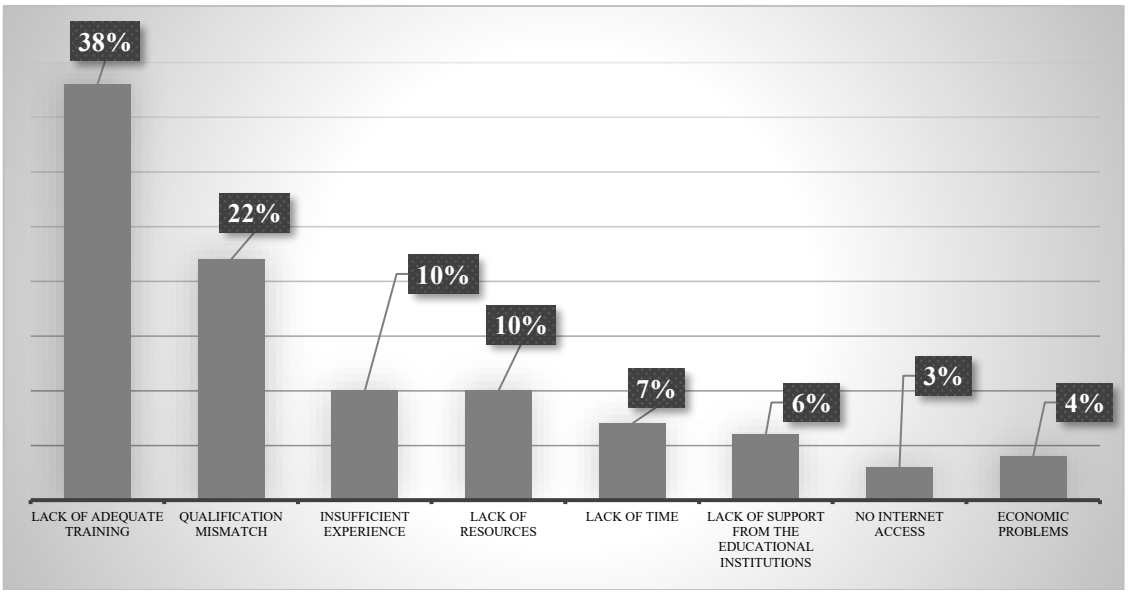

Figure 1. Factors hindering digital competence development

The main challenges to successfully integrating digital incorporating technologies into instructional practice are the lack of adequate training (38%) and the mismatch of qualifications (22%). Hence, teacher education universities need to redefine their teaching programs to provide students with additional training aimed at preparing them for the labor market demands of the digital world. A substantial number of respondents labeled the lack of experience with digital tools (10%) and the lack of necessary resources (10%) as barriers to the successful integration of digital technologies into teaching. This finding highlights the importance of providing teachers not only with the essential knowledge and abilities but also with access to modern educational resources and equipment. Other factors include the shortage of time (7%) and institutional support (6%), economic problems (4%), and no internet access (3%), but their influence is less significant compared to the factors.

4. DISCUSSION

Higher education is becoming increasingly digitally enabled [12]. As digital technology continues to develop, new practices can be introduced into teaching and learning. The digital revolution has dramatically changed the way universities work, interact, and teach [28]. The general framework for digital competence of teachers, developed by the Spanish Ministry of Education, was used to assess the digital competence of secondary school teachers [3]. Similarly, to this study, researchers covered five areas of digital competence which were identified by the digital competence project. Overall, pre-service teachers perceived their digital competence as low, particularly in areas such as digital content creation and problem-solving, which are related to the integration of ICTs. In addition, the knowledge and skills teachers possessed were largely self-taught. These findings highlight an urgent need to intentionally integrate both relational and instructional aspects of ICT. In the present study, students exhibited significant increases in information literacy, collaboration, safety, and problem-solving. Post-training values of digital content creation were higher as well ($p=0.020$), even though the statistical significance of this improvement was lower compared to other areas.

A non-experimental study examining the differences in the understanding and application of ICT among teachers and the influence of various factors (i.e., gender, age, and educational stage) on digital competence reported the presence of statistically significant variations in the understanding and application of 2.0 tools and Moodle modules [29]. The age and gender affected the prediction of the level of pedagogical digital competence, while the educational stage in which educators teach had no effect. The impacts of gender and age were not the focus of the present study, but the results obtained here support the previous observation that the levels of knowledge and use of digital tools are different.

Another study examined the digital competence levels of university instructors in relation to their use of ICT [30]. The focus was on digital tools used to consume or produce information and on emerging technologies. In contrast to the current study, Guillén-Gámez *et al.* [30] research included teachers from

various fields of knowledge (such as arts and humanities, engineering, and medicine) and with different levels of teaching experience (ranging from 0–5 years, 6–14 years, to 15 years or more). It was found that teachers with 15 or more years of experience demonstrated the most substantial improvements in digital literacy when comparing the use of three different types of ICT resources. A similar trend was seen across all areas of knowledge. The most significant resources for all levels of experience were the creation of videos, posters, and concept maps (i.e., visualization). In comparison to this study, our research did not investigate the digital competence of experienced teachers. However, it was highlighted that a significant number of respondents identified a lack of experience with digital tools (10%) and a lack of necessary resources (10%) as obstacles to the successful integration of digital technologies into teaching. This finding underscores the importance of providing teachers not only with essential knowledge and expertise but also with access to modern educational resources and equipment.

A study with a sole focus on biology teachers assessed the use of innovative technologies in the context of Bangladesh [16]. It was found that school teachers had better access to computers than the average populace. They had the basic knowledge of Microsoft Office Word, Excel, PowerPoint, and different web browsers. Many use computers to prepare lectures, find teaching materials on the Internet, and hold classes using multimedia and ICT. At the same time, about 17% to 25% of teachers made no use of ICT tools because of the absence of necessary hardware. In the present study, the hindering elements affecting the growth of pre-service teachers' digital literacy were found to be the lack of adequate training (38%), insufficient experience (10%), and lack of resources (10%).

Another study aimed to objectively and comprehensively describe the digital competence profile of biology teachers [31]. It employed a quantitative descriptive research design and utilized a specially developed questionnaire to assess the digital proficiency of biology teachers. The study results indicated that the average score for the intermediate extent of digital proficiency among early-stage biology teachers was 3.13, reflecting a moderate level. These results are consistent with earlier studies: the proposed program significantly enhanced biology teachers' knowledge in the area of information and digital literacy ($p=0.001$). The assessment of communication and collaboration skills demonstrated significant improvement after the intervention ($p=0.001$), indicating that the participants became better collaborators following the digital competence development program. Upon completion of the training program, respondents exhibited a significantly higher level of knowledge in digital content creation ($p=0.020$).

Another study examined phenomena happening during the educational process [32]. This study involved 64 participants from every university in Bali offering biology education programs, who completed the "metacognitive abilities", "self-regulated learning", and "digital literacy" questionnaires disseminated through Google Forms. The results indicated that metacognitive abilities accounted for 23.1% of the digital literacy skills among biology students in Bali. Conversely, the impact of metacognitive abilities on the development of self-regulation skills was 41.8%. Moreover, in biology courses, metacognitive abilities had a significant impact on digital literacy, in contrast to self-regulated learning. This research demonstrated that innovative teaching practices could enhance teachers' digital competence, while the aforementioned study identified the role of metacognitive abilities in the development of students' digital literacy and self-regulation skills.

Some studies have also addressed the issue of ICT in education, but their results differ somewhat from our findings. Some researchers assessed the use of digital information in the physics classroom by teachers and in students' preparation at home while also exploring how the incorporation of existing software and hardware into teaching affects digital competence [33]. The combination of traditional teaching practices with modern gadgets and specialized software programs was deemed contributory to the formation of informational and digital competence. Another study suggested using social media as an instrument to generate and share knowledge related to sustainability, the classification of living organisms, and the functioning of the human body [34]. Those who participated in the initiative reported that they were aware of social networks, but not their educational applications. This perception changed after these networks were used in the educational setting. Students recognized social media as a source of resources for education, highlighting the need to explore all the possibilities they offer.

5. CONCLUSION

The present findings suggest that innovative teaching enables pre-service biology teachers to achieve a significant increment in the extent of digital proficiency. Teacher students demonstrated significant improvements in information and digital literacy, communication and collaboration, digital content creation, safety, and troubleshooting. The results show that there are five main barriers to successful digital technology integration: inadequate training of teachers, lack of experience, lack of resources, lack of time, and no internet access. This study informs about the current extent of digital proficiency among pre-service biology teachers in Kazakhstan. The present findings can be used by universities (to develop and tailor teacher

training programs) and government authorities (to create conditions conducive to digital competence development in teacher education). Future research can provide a more in-depth analysis of factors influencing the integration of digital technology into teaching and assess the impact of other innovative teaching practices on digital competence. Another potential direction of further research is the possibility of developing teachers' awareness of computers against the backdrop of changing trends in education and technology.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

This research has no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the author' ethical committee of Abai Kazakh National Pedagogical University (Protocol HRW527 of October 13, 2023).

DATA AVAILABILITY

All data generated or analyzed during this study are included in this published article.

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