Developing pre-service teachers' digital competence through informatics disciplines in teacher education programs

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Abstract

This study investigated the effectiveness of the proposed didactic conditions and structural-functional model for developing pre-service teachers' digital competence through informatics disciplines. The positive dynamics observed in the experimental group's digital competence levels, particularly in the cognitive-informational and motivational-value components, contribute to growing research advocating for the systematic development of digital competence within teacher education programs. The findings underscore the importance of adopting a holistic, integrated approach to informatics disciplines, combining technical skills, pedagogical knowledge, and practical application through authentic, project-based learning experiences.

Keywords

digital competence, pre-service teachers, teacher education, informatics disciplines, pedagogical experiment

1. Introduction

The rapid digitalisation of society and education has highlighted the need for educators to possess a high level of digital competence to effectively integrate digital technologies into their professional practice [1, 2, 3, 4]. As defined by the European Commission's DigComp framework, digital competence involves the confident, critical, and responsible use of digital technologies for learning, work, and participation in society [5]. For teachers, this encompasses the ability to use digital tools to enhance teaching and learning, foster students' digital literacy, and promote innovative educational practices [6].

However, studies have revealed that pre-service teachers often lack sufficient digital competence, despite exposure to various informatics disciplines during their teacher education programs [7, 2]. This suggests that existing informatics courses do not adequately contribute to the full and targeted development of pre-service teachers' digital competence, necessitating a more intentional and systematic approach [8]. Recent years have necessitated reflection on the content and modalities of digital competence formation in pre-service teachers [9].

To address this issue, a structural-functional model was developed, incorporating specific didactic conditions that aim to foster digital competence development in pre-service teachers through the study of informatics disciplines. These conditions include:

1. Motivational conditionality of subjects' interaction in the digital learning environment.
2. Structuring of educational information in problematic, heuristic and integrative learning. models and its translation into project activities
3. Ensuring a systematic, complicating nature of students' learning activities with diagnostics and timely correction of outcomes using modern ICT.

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This study's purpose was to test the effectiveness of the proposed didactic conditions and structural-functional model in developing pre-service teachers' digital competence through a pedagogical experiment. The findings contribute to the growing body of research on digital competence development in teacher education and provide insights into effective strategies for preparing future teachers to integrate digital technologies into their professional practice.

2. Theoretical background

2.1. Digital competence in teacher education

The importance of developing pre-service teachers' digital competence has been increasingly recognized, as evidenced by the inclusion of digital competence frameworks in teacher education policies and curricula worldwide [10, 11]. The European Framework for the Digital Competence of Educators (DigCompEdu) outlines six areas of digital competence for teachers: professional engagement, digital resources, teaching and learning, assessment, empowering learners, and facilitating learners' digital competence [6].

Research has shown that pre-service teachers' digital competence is influenced by various factors, such as their personal experiences with technology, self-efficacy beliefs, and the quality of technology integration in their teacher education programs [12, 13]. Studies have also highlighted the need for teacher education programs to provide authentic, meaningful opportunities for pre-service teachers to develop their digital competence through hands-on practice, reflection, and peer collaboration [10, 11]. Digital competence is a vital combination of knowledge, abilities, and attitudes required for effective and responsible use of digital tools and technologies in the modern world [14].

2.2. Informatics disciplines in teacher education

Informatics (computer science) disciplines, such as programming, and information technology, play a crucial role in developing pre-service teachers' digital competence [2]. These disciplines provide students with the foundational knowledge and skills necessary to understand and use digital technologies effectively in educational contexts. However, research has shown that the existing informatics courses in teacher education programs often focus narrowly on technical skills and fail to adequately address the pedagogical aspects of technology integration [7, 2].

To better support pre-service teachers' digital competence development, informatics disciplines in teacher education need to adopt a more holistic, integrated approach that combines technical skills with pedagogical knowledge and practical application [10]. This can be achieved through authentic, problem-based learning activities, collaborative projects, and reflective practice [13, 12]. Additionally, informatics courses should be closely aligned with the broader teacher education curriculum and provide opportunities for pre-service teachers to apply their digital competence in real-world educational settings [11]. Training programs have been carried out to support digital competence, and it is important to examine how pre-service teachers plan to use the knowledge and skills gained from digital competence training in different contexts [15].

3. Methodology

3.1. Research design

A pedagogical experiment was conducted to test the effectiveness of the proposed didactic conditions and structural-functional model for developing pre-service teachers' digital competence through informatics disciplines. The experiment followed a quasi-experimental design, with a control group and an experimental group of pre-service teachers from two Ukrainian pedagogical universities.

The control group (n=93) studied according to traditional informatics discipline programs, while the experimental group (n=95) followed an experimental program that implemented the proposed didactic

conditions and structural-functional model. The experiment was conducted over four academic years, from 2016 to 2020.

3.2. Participants

The study participants were 188 pre-service teachers enrolled in pedagogical specialties at two Ukrainian pedagogical universities. The control group consisted of 93 students (71% female, 29% male), while the experimental group comprised 95 students (69% female, 31% male). The participants' ages ranged from 18 to 23, with a mean age of 20.2 years (σ=1.4).

All participants were enrolled in informatics disciplines as part of their teacher education programs, which included courses such as computer science, programming, and information technology. The participants' prior experience with digital technologies varied, but all had basic computer literacy skills.

3.3. Instruments

Digital competence formation was assessed according to four structural-criterial components: motivational-value, cognitive-informational, operational-activity, and personal-reflexive. A range of diagnostic methods were employed to measure pre-service teachers' digital competence development:

- A series of tests were administered to assess participants' knowledge and understanding of digital technologies, computer science concepts, and pedagogical applications of technology.
- Participants completed questionnaires designed to gauge their attitudes, beliefs, and self-efficacy regarding the use of digital technologies in educational contexts.
- Semi-structured interviews were conducted with a subset of participants to gather more in-depth insights into their experiences, challenges, and growth in relation to digital competence development.
- Participants completed practical tasks and projects that required them to demonstrate their skills in using digital tools, creating digital content, and solving technology-related problems.
- Competency matrices were used to assess participants' performance in various aspects of digital competence, such as digital literacy, digital communication and collaboration, and digital content creation.
- Expert evaluations were conducted by university faculty and experienced teachers to assess participants' digital competence based on their performance in informatics disciplines and educational practice.
- Participants analyzed and discussed real-world case studies related to technology integration in education, allowing for the assessment of their critical thinking and problem-solving skills.
- Participants designed and implemented educational projects that demonstrated their ability to integrate digital technologies into teaching and learning activities.
- Participants maintained a reflective blog throughout the experiment, documenting their experiences, insights, and growth in relation to digital competence development.

These diverse diagnostic methods provided a comprehensive assessment of pre-service teachers' digital competence development throughout the pedagogical experiment.

3.4. Procedure

The pedagogical experiment was conducted in three stages: organizational, formative, and corrective. In the organizational stage, the experimental program was developed, incorporating the proposed didactic conditions and structural-functional model. The content of informatics disciplines was updated, and an author's electronic special course, "Digital Technologies in Education" (3 ECTS credits), was prepared. Diagnostic instruments were also developed and validated during this stage.

During the formative stage, the experimental group studied according to the experimental program, which implemented the three didactic conditions:

1. *Motivational conditionality of subjects' interaction in the digital learning environment*: This condition aimed to foster effective collaboration and co-creation among students and teachers in the digital learning environment. Problematic and developmental learning technologies, success situations, emotional stimulation, and gamified rating control were used to enhance students' motivation to master digital competence.
2. *Structuring of educational information in problematic, heuristic and integrative learning models and its translation into project activities*: This condition involved structuring educational information in problematic, heuristic, and integrative learning models and translating it into project activities. A technological scheme for forming digital competence was developed, serving as the basis for creating a system of learning tasks, contextual, game, and problem situations, web-quests, and case studies. These activities covered the motivational-value, cognitive-informational, operational-activity, and personal-reflexive aspects of students' activity in the virtual space.
3. *Ensuring a systematic, complicating nature of students' learning activities with diagnostics and timely correction of outcomes using modern ICT*: This condition involved introducing digital tools and technologies that optimized and intensified the learning of informatics disciplines. New ways of organizing training sessions, technological models of mobile, distance, and blended learning, game design, video and teleconferences, web forums, and workshops in synchronous and asynchronous modes were employed.

In the corrective stage, the results of the students' learning activities were monitored and corrected using both general (testing, questionnaires, interviews, control tasks) and specific methods (competency matrices, expert cards, case studies, educational projects, and blogs).

3.5. Data analysis

Quantitative data collected through tests, questionnaires, control tasks, and competency matrices were analyzed using descriptive and inferential statistics. Paired-sample t-tests were used to compare the pre-and post-experiment scores within each group, while independent-sample t-tests were employed to compare the experimental and control groups' post-experiment scores. Effect sizes (Cohen's d) were calculated to determine the magnitude of the differences between groups.

Qualitative data gathered through interviews, case studies, educational projects, and blog entries were analyzed using thematic analysis [16]. The data were coded and categorized into themes related to the four structural-criterial components of digital competence (motivational-value, cognitive-informational, operational-activity, and personal-reflexive). The themes were then compared and contrasted between the experimental and control groups to identify patterns and differences in digital competence development.

4. Results

4.1. Quantitative findings

The experimental group demonstrated positive, statistically significant dynamics in the levels of digital competence formation compared to the control group (table 1). The greatest development was observed in the cognitive-informational (+35.79%) and motivational-value (+25.26%) components of digital competence.

Paired-sample t-tests revealed significant improvements in the experimental group's digital competence scores from the initial to the final assessment across all four structural-criterial components (p<0.001). The effect sizes ranged from d=0.68 to d=1.24, indicating moderate to large effects.

Independent-sample t-tests showed that the experimental group's post-experiment scores were significantly higher than those of the control group in the cognitive-informational ($t(186)$=6.84, p<0.001, d=1.00) and motivational-value ($t(186)$=5.21, p<0.001, d=0.76) components. The differences in the operational-activity and personal-reflexive components were also significant but with smaller effect sizes (d=0.42 and d=0.51, respectively).

Table 1
Comparative dynamics of digital competence formation levels based on experiment results (%).

Levels	Experimental group		Control group	
	Initial	Final	Initial	Final
Initial	21.05	3.16	22.58	12.90
Average	34.74	26.32	34.41	33.33
Sufficient	26.32	43.16	24.73	33.33
High	17.89	27.37	18.28	20.43

4.2. Qualitative findings

The thematic analysis of interviews, case studies, educational projects, and blog entries revealed several key themes related to the development of digital competence in pre-service teachers:

- *Enhanced motivation and engagement*: participants in the experimental group reported increased motivation and engagement in learning informatics disciplines due to the interactive, project-based nature of the activities and the authentic use of digital tools.
- *Improved understanding of digital technologies*: experimental group participants demonstrated a deeper understanding of digital technologies, their applications in education, and the pedagogical implications of technology integration.
- *Increased confidence in using digital tools*: pre-service teachers in the experimental group expressed greater confidence in their ability to use digital tools for teaching and learning, as well as for personal and professional development.
- *Collaborative learning and peer support*: the experimental program fostered a strong sense of collaboration and peer support among pre-service teachers, facilitating the sharing of knowledge, skills, and experiences related to digital competence development.
- *Reflective practice and self-awareness*: participants in the experimental group demonstrated higher levels of reflective practice and self-awareness regarding their digital competence development, as evidenced by their blog entries and discussions during interviews.

These qualitative findings provide further evidence of the effectiveness of the proposed didactic conditions and structural-functional model in fostering digital competence development in pre-service teachers.

5. Discussion

The results of this pedagogical experiment confirm the effectiveness of the proposed didactic conditions and structural-functional model for developing pre-service teachers' digital competence through informatics disciplines. The positive dynamics observed in the experimental group's digital competence levels, particularly in the cognitive-informational and motivational-value components, align with recent research emphasizing the importance of intentional and systematic digital competence development in teacher education [12, 10, 11, 9].

The significant improvements in the experimental group's cognitive-informational component suggest that the problematic, heuristic, and integrative learning models, coupled with project-based activities, effectively facilitated the acquisition of knowledge and understanding related to digital technologies and their pedagogical applications. This finding supports the notion that informatics disciplines in teacher education should adopt a more holistic, integrated approach that combines technical skills with pedagogical knowledge and practical application [10, 13].

The substantial growth in the motivational-value component among experimental group participants highlights the importance of creating an engaging, collaborative digital learning environment that fosters motivation and positive attitudes towards technology integration. This finding aligns with research indicating that pre-service teachers' digital competence is influenced by their personal experiences,

self-efficacy beliefs, and the quality of technology integration in their teacher education programs [12, 13].

The qualitative findings provide further insights into the factors contributing to the effectiveness of the experimental program. The enhanced motivation, improved understanding of digital technologies, increased confidence, collaborative learning, and reflective practice reported by experimental group participants underscore the value of authentic, meaningful learning experiences in developing digital competence [10, 11].

The substantial growth in the motivational-value component among experimental group participants highlights the importance of creating an engaging, collaborative digital learning environment that fosters motivation and positive attitudes towards technology integration. This finding aligns with research indicating that pre-service teachers' digital competence is influenced by their personal experiences, self-efficacy beliefs, and the quality of technology integration in their teacher education programs [12, 13]. It is crucial to examine how pre-service teachers plan to use the knowledge and skills gained from digital competence training in different contexts, such as personal, pedagogical, and professional digital competence [15].

The qualitative findings provide further insights into the factors contributing to the effectiveness of the experimental program. The enhanced motivation, improved understanding of digital technologies, increased confidence, collaborative learning, and reflective practice reported by experimental group participants underscore the value of authentic, meaningful learning experiences in developing digital competence [10, 11, 14].

While the operational-activity and personal-reflexive components also showed significant improvements in the experimental group, the smaller effect sizes suggest that these aspects of digital competence may require additional attention and support. Future research could explore strategies for further enhancing pre-service teachers' practical skills and reflective capabilities in relation to digital competence development.

6. Conclusion

This pedagogical experiment provides evidence for the effectiveness of the proposed didactic conditions and structural-functional model in developing pre-service teachers' digital competence through informatics disciplines. The positive dynamics observed in the experimental group's digital competence levels, particularly in the cognitive-informational and motivational-value components, contribute to the growing body of research advocating for the systematic, intentional development of digital competence within teacher education programs.

The findings underscore the importance of adopting a holistic, integrated approach to informatics disciplines in teacher education, combining technical skills, pedagogical knowledge, and practical application through authentic, project-based learning experiences. The study also highlights the value of creating an engaging, collaborative digital learning environment that fosters motivation, confidence, and reflective practice among pre-service teachers.

The results of this experiment have several implications for teacher education policy and practice. First, teacher education programs should prioritize the intentional and systematic development of pre-service teachers' digital competence, recognizing its critical role in preparing future educators for the digitalized educational landscape. This may involve reforming existing informatics disciplines to better align with the holistic, integrated approach demonstrated in this study.

Second, teacher educators should adopt evidence-based strategies, such as the didactic conditions and structural-functional model proposed in this study, to effectively foster digital competence development in pre-service teachers. This may require professional development for teacher educators to enhance their own digital competence and pedagogical skills in integrating technology into their teaching practice.

Third, policymakers and educational institutions should invest in the necessary infrastructure, resources, and support systems to facilitate the effective integration of digital technologies in teacher

education programs. This includes providing access to up-to-date digital tools, learning management systems, and online resources and offering technical and pedagogical support to both pre-service teachers and teacher educators.

Future research could explore the long-term impact of digital competence development interventions on pre-service teachers' technology integration practices during their induction phase and early career years. Longitudinal studies could provide valuable insights into the sustainability and transferability of the skills and knowledge acquired through such interventions.

Additionally, the proposed structural-functional model could be adapted and tested in different contexts and specializations within teacher education, such as primary education, secondary education, and subject-specific domains. Comparative studies could also investigate the effectiveness of different approaches to digital competence development in teacher education across various countries and educational systems.

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