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# From Shaping to Influencing: Validating the Cascade Model of Digital Competency of Educators in the Context of Ar and Genai Technologies

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## ABSTRACT

This article is devoted to the development and comprehensive analysis of the cascade model of formation of digital competencies (CC) of teachers, which is a systemic response to the challenges of global digital transformation and the national strategy of education development in the Republic of Kazakhstan. The model is conceptually structured into three interrelated stages: the first is a systematized process of formation of DSC, including motivational-target, methodological, content-technological and regulatory-result blocks; the second is the direct application of formed DSC in everyday pedagogical activities; and the third is the assessment of the impact of these competencies on the academic results of students. Special attention in the content-technological block is paid to the integration of augmented reality (AR) and generative artificial intelligence (GenAI) technologies, including details of specific pedagogical scenarios of their use. To confirm the relevance and demand for the model, the results of the first stage of a large-scale empirical survey covering 1352 teachers are presented. This survey has convincingly demonstrated the high interest of the teaching community in mastering interactive lesson formats and introducing AR and GenAI technologies.The paper compares the proposed model with relevant foreign frameworks, including DigCompEdu, which ensures its theoretical validity. Implications of the primary empirical results for further adaptation are discussed, and the plan for longitudinal validation of the "Application" and "Impact" stages is detailed.Thus, the article is a contribution to the development of theoretical and methodological foundations for the formation of teachers' CK and their practical realization in the conditions of digital educational environment.

**Keywords:** Digital Competencies (DC), Cascade Model, Augmented Reality (AR), Generative Artificial Intelligence (GenAI), Digital Didactics, Empirical Validation, Interactive Educational Technologies.

## INTRODUCTION

The modern stage of education development is inextricably linked to the processes of digital transformation, which is becoming a global trend. With the rapid introduction of artificial intelligence (AI), augmented reality (AR) and other innovative technologies, pedagogical competencies are no longer limited to traditional methods, requiring the integration of digital skills into professional activities.

This issue is particularly important in the context of national strategies, such as the digitalization programs of the Republic of Kazakhstan, where the formation of digital competencies (DC) of teachers is enshrined as a priority of educational policy. The formation of digital competencies is more than just mastering instrumental skills; it implies the development of the ability to effectively integrate digital technologies into pedagogical practice in order to improve the quality of education and optimize the academic results of students.

The insufficient level of development of these competencies can potentially lead to a significant lag of the national education system from the actual requirements of the information society.

The main purpose of this scientific publication is to present the cascade model of teachers' CK formation, its detailed description and in-depth analysis, comparison with relevant foreign and domestic scientific research. In addition, the presentation of primary empirical results confirming the practical significance and relevance of the proposed methodological approach is presented.

The proposed cascade model is conceptually structured into three interrelated stages:

- The first one is a systematized process of digital competencies formation.
- The second is the direct application of the formed digital competencies in everyday pedagogical activities.
- The third is the assessment of the impact of these competencies on students' academic performance.

Further research is aimed at empirical validation of the Application and Impact phases, focusing on the integration of Augmented Reality (AR) and Generative Artificial Intelligence (GenAI) technologies.

## METHODOLOGICAL BASIS AND THEORETICAL RATIONALE

### Global Context and Challenge Analysis

The global academic discourse is actively developing digital competencies for educators, as evidenced by numerous studies and the development of national and international frameworks. A fundamental reference point is DigCompEdu (European Digital Competency Framework for Educators), which structures educators' digital competencies into six key areas: professional interaction, digital resources, teaching and learning, assessment, learner empowerment, and promoting digital competencies in learners themselves.

The global scientific discourse is actively developing the problematics of digital competencies of pedagogical staff, which is confirmed by numerous studies and the development of national and international frameworks. A fundamental reference point is DigCompEdu (European Digital Competency Framework for Educators) [1], [2], which structures educators' digital competencies into six key areas: professional interaction, digital resources, teaching and learning, assessment, learner empowerment, and promoting digital competencies in learners themselves [3]. This framework serves as the basis for national strategies for teacher professional development around the world.

The analysis of foreign studies reveals a number of general trends and critical factors determining the successful integration of digital technologies into the educational process. These include:

- Developed technological infrastructure and availability of resources: a fundamental condition is the availability of modern equipment and high-speed Internet connection, providing uninterrupted access to digital educational platforms and tools [7]. Studies show that insufficient infrastructure is a serious barrier to innovation.

- Adequate methodological and pedagogical support: educators' training should not be limited to mastering technical aspects, but should focus on effective didactic methods of integrating digital tools into the learning process, building a deep understanding of their pedagogical potential [8].
- Educators' motivation and attitudes towards digital innovations: an important factor is teachers' awareness of the fundamental value of digital tools to enhance learning, student engagement and personalization of the educational process [4]. Negative attitudes or lack of motivation can offset any technological and methodological efforts.
- Continuous professional development and personalization of learning: in the face of rapidly changing technologies, a systematic system of updating the knowledge and skills of teaching staff is necessary. Studies emphasize the importance of personalized educational trajectories that take into account the individual needs and initial level of CK of each teacher [6].

 

Despite global efforts, foreign research also reveals specific challenges. These include: digital inequality among educators (differences in access and skills), insufficient readiness to adopt and implement innovative approaches (e.g., AR and GenAI), as well as difficulties in adapting traditional pedagogical methods to the requirements of the digital format [5], [12]. The works of leading researchers, such as Redecker & Punie [1] and Ferrari [2], emphasize the critical importance of forming a favorable digital ecosystem that supports and stimulates the development of educators' CC.

Global digitalization and the rapid development of artificial intelligence technologies necessitate a revision of educators' digital competencies. In particular, the development of skills for interacting with AI and AI-supported pedagogy is required These skills involve the competent use of AI-based learning tools in the role of assistants for teachers, thereby enhancing the application of the latest educational technologies in teaching practice [9][10][11][12].

A systematic review [13] revealed that of the eight emerging educational technologies, the most significant are those based on AI, augmented/virtual reality (AR/VR), gamification and simulation technologies. These technologies act as teaching and learning tools to promote academic excellence through visualization, interactivity and personalization of the digital educational process. Current technologies such as artificial intelligence, machine learning, the Internet of Things (IoT), and augmented and virtual reality make learning more flexible [14], adaptive, and personalized [15, 16]. Most importantly, they ensure accuracy and depth of learning, helping students to acquire not only declarative knowledge, but also the necessary cognitive and practical skills. This, in turn, increases their readiness to consciously solve complex problems in the real world and builds their professional confidence [17][18][19].

International studies on the use of the latest educational technologies in the teaching process confirm the high effectiveness of augmented reality (AR) technology at different levels of education. Examples of such studies can be found in the field of teaching physics, astronomy, anatomy, chemistry and other disciplines [20-26]. Researchers have noted that through AR-enabled end-to-end technologies, students show high learning motivation, easily discover new knowledge about complex and inaccessible real-life processes, and can practice practical skills [27]. As an example: it has been shown that traditional teaching methods led to mislearning of some astronomy concepts and these misconceptions persisted for years. The use of AR technology has enabled accurate understanding of these concepts [21, 22]. AR has also been shown to be effective in chemistry classes, where students can safely conduct experiments and mix substances without fear of mistakes or undesirable consequences [24-26].

In addition, there are studies showing that AR technologies accelerate the formation of cognitive skills, such as spatial reasoning. This skill is necessary for 3D modeling and is a key professional competence for design engineers and AR developers, for whom it is important to be able to think in three-dimensional space and take into account the smallest details of objects [20, 28, 29].

In the Republic of Kazakhstan, the process of formation of teachers' CC is actively supported at the state level and regulated by national strategic documents. Kazakhstani scientists and educational institutions conduct their own research aimed at adapting international experience and developing national standards. Despite significant state support, domestic research, in particular the works of Abildina et al. [10] and Karmanova et al. [11], identify a number of specific challenges characteristic of the region: ensuring widespread and equitable access to digital educational resources, further professional development of teaching staff in accordance with current technological trends, and intensive development of digital pedagogy as an independent scientific and practical discipline [12].

The cascade model presented in this article is designed to systematically respond to these global and specific challenges, offering a comprehensive and adaptive approach to the formation of CK, which corresponds to both global educational trends and the unique conditions of the Kazakhstani educational environment.

### Comparison of the Cascade Model with the DigCompEdu Framework

To ensure theoretical validity and universality, the building blocks of the proposed Cascade Model are correlated with the key areas of the international DigCompEdu framework. This mapping demonstrates how each of the four blocks of the first stage of the model covers the required range of professional digital competence (Table 1).

**Table 1.** Comparison of the Cascade Model with the DigCompEdu framework

| Cascade Model Unit | Key Objective of the Block | Relevant Areas of DigCompEdu |
|---|---|---|
| Motivational and goal-oriented block | The goal is to achieve a high level of digital competence of teachers in the context of applied education and effective use of technology in the learning process to maximize its impact. The | 5. Empowering learners.<br>6. Facilitating the development of CK in the learners themselves. |

 

| | | |
|---|---|---|
| | objective is to train educators in practical skills in the use of digital technologies, techniques for creating interactive forms of lessons, and strategies for implementing AR and GenAI. | |
| Methodological block | It is based on the principles of collaborative, competency-based, problem-based and activity-based approaches, as well as scaffolding learning. | 1. Professional interaction.<br>3. Teaching and learning. |
| Content and technology block | Covers systematized training in digital educational technologies, AR and GenAI tools, and details the digital eco-environment. | 2. Digital Resources.<br>3. Teaching and learning. |
| Regulatory and results block | The goal is to achieve a formed level of digital competence of teachers and increase the efficiency of using complex educational technologies. It provides for the development of a system of objective evaluation criteria. | 4. Evaluation. |

This analysis confirms that the cascade model is not a static local development, but a comprehensive system that meets international standards for digital pedagogy.

**Cascade Model of Digital Competency Building**

The proposed model of formation of digital competencies of a teacher is a cascade process, logically divided into three interdependent stages (Fig. 1):

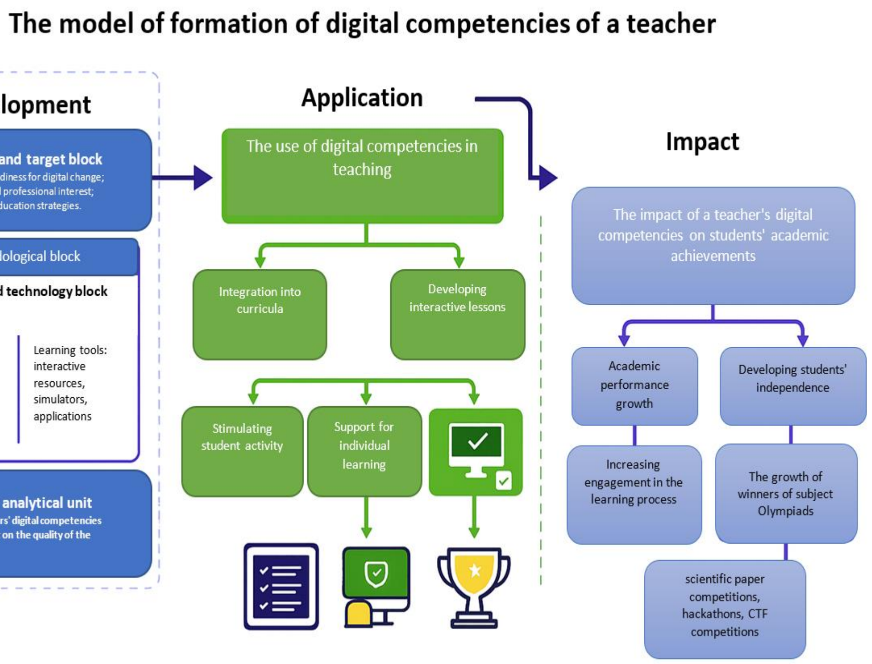


**Figure 1.** Cascade Model of Digital Competence Building

1. The stage of CK formation: a purposeful and systematized process of acquiring digital knowledge, skills and abilities by teachers.
2. The stage of applying CK in pedagogical activity: practical realization and integration of the formed competencies directly into the teaching and learning process.
3. the stage of the impact of the formed CCs on learning outcomes: analytical assessment of the impact of effective use of CCs on the academic achievements and overall development of students.

### Stage of CC Formation

This stage is cornerstone and defining, forming the necessary foundation for the subsequent application and transformational impact of CC. It is structured around four key blocks (Table 2).

**Table 2.** Assignment of blocks of the stage of CK formation

| Block | Key Objective and Content |
|---|---|
| Motivational and goal-oriented block | The goal is to achieve a high level of digital competence of teachers in the context of applied education and effective use of technology in the learning process to maximize its impact. The objective is to train educators in practical skills in the use of digital technologies, techniques for creating interactive forms of lessons, and strategies for implementing augmented reality (AR) and generative artificial intelligence (GenAI) technologies. |
| Methodological block | It is based on the principles of collaborative learning (encouraging the sharing of experiences), competency-based approach (focusing on practice-oriented skills), activity-based approach (active involvement in the creation of digital didactic products), and scaffolding learning (incrementally increasing the complexity of learning material with systematic support). |
| Content and technology block | Covers the content and educational trajectories of systematized training in digital educational technologies and tools. The digital eco-environment includes LMS platforms, AR Tools (Meta Spark Studio, Unity), GenAI Tools (ChatGPT, Midjourney). Teaching methods include web-based learning, project-based approach, and "flipped" methodology. |
| Regulatory and results block | The goal is to achieve the formed level of digital competence of teachers and increase the efficiency of using complex educational technologies. It provides for the development of a system of objective evaluation criteria for diagnosing the achieved level of CK. |

### Detailed Pedagogical Scenarios of AR and GenAI

Training in the Content and Technology Block focuses on practical scenarios for using AR and GenAI:

1. ***Augmented Reality (AR):*** used to visualize complex concepts (e.g., 3D DNA models or historical reconstructions), which increases visibility and promotes spatial thinking.
2. ***Generative Artificial Intelligence (GenAI):*** used to personalize assignments (generating variation tasks adapted to the student's level) and as a tool for student creativity and optimizing teacher time (to receive drafts of personalized feedback).

### Stage of Applying CK in Pedagogical Activities

After successful formation of CCs, teachers start their active integration into the teaching process. This stage includes:

1. integration into the curriculum: systematic incorporation of digital tools and innovative methodologies into daily lesson planning and delivery.
2. Developing interactive lessons: creating training sessions with active use of AR, GenAI and a variety of interactive tasks, which significantly increases the level of student engagement.
3. Stimulating student engagement: utilizing digital tools to increase cognitive interest and intrinsic motivation for learning.
4. Support individualization of learning: adapting learning material and methodological approaches to the unique learning needs and individual pace of each student using digital technologies.

### Stage of Influence of Formed CCs on Learning Outcomes

The ultimate goal of the entire cycle is to achieve a positive and measurable impact on learners' academic outcomes. This stage is manifested in the following aspects:

1. Achievement growth: direct improvement in grades and overall academic achievement.
2. Development of learner autonomy: increased self-organization, critical thinking, research and creative skills.
3. Increased involvement in the learning process: increased cognitive activity and intrinsic motivation for learning.
4. Increase in the number of prizes: successful participation in subject Olympiads, research paper competitions, hackathons, CTF-competitions and other events.

 

## RESULTS OF THE EMPIRICAL STUDY AND DISCUSSION

### Results of the First Phase of the Survey

Within the framework of this study, the first stage of a large-scale sociological survey was conducted, in which 1,352 secondary school subject teachers from all regions of Kazakhstan participated (Fig. 2). The main goal of this stage was to identify the current level of digital literacy of the teaching staff, as well as to determine their needs and interest in the development of digital competencies.

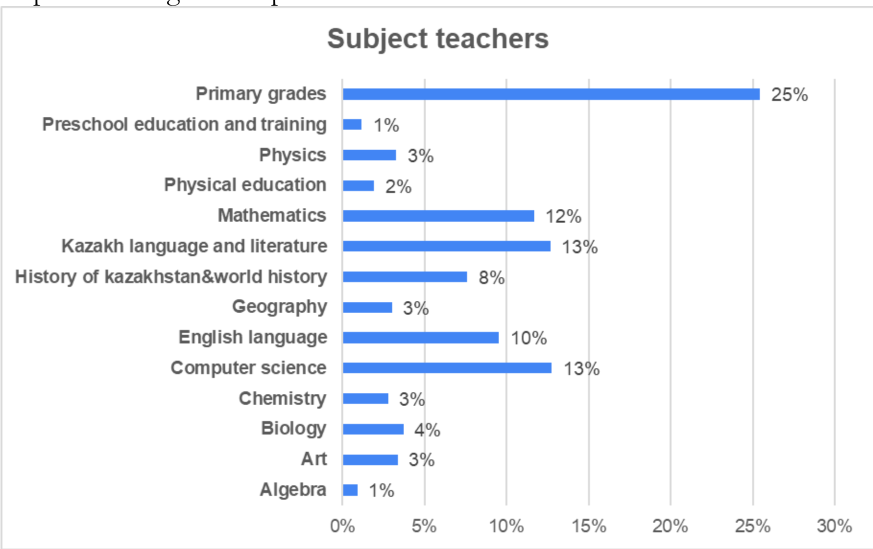


**Figure 1.** Subject Teachers

The obtained results convincingly demonstrated the high interest of teachers in creating interactive forms of lessons and active implementation of augmented reality (AR) technologies in the teaching process. This fact confirms both the relevance of the developed model and its compliance with the urgent needs of the modern pedagogical community. Teachers expressed a clear willingness to master new tools and techniques aimed at improving the quality and interactivity of the educational process.

According to the survey data, the majority of respondents are interested in mastering the following digital technologies (by the example of Russian- and Kazakh-language segments, Figure 5):


**Figure 5.** Responses of 1,352 respondents about learning new digital technologies

1. Interactive assignments (compilation): 59.5% (524 responses) and 55.8% (832 responses).
2. Interactive tests (matching): 55.5% (524 responses) and 58.5% (832 responses).
3. Augmented reality (AR) objects: 57.4% (524 responses) and 38.8% (832 responses).

### Discussion and Implications for the Model

The revealed high interest of teachers in mastering AR-technologies and interactive lesson formats is a direct empirical confirmation of the relevance of our model's focus on these cross-cutting technologies. These results directly correlate with the objectives of the Motivation-Target Block (emphasizing the need to master innovative tools) and the Content-Technology Block (including AR and GenAI training).

However, the first stage of the study only confirms the relevance and demand for training, but does not validate the effectiveness of the entire cascade model, especially the "Application" and "Impact" stages. For this purpose, a toolkit for the second stage of the questionnaire was developed.

The purpose of the second stage, which was launched after the training module on the Kazakhstani platform BilimLand.com on interactive forms of learning and AR-technologies, is to assess the effectiveness of the training conducted, to identify the dynamics of changes in the level of teachers' CK, as well as their readiness for further deep integration of digital tools in educational practice. The data obtained will make it possible to significantly refine the training methodology and adapt the content component of the model, ensuring its maximum effectiveness and practical applicability.

The model presented is thus not a static construct, but a dynamic and adaptive system capable of integrating feedback from educators and research findings for its continuous improvement.

## CONCLUSION AND LONGITUDINAL VALIDATION PLAN

### Conclusion

The presented cascade model of teachers' digital competencies formation offers a system-integrated approach to teacher training for the challenges of the digital era. It comprehensively takes into account not only the direct learning process, but also the subsequent practical realization of the acquired knowledge in pedagogical activity, as well as its implicit and explicit impact on the academic results of students. Comparison of the model structure with the international DigCompEdu framework ensures its theoretical validity.

The first results of the empirical study, which covered 1352 teachers, convincingly confirm the high degree of interest of Kazakhstani teachers in mastering modern digital tools such as AR and GenAI. This fact serves as a powerful catalyst for further development and large-scale implementation of this model.

### Research Perspectives and Validation Plan

Future research will focus on a detailed analysis of the results of the second phase of the survey conducted after the training module on interactive forms of teaching and AR technologies. The methodology of this phase includes processing an online questionnaire aimed at measuring teachers' proficiency in AR tools, as well as conducting semi-structured interviews to collect qualitative data on barriers and success factors.

The ultimate goal is to empirically validate the entire Cascade Model, particularly the Influence Stage (Stage 3). Long-term longitudinal evaluation of the impact of the formed CCs on the quality of education and academic achievement of students in real educational settings will be the subject of subsequent research.

### Plan for the Longitudinal Evaluation of the Impact Stage

A Quasi-experimental, longitudinal design will be used to verify the positive and measurable impact of educators' CC on student outcomes.

1. ***Exploratory Design:***
   - A comparative study of students in the experimental group (educators trained and actively using CK) and the control group (educators using traditional methods).
   - Evaluation period: at least two measurements during the school year to assess the dynamics of change.
2. ***Measurable Indicators and Evaluation Methods:***
   - ***Academic Growth:*** Analysis of academic data (GPA, results of standardized tests).
   - ***Development of Autonomy:*** Use of specialized questionnaires (e.g., to assess self-organization) and peer review of research products.
   - ***Increased Engagement:*** Use of engagement scales and analysis of frequency of participation in interactive assignments.
   - ***Increase in Competition Winners:*** Collect statistics on student participation in subject olympiads, hackathons and science competitions.
3. ***Statistical Analysis:***
   - Mixed models (ANOVA) will be applied to compare the dynamics of results between groups and regression analysis will be used to identify the correlation between the degree of teacher's CC proficiency and the academic results of his/her students.

The results of this phase will provide specific practical recommendations for scaling the model and improving instructional practices.

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