

Article

Current development trends in pedagogical education: competency-based education in natural sciences

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Abstract: The reform of national education systems is driven by rapid technological and economic change, unequal access to quality education, the digital economy, the growing mobility of students and teachers, the alignment of qualifications with international standards, the changing role of the teacher (tutor, facilitator, mentor) and the development of lifelong learning. Under these conditions, teacher education has to adopt international standards and good practice and remain flexible, and its leading paradigm is the competency-based approach. The aim of this study is to analyse current trends in the development of pedagogical education and to substantiate competency-based education in the natural sciences, using the innovative educational programmes introduced at Abai Kazakh National Pedagogical University as an example. The study is conceptual and analytical: publications identified in Scopus, Web of Science and Google Scholar, policy documents and programme documentation were examined by content and comparative analysis. The results systematize the main research areas, specify the structural components of competency-based education (target, content, process, assessment, resource and reflective components) and compare international and domestic research on scientific and functional literacy, research competence, digital competence and problem solving in the natural sciences. The implementation of the approach is illustrated by the educational programme 6B01515-Geography, in which new courses link subject knowledge with research-based, practice-oriented, STEM and CLIL teaching and with the Sustainable Development Goals. The study concludes that the successful implementation of competency-based programmes depends on their methodological support and on the continuous professional development of university teachers, and it formulates practical recommendations for programme developers and teaching staff.

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1 Introduction

The sustainable development of pedagogical education in Kazakhstan is aimed at the continuous modernization of the education system and its adaptation to the changing requirements of society and the labour market, so that competitive teachers can be trained. It creates conditions for the professional development of teachers through lifelong learning and bases the content of teacher education on competence, innovation and the effective use of digital technologies.

Modern higher education institutions are active organizational systems that take part in the life of society at global and local levels and are continuously transformed by globalization. Carnoy (2016) shows that, under globalization, states give priority to education and change the mission, organizational

structures and educational programmes of universities in order to increase competitiveness. Current trends in teacher education also lead to a reorientation of teaching skills: transversal or meta-disciplinary skills, 21st-century skills and soft skills are in growing demand in the labour market (Deming & Silliman, 2024). These changes reflect a volatile, uncertain, complex and ambiguous (VUCA) world and determine the competencies needed by future professionals.

Digital technologies and the Internet are taking education and training to a new level. Innovation, access to education, sustainability, quality, differentiation and integration, partnership and research-based education have become key concepts in planning the future university (Sagintayeva et al., 2021). Practice-oriented models of teacher training are being developed and implemented, such as the Professional Development School (Hunzicker, 2019) and project-based and work-based learning models used, for example, in Finland and Australia. These models are characterized by an equal partnership between university and school teachers, a close connection with practice and a learning environment that supports the solution of educational problems; they emphasize meta-skills, soft skills and universal competencies (Sharples et al., 2014; Sulima, 2017; Darling-Hammond, 2017).

In the Republic of Kazakhstan, the methodological base of competency-based educational programmes rests on socio-economic, regulatory, scientific, pedagogical and methodological prerequisites that reflect the strategic directions of the national education system. The transformation of higher and postgraduate education gives priority to a competency-based approach, the quality of educational content, learning outcomes expressed as competencies and the formation of the competencies required by the labour market and the economy (Kunanbayeva, 2016). Within the Modernization of Education project of the Ministry of Science and Higher Education and the World Bank, academic staff and experts from Kazakhstani and Finnish higher education institutions carry out two related projects, Strengthening the Capacity of Pedagogical Education (KZEMP/QCBS-03) and Implementation of the Pedagogical Education Model and Strengthening Its Content (KZEMP/DS-02), which aim to develop and harmonize Kazakhstani teacher education and to improve its methodological and regulatory tools (ENIC-Kazakhstan, 2026). The Development Program of Abai University for 2023–2029 sets the goal of implementing an innovative model of pedagogical education as a centre of academic excellence.

The main problem of modern pedagogical education is the gap between the training of future teachers at universities and the innovations introduced in general secondary schools. The traditional information- and subject-centred paradigm is still preserved in the educational process, and teaching methods are insufficiently focused on students' research skills. Growing competition between teacher-training programmes and new requirements for pedagogical universities (a competency-based approach, dual education, multilingualism and practice orientation) call for a redesign of programmes. In the natural sciences this problem is especially acute, because the scientific literacy of school students depends directly on how their teachers were prepared.

The aim of this study is to analyse current trends in the development of pedagogical education and to substantiate competency-based education in the natural sciences. The objectives are: (1) to systematize the main areas of research on trends in pedagogical education; (2) to specify the structural components of competency-based education; (3) to compare international and domestic research on the competencies developed in natural science education; and (4) to show how the approach is implemented in the innovative educational programmes of a pedagogical university, using the Geography programme as an example.

2 Materials and methods

The study is conceptual and analytical. It did not include a pedagogical experiment; its conclusions are based on the analysis of publications, policy documents and programme documentation.

Three groups of sources were examined. The first group comprised scientific publications. International publications were searched in Scopus and Web of Science, and Kazakhstani and Russian-language publications in Google Scholar, using the keywords “competency-based education”, “competence

approach", "teacher education", "pedagogical education", "natural science education", "scientific literacy", "functional literacy" and "professional competence of teachers" in English, Kazakh and Russian. Publications were included if they addressed teacher education or natural science education, described a concept, model or empirical result related to competencies, and were available in full text; foundational works were included irrespective of their year of publication. The second group comprised reports and frameworks of international organizations (UNESCO, the OECD and the European Commission). The third group comprised national and institutional documents: the Concept for the Development of Pedagogical Education, the Development Program of Abai University for 2023–2029, the documentation of the World Bank projects and the innovative educational programmes in the natural sciences.

The sources were analysed in three steps. Content analysis was used to assign publications to research areas (the theory and development of education, the competency approach, and digitalization and innovation) and to identify the structural components of competency-based education. Comparative analysis was used to relate international and domestic findings on the competencies developed in natural science education. Finally, the documentation of the educational programme 6B01515 - Geography was analysed to show how the components are implemented in practice. A systems approach was applied throughout, in which the phenomenon under study is considered as a system of interconnected elements.

3 Results and discussion

3.1 Research areas and trends in pedagogical education

The content analysis showed that research on trends in pedagogical education forms four areas (Table 1). Studies of the theory and development of education consider teacher training, educational policy and teaching quality as a continuous process aimed at forming the teacher's professional competence. In this view, the modern teacher is not only an educator but also a facilitator, researcher, reflective practitioner and organizer of an innovative learning environment, so teacher education programmes should focus on competency-based and practice-oriented training, a culture of inquiry and lifelong professional development (Darling-Hammond, 2017; Loughran, 2006; Grossman, 2018). Shulman (1986) showed that teaching requires pedagogical content knowledge, that is, the integration of subject knowledge with knowledge of how to teach it.

Table 1. Areas of research on trends in the development of modern education

Research area	International scholars and organizations	Scholars of Kazakhstan and the CIS	Main focus
Theory and development of education	L. Darling-Hammond, L. Shulman, A. Hargreaves, J. Loughran, P. Grossman	V.V. Kraevsky, I.Ya. Lerner, M.N. Skatkin, E.V. Bondarevskaya, V.V. Serikov, N.D. Khmel, A.A. Beisenbayeva	Teacher training, content of education, teaching quality, holistic pedagogical process
Competency approach	P. Perrenoud, G. Le Boterf, J. Delors	V.A. Slastenin, V.A. Bolotov, A.V. Khutorskoy, K.K. Zhampeisova, N.N. Khan, M.Zh. Zhadrina, S.S. Kunanbayeva	Competence as the mobilization of knowledge and experience in a specific situation; key competencies
Digitalization and innovation in education	P. Mishra, M. Koehler	E.D. Patarakin, A.Yu. Uvarov, M.V. Moiseeva, E.S. Polat, Zh.A. Karaev, Zh. Sardarova, G. Salgaraeva	Technological pedagogical content knowledge; digital learning environment
Frameworks of international organizations	UNESCO, OECD, European Commission, Education International	–	Key competences for lifelong learning; scientific literacy; education for sustainable development

Source: compiled by the authors.

Kraevsky and Berezhnova (2006) treat education as a socio-cultural process that ensures the all-round development of the personality; its content should combine scientific knowledge, practical experience,

creative experience and value orientations. The development of pedagogical education therefore requires that the content of education be updated on a scientific basis and that teachers be able to design the educational process. In Kazakhstan, the theory of the holistic pedagogical process (Khmel, 1998) shows that professional experience is formed when theory is combined with practice.

The competency approach treats the outcome of education not as a set of knowledge, skills and abilities but as the ability to mobilize knowledge and experience in a specific professional situation. Le Boterf (2018) defines competence as the ability of an individual to mobilize knowledge, experience, skills and other resources effectively in a professional or life situation; competence is therefore determined not by the possession of knowledge but by its effective application. Khutorskoy (2013) considers the main result of competency-based education to be a competent person who can apply theoretical knowledge in practice. The European framework of key competences for lifelong learning describes competences as a combination of knowledge, skills and attitudes that are formed in formal, non-formal and informal learning and are assessed by their application in specific situations (European Commission, 2019). These works form the methodological foundation of the modern competency-based model and of the unity of theory and practice in teacher education.

3.2 Structural components of competency-based education

On the basis of the analysed works, competency-based education can be described as a system of six interrelated components (Table 2). The target component defines competencies as intended learning outcomes; the content component organizes the curriculum in modules around these outcomes; the process component relies on active, research-based and practice-oriented methods; the assessment component uses criterion-based assessment of performance; the resource component provides a digital learning environment and partnership with schools; and the reflective component supports self-assessment and continuous professional development (Loughran, 2002). The components are implemented together: a change in learning outcomes requires corresponding changes in content, methods and assessment.

Table 2. Structural components of competency-based education and their implementation in natural science teacher education

Component	Content	Example of implementation in the educational programme 6B01515 Geography
Target	Competencies formulated as learning outcomes of the programme, modules and courses	The programme aims to train geography teachers with subject, communicative, digital and professional competencies and inclusive education skills
Content	Modular curriculum; integration of subject, pedagogical and research content; Sustainable Development Goals	Courses "Theories and concepts of modern geography", "Environment and sustainable development", "Climate change and its consequences"
Process	Active, student-centred, research-based and practice-oriented methods; STEM/STEAM, CLIL, inquiry-based learning	Course "Geographical research, development and innovation"; independent monitoring of weather and climate change
Assessment	Criterion-based assessment of learning outcomes in authentic tasks	Learning outcomes of each course are formulated as observable actions (analyses, assesses, applies)
Resource	Digital and artificial intelligence tools; partnership between university and school; teaching materials	Educational and methodological support of the programme; pedagogical practice at schools
Reflective	Self-assessment, reflective practice, continuous professional development	Course "Planning geography teaching and individualization of teaching"; professional development of university teachers

Source: compiled by the authors.

3.3 Research on competencies in natural science education

The second objective of the analysis was to compare research on the competencies that natural science education is expected to develop (Table 3). Scientific literacy is the central concept. Roberts (2007) distinguishes two visions: one oriented towards the concepts and methods of science itself and the other towards situations in which citizens meet science in everyday life. The OECD framework follows the second vision and defines scientific literacy through three competencies: explaining phenomena scientifically, evaluating and designing scientific enquiry, and interpreting data and evidence scientifically (OECD, 2019). In Kazakhstan, the corresponding concept is functional literacy, understood as the ability to apply knowledge in real situations; it has become an explicit goal of school and teacher education.

Research competence is developed mainly through inquiry-based learning, whose phases are orientation, conceptualization, investigation, conclusion and discussion (Pedaste et al., 2015). A meta-analysis of experimental and quasi-experimental studies showed a positive mean effect of inquiry-based science teaching on learning of about half a standard deviation, with larger effects for teacher-guided than for student-led inquiry (Furtak et al., 2012). For geography, Sadykova et al. (2023) validated a scale of geographic inquiry process skills on a sample of Kazakhstani school students and showed that inquiry should be assessed as a set of interrelated procedural skills. Digital competence is described by the technological pedagogical content knowledge framework (Mishra & Koehler, 2006) and by the European framework for the digital competence of educators (Redecker, 2017). Problem solving and transversal skills are emphasized in the key-competence frameworks (European Commission, 2019) and in education for sustainable development (UNESCO, 2017).

Table 3. Comparison of international and domestic research on competencies in natural science education

Competence	International research and frameworks	Research and practice in Kazakhstan	Main finding
Scientific and functional literacy	Roberts (2007); OECD (2019)	Functional literacy as a goal of updated school content; PISA results (OECD, 2023)	Literacy means applying knowledge in real contexts; in PISA 2022 the mean science score of Kazakhstan was 423 points against an OECD average of 485
Research (inquiry) competence	Pedaste et al. (2015); Furtak et al. (2012)	Sadykova et al. (2023); research-based courses in innovative programmes	Guided inquiry improves learning; inquiry skills should be taught and assessed as interrelated procedures
Pedagogical content knowledge	Shulman (1986); Grossman (2018); Loughran (2006)	Theory of the holistic pedagogical process (Khmel, 1998)	Subject and pedagogical knowledge should be integrated and practised in core teaching practices
Digital competence	Mishra & Koehler (2006); Redecker (2017)	Digital and artificial intelligence tools in programme outcomes	Technology should be integrated with content and pedagogy rather than taught separately
Problem solving and transversal skills	European Commission (2019); UNESCO (2017); Deming & Silliman (2024)	Competence-based approach in higher education (Kunanbayeva, 2016)	Transversal skills are in growing demand and are formed in authentic, interdisciplinary tasks

Source: compiled by the authors.

The comparison shows that international and domestic research agree on the goal – the ability to apply knowledge – but differ in emphasis. International studies provide operational frameworks and empirical evidence on the effectiveness of particular methods, whereas domestic studies have concentrated on the theoretical justification of the competency approach and on programme design; empirical studies of the competencies of natural science students and teachers are still few. The gap between Kazakhstan and the OECD average in the PISA science results (OECD, 2023) indicates that the application of knowledge remains a weak point and confirms the need to prepare teachers who can organize inquiry and work with data and evidence.

3.4 Implementation in the innovative educational programmes of pedagogical universities

Academic staff of the pedagogical universities of Kazakhstan have developed and introduced educational programmes in the field of Pedagogical Sciences within the World Bank project on strengthening the capacity of pedagogical education. The main goal of these programmes is to enable students to act in changing situations, to develop their knowledge independently and to make responsible decisions. Since the 2023–2024 academic year, innovative educational programmes (IP) have been introduced at pedagogical universities, including Abai Kazakh National Pedagogical University, in order to implement competency-based education in the natural sciences, and 100–150 university teachers have upgraded their qualifications.

As a result, the professional competence of teachers of the natural sciences has been developed in the following areas: the use of competency-based teaching methodologies and innovative pedagogical technologies; the formation of students' functional literacy; criterion-based assessment of learning outcomes; the use of digital and artificial intelligence tools; interdisciplinary links; STEM/STEAM, CLIL and inquiry-based teaching methods; the integration of the Sustainable Development Goals into teaching; and the formation of students' 21st-century skills.

The educational programme 6B01515 Geography illustrates this approach. Its goal is to train geography teachers who have modern subject, communicative, digital and professional competencies and inclusive education skills and are able to create high-quality educational content and organize the educational process. The competence of a geography teacher combines pedagogical and subject-specific competencies: knowledge of the theory and methodology of geography, practical methods of teaching geography, research competencies and value orientations. The programme integrates practice-oriented models of teaching, in particular STEM and content and language integrated learning (CLIL), which bring theoretical knowledge closer to real situations. Several new courses were introduced into the cycles of basic and major disciplines (Table 4).

Table 4. Examples of new courses in the educational programme 6B01515 - Geography (IP)

No.	Module	Course	Purpose	Learning outcomes
1	Supporting learners as individuals	Planning geography teaching and individualization of teaching	To develop skills in individualizing teaching, taking into account learner diversity and using geography teaching technologies on the basis of pedagogical and independent research	Applies the principles of teaching and guidance to learners as individuals; takes individual needs into account; supports personal development and self-esteem
2	Teacher – regulatory practitioner	Geographical research, development and innovation	To form research-oriented thinking and the ability to develop, update and apply innovative methods and technologies of teaching geography in a changing society and educational environment	Develops teaching skills through research-based approaches; takes part in research and in cooperation between the university and stakeholders
3	Geographical picture of the world	Theories and concepts of modern geography	To acquire knowledge of the geographical sciences and of modern theories and concepts of geography	Knows the conceptual ideas underlying methodological and theoretical content; selects research methods suitable for teaching; applies developments in geographical science in the educational process
4	Interaction of society and nature	Environment and sustainable development	To study the current state of the environment and the sustainable development of regions	Studies the interaction between humans and the environment; analyses the sustainable development of Kazakhstan; assesses the state of the environment
5	Interaction of society and nature	Climate change and its consequences	To study current issues of global climate change	Monitors weather and climate change independently; analyses approaches to studying climate change

Note: the title, purpose and learning outcomes of several newly introduced courses are given as examples. Source: compiled by the authors from the programme documentation.

The examples show how the structural components in Table 2 are implemented. The learning outcomes are formulated as actions that can be observed and assessed; the content links geographical science with sustainable development and climate change; and the courses on research and on the individualization of teaching develop research and reflective competencies. Competency-based programmes also take into account what motivates students to participate fully in learning: the active methods used in basic and major courses support students' independence and take their social, cultural, cognitive and motivational characteristics into account.

The analysis also revealed a need for educational and methodological support. The innovative programmes in the natural sciences require systematic teaching materials of a scientific and applied nature, presented in a form convenient for learning and teaching and organized by structure, function and competence. Developing this methodological base is a condition for a stable and effective learning environment.

The study has limitations. It is based on the analysis of literature and documents and does not report experimental or pilot data on the effectiveness of the programmes; the outcomes of the innovative programmes, including the competencies of their first graduates, should be evaluated empirically in further research.

4 Conclusion

Despite changes in the economy and society, the demand for well-prepared teachers remains high, and the requirements for them are changing with technology and educational standards. The analysis of the theoretical foundations of competency-based education and of international experience (the OECD, UNESCO, the European Commission and practice-oriented models of teacher education) showed that modern pedagogical education is moving from the transmission of knowledge to the development of professional competence, research skills, reflective practice and the ability to apply knowledge in real educational situations.

Competency-based education was described as a system of target, content, process, assessment, resource and reflective components. The comparison of research on the natural sciences showed agreement on the goal of applying knowledge and a shortage of domestic empirical studies. The innovative educational programmes introduced at pedagogical universities of Kazakhstan since 2023–2024, illustrated by the Geography programme, implement these components through new courses, research-based and practice-oriented teaching and the professional development of university teachers.

On this basis, the following practical recommendations are proposed. (1) Programme developers should formulate learning outcomes as assessable competencies and align the content, teaching methods and criterion-based assessment of every course with them. (2) Universities should provide innovative programmes in the natural sciences with systematic educational and methodological materials and update them regularly using feedback from students, graduates and employers. (3) The continuous professional development of university teachers should focus on competency-based teaching and assessment, digital and artificial intelligence tools, and STEM, CLIL and inquiry-based methods. (4) Research-based learning and partnership with schools should be extended so that students apply their knowledge in real pedagogical situations. (5) The effectiveness of competency-based programmes should be monitored empirically, including the scientific and functional literacy and research competence of students.

The implementation of competency-based educational programmes in the natural sciences within the new model of pedagogical education is a key stage of the reform of higher education in Kazakhstan. Its success depends on the methodological support of the programmes and on strengthening the capacity of the teaching staff.

Author contributions statement:

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Sholpan Karbayeva	✓	✓				✓	✓	✓	✓	✓				

Yenglik Khorgasbay	✓		✓	✓	✓		✓		✓	✓	✓	✓		
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C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

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