

Pedagogical conditions for forming the readiness of future teachers at the university to use modular E-learning technology

Bayan Kylyshpai¹, Indira Yusupova¹, Raikhan Skakova², Kenzhekhan Medeubayeva²,
Seitenova Salima ^{*3}

¹ Department of Theory and Practice in Education, Kazakh National Women's Pedagogical University, Republic of Kazakhstan

² Department of Pedagogy, Psychology and Social Disciplines, Almaty Humanitarian and Economic University, Republic of Kazakhstan

³ Department of Pedagogy of Preschool and Primary Education, non-profit limited company «Makhambet Utemisov West Kazakhstan University»; Republic of Kazakhstan.

*Corresponding author E-mail: seitenovasalima@gmail.com.

ABSTRACT

The study aims to determine the impact of the use of modular e-technology on the level of formation of motivational-value, cognitive and activity-practical components of readiness of students of the pedagogical university. The study is based on a quasi-experimental design of “pre-testing with a control group”. The sample was formed by 162 students of pedagogical specialties of 2–4 years, evenly distributed between the experimental (n = 81) and control (n = 81) groups. The diagnostic complex consisted of the author's questionnaire RMETQ, the knowledge test KMELT and a practical task with the analytical rubric ARMECD. Statistical analysis consisted of MANOVA, ANCOVA, dependent and independent t-tests, correlation analysis (Pearson/Spearman) and effect size estimation. The results indicated the superiority of the experimental group in all components of readiness ($p < .001$; $d = 1.77-2.58$; $\eta^2 p = .439-.622$). The greatest increase was recorded for the activity-practical component (+103.8%). In the experimental group, an integrated structure of readiness with strong intercomponent correlations ($r = .61-.72$) was formed, in contrast to weak connections in the control group ($r = .27-.33$). The results determined the feasibility of introducing modular e-technology into the system of pedagogical university training.

Keywords: Modular e-technology of learning, Readiness of future teachers, Pedagogical conditions, LMS Moodle, Quasi-experiment, Pedagogical education.

1. Introduction

The fast development of digital technologies and the large-scale integration of electronic learning platforms into the modern education system have changed approaches to the training of future teachers. Today, universities, as academic and educational centers, are faced with the need to form in students of pedagogical specialties both subject knowledge and practical readiness to design and implement the educational process using digital tools [1], [2]. Among the available technological solutions, modular electronic learning technology – in particular, systems based on the Moodle platform – had the greatest pedagogical flexibility. This made it the most optimal for organizing the educational process in university environments [3]. Despite the significant number of studies devoted to the implementation of electronic learning in higher education, many problems have not yet been investigated. First, it was about the special pedagogical conditions that ensured the formation of readiness of future teachers to use modular e-learning technology [4]. Most of the existing research has focused on students' academic performance and the issue of teachers' digital competence development. Thus, the preparatory dimension of initial teacher education has been neglected [5]-[7].

1.1. The concept of readiness in pedagogical education

The concept of “readiness” generally encompasses motivational, cognitive, operational, and reflective components. Taking together, this has enabled future teachers to effectively design, implement, and evaluate modular e-learning systems.

The concept of professional readiness was one of the central ones in Kazakh and foreign pedagogical science. Researchers defined readiness as an integrative personal formation that combined motivational orientation, theoretical knowledge, practical skills and reflective ability, which were necessary for effective professional activity [8], [9]. In the context of pedagogical education, scientists considered readiness as a dynamic, manageable quality that was formed in the conditions of a purposeful educational process [10]. Several Kazakh researchers made a significant contribution to the conceptualization of readiness for technologically enriched learning. They emphasized that important components of its structure were the need for a holistic approach to its formation at the university [11], [12]. It is fundamentally important that the readiness to use digital tools was different from general digital literacy. This difference was that it implied awareness of technologies and at the same time a formed professional orientation and the ability to consciously integrate them into the educational process [13].

1.2. Pedagogical conditions as a category of pedagogical science

Pedagogical conditions were traditionally considered by scientists to be a certain set of circumstances, measures and factors of the educational environment, the purposeful creation of which ensured the effective achievement of a specific pedagogical goal [14]. Modern studies have identified organizational-pedagogical, psychological-pedagogical and didactic conditions, each of which performed its specific function in the structure of the pedagogical process [15]. Regarding the formation of future teachers' readiness to use electronic technologies, scientists emphasized the need for a combination of content, procedural and environmental conditions. Together, they provided a systemic impact on all components of readiness [16], [17]. The role of subject-subject interaction between a teacher and a student was especially emphasized as a necessary psychological and pedagogical condition, without which other measures lost their effectiveness [18].

1.3. E-learning and modular technologies in higher education

E-learning in the university environment has gone from an auxiliary tool to a full-fledged educational paradigm. It provided for the implementation of a new understanding of the roles of a teacher and a student, the structure of educational material and forms of pedagogical interaction [19], [20]. The modular approach to organizing e-learning, implemented through online platforms, provided structure, flexibility, and the ability to personalize the learning process, which generally met the modern requirements of competency-based education [21], [22].

Research shows that the effective use of modular e-learning technologies requires a teacher to have a specific combination of technological, pedagogical, and subject knowledge, which is described by the TPACK (Technological Pedagogical Content Knowledge) model [23], [24]. In the Kazakhstan educational space, the issue of preparing future teachers to work with electronic learning systems has become particularly relevant in the context of martial law and the forced transition to distance learning [25], [26].

Thus, the analysis of scientific literature demonstrated that, despite the significant interest of researchers in certain aspects of the problem under study, a comprehensive study of the pedagogical conditions for the formation of future teachers' readiness to use modular e-learning technology has not been carried out. Therefore, the problem has not been sufficiently developed, which is important for its further relevance.

1.4 Aim and hypothesis

The proposed study was aimed at addressing this gap by studying the pedagogical conditions for the formation of future teachers' readiness to use modular e-learning technology at the university. Therefore, the aim of the article was to investigate and experimentally verify the set of pedagogical conditions, the implementation of which ensured the effective formation of appropriate readiness among students of pedagogical specialties.

In accordance with the purpose of the study, the following research questions and hypotheses were formulated. The main Research Questions were:

RQ1. What was the initial level of readiness of future teachers (before the application of modular e-learning technology)?

RQ2. Were there statistically significant differences in the level of readiness of future teachers to use modular e-learning technology between students who studied using modular e-learning technology?

RQ3. Which of the three components of readiness demonstrated the greatest increase in indicators under the influence of learning using modular e-learning technology?

The main Research Hypotheses were:

H1. Students in the experimental group who studied using modular e-learning technology will demonstrate statistically significantly higher indicators of the motivational and value component of readiness according to the RMETQ questionnaire compared to students in the control group after the intervention, provided that the pre-test input indicators are controlled (ANCOVA, $p < 0.05$, $d \geq 0.50$).

H2. Students in the experimental group will demonstrate statistically significantly higher indicators of the cognitive component of readiness according to the KMELT knowledge test and the activity-practical component according to the ARMECD rubric compared to students in the control group after the intervention, and the increase in the indicators of the activity-practical component (Cohen's d) will exceed the increase in the cognitive component, which will reflect the higher effectiveness of modular e-technology in the formation of practical skills compared to theoretical knowledge.

H3. After the intervention, students in the experimental group will have statistically significant positive correlations between all three components of readiness (motivational-value, cognitive, and activity-practical) at the level of $r \geq 0.50$ ($p < 0.05$), while students in the control group will have the strength of intercomponent correlations at the level of $r < 0.30$, which will indicate the integrative nature of the formation of readiness in the conditions of modular e-learning as opposed to the fragmentary development of individual components in traditional learning.

2. Research method

2.1. Research design

The study was implemented based on a quantitative quasi-experimental approach and using the concept of “pre-test – post-test control group design”. The chosen design is a generally accepted standard in pedagogical research aimed at determining and establishing the effectiveness of educational interventions in the formation of professional competencies of future specialists. The choice of quasi-experimental is due to the natural organizational limitations of the university environment. Academic groups are formed administratively, which would complicate individual randomization of participants. To ensure the equivalence of the groups before the intervention, a pre-test was conducted. It confirmed the absence of statistically significant differences between the experimental and control groups in terms of initial readiness indicators ($p > .05$).

The study was conducted in 6 academic groups of 2nd, 3rd and 4th year students of the pedagogical university (two groups from each year). From each pair of groups, one was defined as experimental (here training took place using modular e-learning technology). The other group was defined as control (participants underwent traditional classroom training without the use of modular e-learning technology). The distribution of groups by conditions was at the level of academic cohorts. The independent variable in the study was the pedagogical condition of organizing training: the use of modular e-learning technology (experimental condition) versus traditional training (control condition).

The dependent variable was the level of readiness of future teachers to use modular e-learning technology. This level was determined on the basis of several structural components: 1. motivational and value component - attitude to e-learning, internal motivation, awareness of the value of digital technologies in pedagogical activity; 2. cognitive component - the volume and quality of theoretical knowledge about modular e-learning technology, its principles; 3. activity-practical component - the formation of practical skills and abilities in the development and application of modular e-content.

2.2. Research participants

The study was attended by students of the pedagogical university who receive higher education at the educational and qualification level of "bachelor" in pedagogical specialties. The selection was implemented based on the method of purposeful sampling based on the defined inclusion and exclusion criteria.

Inclusion criteria:

1. Studying in the pedagogical specialty of the university (2nd–4th year of bachelor's degree).
2. Passing the academic discipline within which the research intervention was implemented.
3. Availability of basic experience with digital educational tools (LMS, online platforms, e-mail).
4. Voluntary written informed consent to participate in the study and processing personal data.

Exclusion criteria:

1. Students who missed more than 20% of classes during experimental intervention.
2. Participants who withdrew consent to the processing of personal data.
3. Students involved in parallel educational programs use similar e-technologies, which could affect the purity of the results.

The total sample was $N = 168$ people in six academic groups (two groups in each of the three courses: 2nd, 3rd, 4th). After applying the exclusion criteria (6 students did not meet the participation conditions or withdrew consent), the final sample was $N = 162$ people. From each course, one group entered the experimental condition (training using modular e-technology), the other - the control condition (traditional form of training). The experimental group was formed by 81 students, the control group - by 81 students. Detailed characteristics of the participants are presented in Table 1.

Table 1. Demographic and Academic Characteristics of Study Participants ($N = 162$)

Characteristic	Experimental Group ($n = 81$)	Control Group ($n = 81$)	Total ($N = 162$)
Gender			
Female	59 (72.8%)	58 (71.6%)	117 (72.2%)
Male	22 (27.2%)	23 (28.4%)	45 (27.8%)
Year of Study			
2nd year	27 (33.3%)	27 (33.3%)	54 (33.3%)
3rd year	27 (33.3%)	27 (33.3%)	54 (33.3%)
4th year	27 (33.3%)	27 (33.3%)	54 (33.3%)
Field of Specialization			
Primary Education	28 (34.6%)	27 (33.3%)	55 (33.9%)
Ukrainian Language & Literature	27 (33.3%)	27 (33.3%)	54 (33.3%)
Mathematics & Informatics	26 (32.1%)	27 (33.3%)	53 (32.7%)
Prior Experience with LMS			
Yes	51 (63.0%)	50 (61.7%)	101 (62.3%)
No	30 (37.0%)	31 (38.3%)	61 (37.7%)
Age, $M \pm SD$	20.3 ± 1.1	20.5 ± 1.2	20.4 ± 1.1

2.3. Instruments

The study used three diagnostic instruments, each of which corresponded to one of the structural components of the construct studied: motivational value, cognitive, and activity-practical.

This approach made it possible to implement the principle of methodological triangulation. It involved the use of several independent methods of measuring one construct to increase the construct and criterion validity of the results. The use of a self-report questionnaire, an objective knowledge test, and a practical task made it possible to cover different dimensions of readiness and minimize individual limitations.

All three instruments were used by the participants twice – at the pre-test and post-test stages of the study – using an identical administration procedure. The total maximum score for the set of instruments was 150 points.

The first instrument was the author's questionnaire Readiness for Modular E-Learning Technology Questionnaire (RMETQ). This instrument was aimed at determining the motivational-value component. The theoretical basis of the instrument was the concept of Teacher Technology Readiness [27], [28], the Technology Acceptance Model (TAM), and modern approaches to operationalizing the motivational component of readiness for e-learning in teacher education.

The development of the RMETQ was carried out in five stages. In particular, the theoretical operationalization of the construct was first determined, i.e., the formation of subconstructs of the motivational-value component (attitude towards e-learning, intrinsic motivation, value awareness, self-efficacy regarding e-technologies) based on a systematic literature review. Next, the statement pool was formed, i.e., the development of an initial set of 58 statements with uniform coverage of all selected subconstructs. After that, an expert assessment of content validity was carried out. To this end, the authors of the study involved five independent experts in the field of higher education pedagogy and educational technology to assess the relevance of each statement using the Content Validity Ratio (CVR) method. Statements with a $CVR < .59$ were excluded. Pilot testing was also provided, in particular, testing on a sample of 24 students (not included in the main sample). This made it possible to check the clarity of the statements and obtain psychometric data. In addition, psychometric selection was provided, i.e. selection of final statements according to the criteria: item-total correlation $r \geq .30$, absence of multicollinearity between statements, internal consistency of subscales $\alpha \geq .70$.

The final version of the RMETQ consisted of 20 statements divided into four subscales: 1. Attitude towards e-learning (5 statements) — general positive/negative attitude towards learning in an online environment; 2. Intrinsic motivation (5 statements) — personal interest and desire to master e-technologies; 3. Value awareness (5 statements) — understanding of the significance of modular e-technologies for future pedagogical practice; 4. Technological self-efficacy (5 statements) — confidence in one's own ability to effectively use e-technologies.

Responses were recorded on a 5-point Likert scale. The total RMETQ score ranged from 20 to 100 points; a higher score corresponded to a higher level of motivational and value readiness.

The levels of motivational and value readiness were determined based on the total score: low (20–46), medium (47–73), high (74–100).

Based on pilot testing, the internal consistency coefficient of the full scale was $\alpha = .83$, subscales — from $\alpha = .76$ to $\alpha = .81$. Such indicators met acceptable standards. Convergent validity was confirmed by positive correlations with the validated TAM-EDU scale ($r = .71$, $p < .001$). The questionnaire was administered online via the Google Forms platform; the average completion time was 10–12 minutes.

At the same time, an author's knowledge test (Knowledge of Modular E-Learning Technology Test, KMELT) was developed to measure the cognitive component of readiness. Such a knowledge test made it possible to provide an objective assessment of the actual level of acquired theoretical knowledge regardless of the subjective perception of the participant. The test content consisted of various thematic blocks: principles of modular learning, e-course architecture, didactic capabilities of LMS, e-content standards (SCORM, xAPI) and pedagogical design of e-modules.

The test specification was developed in accordance with Bloom's Revised Taxonomy and covering three cognitive levels: knowledge/understanding (level 1–2, 40% of tasks), application (level 3, 40% of tasks) and analysis (level 4, 20% of tasks).

KMELT consisted of 30 tasks of three types: 1. Single choice tasks (4 options) - 15 tasks that tested knowledge and understanding of the basic concepts of modular e-technology; 2. Matching tasks - 10 tasks that allowed testing the ability to apply knowledge in standardized situations; 3. Ordering/sequencing tasks — 5 tasks that determined the understanding of procedural knowledge (stages of e-module development, LMS configuration algorithms).

Each task is scored 1 point; maximum total score — 30 points. Time limit — 30 minutes, one attempt. Cognitive readiness levels: low (0–10), medium (11–20), high (21–30).

The development of KMELT consisted of: forming a test specification (test blueprint) with the distribution of tasks by thematic blocks and cognitive levels and developing tasks with the involvement of two subject specialists. After that, an expert assessment of content validity was involved ($CVR > .75$ for all tasks). Pilot testing ($n = 24$) and analysis of the complexity (item difficulty index, p) and discriminability (item discrimination index, D) of each task were also conducted. Tasks with $p < .20$ or $p > .90$, as well as $D < .25$ were revised or replaced.

Test reliability according to the Kuder–Richardson method: $KR-20 = .78$. This indicator corresponded to an acceptable level for achievement tests. Average task complexity index: $M = .61$ ($SD = .12$). This indicated a moderate complexity of the test. Average discriminative index: $M = .38$ ($SD = .09$). The test was based on the

built-in testing module of the Moodle platform with automatic checking of answers and generation of reports for each participant.

At the same time, to determine the activity-practical component of readiness - the formation of practical skills and abilities in the development and application of modular e-content, an authentic practical task (authentic performance task) with evaluation according to an analytical rubric was used. Students were offered a standardized practical task: to independently develop the structure of one educational module of an e-course for a selected educational topic using the LMS Moodle. The task included: 1 Formulation of measurable learning objectives of the module in accordance with Bloom's taxonomy. 2 Structuring of educational content with determination of the sequence of material processing. 3. Selection and justification of types of educational activities (lectures, assignments, tests, forums). 4. Design of tasks for self-testing and final assessment. 5. Technical implementation of the module structure in the LMS Moodle environment. Conditions of performance: individually, outside the classroom, with access to the course's educational resources; completion period - 2 weeks.

The practical task was assessed based on the author's analytical rubric (Analytic Rubric for Modular E-Course Design, hereinafter - ARMECD), which included five assessment criteria (See Appendix A).

The maximum total score is 20 points. The levels of practical readiness were determined based on the total score: low (0–7), medium (8–14), high (15–20).

To ensure objectivity and reliability of the assessment, each student's work was checked by two independent experts - experienced teachers of the Department of Pedagogy and Educational Technologies with at least 5 years of experience. Before the assessment began, a joint calibration session was held: the experts jointly analyzed 5 sample works of different quality levels to agree on a common understanding of the rubric criteria.

The degree of inter-expert agreement was determined by Cohen's kappa coefficient: $\kappa = .81$. This indicator corresponded to the level of "almost perfect agreement" ($\kappa > .80$). The final score for each work was calculated as the arithmetic mean of the assessments of the two experts. In cases of grade discrepancies of more than 2 points ($n = 7$ papers, 4.3% of the total), a third expert was involved for arbitration evaluation; the final score was determined as the median of the three grades. Practical assignments were submitted by students through the Moodle Assignment system within the established deadlines (See Appendix B).

2.4. Research Procedure (Procedure)

Before the start of the study, all participants received detailed information about its purpose, procedure, voluntary nature of participation and the right to withdraw consent at any stage. Written informed consent was obtained from all 162 participants. The study was approved by the university's academic ethics committee. In order to ensure comparability of the study conditions for both groups, teachers of the experimental and control groups had identical curricula, thematic plans and criteria for assessing academic achievements. The difference between the groups was solely in the form and technology of organizing the educational process.

At the beginning of the semester, an initial diagnosis (pre-test) of the level of readiness of all participants ($N = 162$) was carried out based on the RMETQ questionnaire and the KMELT knowledge test. A practical task with the ARMECD rubric was also administered at this stage as a starter task.

The RMETQ questionnaire was administered online via the Google Forms platform. A link to the questionnaire was sent via the university email and the internal Moodle system. The KMELT knowledge test was administered via the built-in Moodle testing module in synchronous mode during the practical session (duration: 30 minutes, one attempt, without access to external resources). The practical task (baseline) was given to students in the 2nd week; the completion period was 2 weeks. The task was submitted via Moodle Assignment. The obtained pretest data were checked for normality of distribution (Shapiro–Wilk test) and were used to confirm the equivalence of the experimental and control groups before the intervention.

For 12 weeks, both groups studied within the same academic discipline under different pedagogical conditions. In the experimental group ($n = 81$), training was conducted using modular e-learning technology on the Moodle platform. The training course was structured in the form of 6 thematic modules (2 weeks each), each of which contained:

- 1 Theoretical block: video lectures (15–20 min), interactive presentations, electronic educational materials in SCORM format;

2. Practical block: individual tasks with automated or expert checking, cases, project microtasks;
3. Communicative block: thematic forums for discussion, group wiki pages, consultations with the teacher in asynchronous mode;
4. Self-test block: modular test (10–15 test tasks) with automatic checking and instant feedback;
5. Reflective block: weekly short reflective diary (learning journal) in Google Forms format.

Students had the opportunity to work through the material at a convenient pace within the established deadlines. The teacher regularly monitored student activity through the Moodle analytical module and provided individual feedback within 48 hours after submitting the tasks.

The control group ($n = 81$) studied according to the traditional form of teaching organization: classroom lectures (2 h/week) and practical classes (2 h/week) without the systematic use of modular e-technology. Basic access to the university's digital resources (electronic library, e-mail, repository of educational materials) was maintained to ensure equal conditions.

After the experiment, all participants ($N = 162$) underwent a final diagnosis (post-test) using an identical procedure to the ascertainment stage:

- RMETQ was administered online via Google Forms during a 5-day window (days 1–5 of week 15);
- KMELT was administered synchronously during the final class (30 minutes, one attempt);
- The practical task (post-test version) was issued on week 14; the submission deadline was week 15; the evaluation was carried out by two independent experts using the ARMECD rubric. The study completion rate was 100%: none of the 162 participants dropped out during the study or missed the post-test procedure.

2.5. Data analysis

Statistical processing of the obtained data was carried out on the basis of IBM SPSS Statistics (version 27.0) and Microsoft Excel (version 2021).

First, a quality check and preparation of the data set for statistical analysis were implemented. The following procedures were performed: data completeness check (missing data analysis) — no missing values were detected, since the Google Forms and Moodle platforms provided for the mandatory filling of all fields; reverse coding of negatively formulated statements of the RMETQ questionnaire ($n = 5$); verification of the correctness of data entry by cross-validation of automatically generated reports of platforms with a consolidated database; standardization of scores on three subscales to ensure comparability of indicators between tools.

Before conducting the main analysis, a check of the statistical prerequisites of parametric methods was carried out. The normality of the distribution of dependent variables was checked based on the Shapiro–Wilk test and taking into account the size of subgroups ($n = 81$). Homogeneity of variances between groups was determined using Levene's test for equality of variances. In case of detection of violation of normality of distribution or homogeneity of variances, nonparametric alternatives were used: Mann–Whitney U test instead of independent t-test and Wilcoxon signed-rank test instead of dependent t-test.

Equivalence of groups before the start of the intervention was checked based on comparison of pre-test indicators between the experimental and control groups on all three instruments (RMETQ, KMELT, ARMECD). The absence of statistically significant differences ($p > .05$) served as confirmation of the comparability of groups at the input level.

For each diagnostic tool and each group at both stages of measurement (pre-test, post-test), the following indicators of central tendency and variability were calculated: arithmetic mean (M), standard deviation (SD), median (Mdn), minimum and maximum value. The study used an independent samples t-test or its nonparametric analogue Mann–Whitney U-test - depending on the results of the verification of the prerequisites. The level of statistical significance was set at $\alpha = .05$. To assess the statistical significance of changes between pre-test and post-test indicators within each group separately, a dependent t-test was used.

The effect size was also calculated. For parametric comparisons, Cohen's d coefficient was used: small effect - $d < 0.50$; medium - $0.50 \leq d < 0.80$; large - $d \geq 0.80$. For nonparametric comparisons, the r coefficient was calculated based on the Z -statistic.

To control for the possible influence of input differences between groups on the post-test results, a one-way ANCOVA was used, where the pre-test indicators acted as a covariate, the factor was the training condition (experimental / control), and the corresponding post-test indicator was the dependent variable. The preconditions of ANCOVA were checked: homogeneity of regression slopes and linearity of the relationship between the covariate and the dependent variable. To compare all three dependent variables (motivational-value, cognitive, and activity-practical components of readiness) between groups, a one-way Multivariate Analysis of Variance (MANOVA) was used.

To compare the distribution of participants by readiness levels (low, medium, high) between groups and between measurement stages, Pearson's chi-square test or Fisher's exact test was used in cases where the expected frequency in individual cells of the conjugation table was less than 5.

3. Results and discussion

3.1. Initial level of readiness of future teachers to use modular e-learning technology

Before conducting a comparative analysis, the normality of the distribution of pre-test indicators was checked using the Shapiro–Wilk test. According to the results of the test, the distribution of indicators for all three tools in both groups did not deviate from normal ($p > .05$). The homogeneity of dispersions between the groups was confirmed by the Levene test ($p > .05$ for all three indicators).

At the beginning of the study, both groups had mainly low and medium levels of readiness for all three components. Such indicators indicated the insufficient formation of the readiness of future teachers to use modular e-learning technology in the conditions of traditional university training.

According to the motivational and value component (RMETQ, max = 100 points), the average indicators of both groups were in the range of the average level of readiness, but with a noticeable proportion of students at a low level. In the experimental group, the average score was $M = 52.4$ ($SD = 9.3$), in the control group - $M = 51.8$ ($SD = 9.1$). Distribution by levels: low level (20–46 points) - 44.4% of students in the experimental group and 45.7% in the control; medium level (47–73 points) - 51.9% and 50.6%, respectively; high level (74–100 points) - 3.7% and 3.7%.

According to the cognitive component (KMELT, max = 30 points), the average indicators of both groups corresponded mainly to a low level of theoretical knowledge about modular e-technology. In the experimental group $M = 12.3$ ($SD = 3.1$), in the control group — $M = 12.1$ ($SD = 3.4$). Distribution by levels: low level (0–10 points) — 46.9% and 49.4%, respectively; medium level (11–20 points) — 50.6% and 48.1%; high level (21–30 points) — 2.5% and 2.5%.

According to the activity-practical component (ARMECD, max = 20 points), the lowest initial indicators among all three components were recorded. In the experimental group $M = 7.8$ ($SD = 2.4$), in the control group — $M = 7.6$ ($SD = 2.3$). Distribution by levels: low level (0–7 points) — 51.9% and 53.1%, respectively; medium level (8–14 points) — 46.9% and 45.7%; high level (15–20 points) — 1.2% and 1.2%.

The pre-test indicators were also compared based on an independent t-test separately for each of the three instruments. The results of the analysis indicated the absence of statistically significant differences between the groups in any of the three components of readiness: in the motivational-value component — $t(160) = 0.41$, $p = .683$, $d = 0.06$; in the cognitive component — $t(160) = 0.38$, $p = .704$, $d = 0.06$; for the activity-practical component — $t(160) = 0.52$, $p = .601$, $d = 0.08$. The effect sizes in all three cases are minimal ($d < 0.10$), which confirms the practical equivalence of the groups.

Thus, at the beginning of the study, the experimental and control groups were statistically equivalent on all measured readiness indicators ($p > .05$).

3.2. The effectiveness of modular e-learning technology in shaping the readiness of future teachers

Before conducting the main analysis, a verification of the statistical prerequisites of parametric and multivariate methods was implemented. The Shapiro–Wilk test confirmed the normal distribution of post-test scores in both groups for all three instruments: RMETQ — $W = .981$, $p = .312$ (experimental), $W = .978$, $p = .274$ (control); KMELT — $W = .976$, $p = .198$ and $W = .974$, $p = .176$; ARMECD — $W = .983$, $p = .341$ and $W = .979$, $p = .289$. The Levene test confirmed the homogeneity of variances between groups for all three components ($p > .05$). For MANOVA, the homogeneity of covariance matrices was additionally checked using the Box's M criterion: Box's $M = 18.42$, $F(12, 284761) = 1.51$, $p = .114$, which is an acceptable result and confirms the

admissibility of using MANOVA. Thus, all the necessary prerequisites for conducting the planned parametric analyses were met.

After the completion of the pedagogical intervention in the experimental group, there was a noticeable practical increase in indicators for all three components of readiness. The general picture of the changes was as follows: modular e-learning technology ensured a qualitative transition of the majority of students in the experimental group to higher levels of readiness, however, in the control group, the dynamics of indicators remained moderate and limited mainly to the average level.

According to the motivational-value component (RMETQ, max = 100 points), the average score of the experimental group increased from $M = 52.4$ ($SD = 9.3$) at the pre-test to $M = 74.6$ ($SD = 8.7$) at the post-test, which is an absolute increase of 22.2 points (+42.4%). This corresponded to the transition from an average to a high level of readiness. In the control group, the increase was more modest: from $M = 51.8$ ($SD = 9.1$) to $M = 57.3$ ($SD = 9.2$), i.e. only 5.5 points (+10.6%), which did not ensure a qualitative transition to a higher level of readiness. The comparison between the groups at the post-test indicated a difference in means of 17.3 points in favor of the experimental group. The shift in the distribution by level was particularly significant: while only 3.7% of the experimental group students were at a high level on the pre-test, this figure increased to 48.1% on the post-test, while in the control group it was only 7.4% (see Appendix A).

An even more pronounced dynamic was recorded for the cognitive component (KMELT, max = 30 points). The average score of the experimental group increased from $M = 12.3$ ($SD = 3.1$) to $M = 22.4$ ($SD = 3.8$), i.e., 10.1 points (+82.1%). In the control group, the increase was only 2.6 points (+21.5%): from $M = 12.1$ ($SD = 3.4$) to $M = 14.7$ ($SD = 3.5$). The activity-practical component (ARMECD, max = 20 points) recorded the largest relative increase among all three components — +103.8% in the experimental group. The average score increased from $M = 7.8$ ($SD = 2.4$) to $M = 15.9$ ($SD = 2.6$). At the same time, in the experimental group, the share of students with a low level decreased from 51.9% to 2.5%, and with a high level — increased from 1.2% to 61.7%. This pattern is especially important from a practical point of view, because the activity-practical component directly indicated the ability of future teachers to apply modular e-technology in real pedagogical practice. The dynamics of changes for all components is presented in Figure 2. Detailed descriptive indicators and distribution by readiness levels are presented in Tables 2–3.

Table 2. Descriptive statistics for pre-test and post-test scores

Component	Group	Pre M	Pre SD	Pre Mdn	Post M	Post SD	Post Mdn	Gain	Gain %
RMETQ (max=100)	Experimental (n=81)	52.4	9.3	51.0	74.6	8.7	75.0	+22.2	+42.4%
	Control (n=81)	51.8	9.1	52.0	57.3	9.2	57.0	+5.5	+10.6%
KMELT (max=30)	Experimental (n=81)	12.3	3.1	12.0	22.4	3.8	23.0	+10.1	+82.1%
	Control (n=81)	12.1	3.4	12.0	14.7	3.5	15.0	+2.6	+21.5%
ARMECD (max=20)	Experimental (n=81)	7.8	2.4	8.0	15.9	2.6	16.0	+8.1	+103.8%
	Control (n=81)	7.6	2.3	8.0	9.1	2.4	9.0	+1.5	+19.7%

Table 3. Distribution of participants by readiness levels at pre-test and post-test (%)

Component	Group	Pre Low %	Pre Mid %	Pre High %	Post Low %	Post Mid %	Post High %	χ^2	p
RMETQ	Experimental	44.4	51.9	3.7	4.9	46.9	48.1	48.62	<.001
	Control	45.7	50.6	3.7	39.5	53.1	7.4	4.18	.124
KMELT	Experimental	46.9	50.6	2.5	3.7	39.5	56.8	62.41	<.001
	Control	49.4	48.1	2.5	42.0	54.3	3.7	1.24	.538
ARMECD	Experimental	51.9	46.9	1.2	2.5	35.8	61.7	74.18	<.001
	Control	53.1	45.7	1.2	46.9	51.9	1.2	0.86	.651

Note. χ^2 = chi-square statistic for pre-test vs post-test distribution comparison within each group. Significant χ^2 indicates meaningful shift in readiness level distribution. Low/Mid/High cut-offs: RMETQ 20–46/47–73/74–100; KMELT 0–10/11–20/21–30; ARMECD 0–7/8–14/15–20.

To compare all three dependent variables between groups, a one-sample MANOVA with the factor “training condition” (experimental/control) was conducted. The choice of MANOVA over a series of separate t-tests was determined by the need to control for Type I error inflation in multiple comparisons.

The multivariate Wilks test indicated a statistically significant and large overall effect of the pedagogical intervention: Wilks' $\Lambda = .124$, $F(3, 158) = 372.6$, $p < .001$, $\eta^2p = .876$. The value of Wilks' $\Lambda = .124$ means that only 12.4% of the total multivariate variance was unknown after accounting for pedagogical condition. Thus, belonging to the experimental or control group explained 87.6% of the joint variance of all three components of readiness. The results of the multivariate tests are presented in Table 4.

Table 4. Multivariate test data (MANOVA) for between-group differences

Test	Value	F	df Effect	df Error	p	η^2p
Pillai's Trace	.876	372.6	3	158	< .001	.876
Wilks' Lambda	.124	372.6	3	158	< .001	.876
Hotelling's Trace	7.082	372.6	3	158	< .001	.876
Roy's Largest Root	7.082	372.6	3	158	< .001	.876

Note. η^2p = partial eta-squared. $\eta^2p \geq .14$ = large effect.

Post-hoc univariate comparisons with Bonferroni correction (adjusted significance level $\alpha = 0.017$) indicated the advantage of the experimental group for each component separately. The largest effect size is noticeable for the activity-practical component ($d = 2.58$), somewhat smaller for the cognitive ($d = 2.18$) and motivational-value ($d = 1.77$). Comparison of effect sizes between components is visualized in Figure 1. Detailed results of univariate comparisons are presented in Table 5.

Table 5. Univariate intergroup comparisons after testing (with Bonferroni correction)

Component	Exp M (SD)	Ctrl M (SD)	Mean Diff	t(160)	p	d	95% CI
RMETQ	74.6 (8.7)	57.3 (9.2)	17.3	11.24	< .001	1.77	[14.2, 20.4]
KMELT	22.4 (3.8)	14.7 (3.5)	7.7	13.86	< .001	2.18	[6.6, 8.8]
ARMECD	15.9 (2.6)	9.1 (2.4)	6.8	16.42	< .001	2.58	[6.0, 7.6]

Note. Bonferroni $\alpha = .017$. All effects large ($d > 0.80$). CI = 95% confidence interval for mean difference.

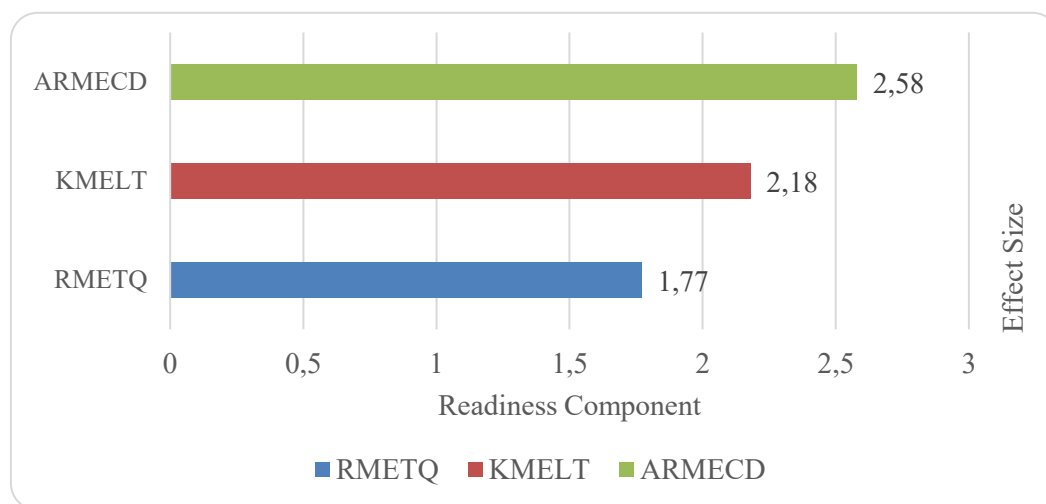


Figure 1. Between-Group Effect Sizes (Cohen's d)

To control the effect of input measures on posttest results and to increase the internal validity of the conclusions about the effectiveness of the intervention, a univariate ANCOVA was conducted for each component separately with the corresponding pretest measure as a covariate. The preconditions for the ANCOVA were carefully tested: the homogeneity of the regression slopes was confirmed by the absence of a significant interaction between the covariate and the educational condition factor— $F(1, 158) = 0.84, p = 0.361$ (RMETQ); $F(1, 158) = 0.92, p = 0.339$ (KMELT); $F(1, 158) = 0.78, p = 0.379$ (ARMECD). The linearity of the relationship between the covariate and the dependent variable was confirmed by visual inspection of the scatter plots for all three components.

After controlling initial readiness, the effect of pedagogical condition remained statistically significant and practically important for all three components. For the motivational-value component: $F(1, 159) = 124.3, p < 0.001, \eta^2p = 0.439$. The pedagogical condition explained 43.9% of the variance in RMETQ scores at the posttest stage even after excluding the contribution of the baseline level. This result indicates a significant effect. For the cognitive component: $F(1, 159) = 187.6, p < 0.001, \eta^2p = 0.541$ — the pedagogical condition explained 54.1% of the variance in knowledge at the posttest stage. For the activity-practical component, the largest effect was recorded: $F(1, 159) = 261.4, p < 0.001, \eta^2p = 0.622$ — 62.2% of the variance in practical skills at the posttest stage is explained solely by the pedagogical condition after controlling for the baseline level. The comparative strength of the effects across components after controlling for pretesting is presented in Figure 3. Detailed ANCOVA results are presented in Table 6.

Table 6. ANCOVA Results: Effect of Training Conditions on Posttest Results (Pretesting as a Covariate)

Component	Source	SS	df	MS	F	p	η^2p
RMETQ	Pre-test	1842.3	1	1842.3	28.4	< .001	.151
	Condition	8063.4	1	8063.4	124.3	< .001	.439
	Error	10313.2	159	64.9			
KMELT	Pre-test	412.6	1	412.6	38.7	< .001	.196
	Condition	2001.4	1	2001.4	187.6	< .001	.541
	Error	1696.8	159	10.7			
ARMECD	Pre-test	284.1	1	284.1	47.2	< .001	.229
	Condition	1572.6	1	1572.6	261.4	< .001	.622
	Error	956.8	159	6.0			

Note. SS = sum of squares; df = degrees of freedom; MS = mean square; η^2p = partial eta-squared. Large effect: $\eta^2p \geq .14$.

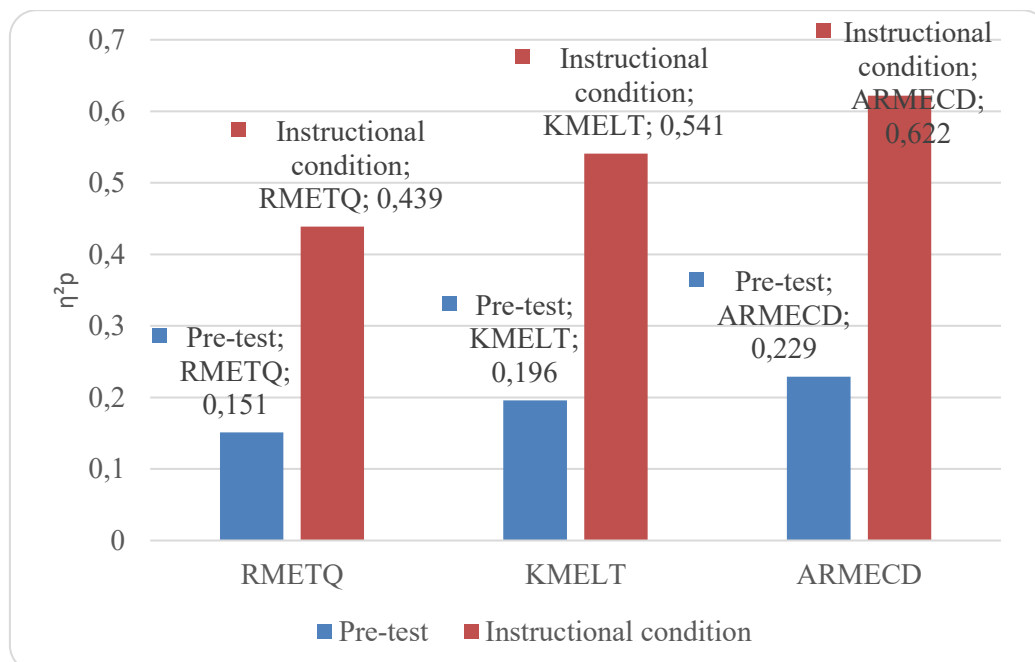


Figure 2. Partial η^2p for covariate pretest and pedagogical condition by readiness components (ANCOVA)

The dependent t-test confirmed the effectiveness of the pedagogical intervention. In particular, in the experimental group, all three components had a statistically significant and practically important increase. For the motivational-value component: $t(80) = 21.6$, $p < 0.001$, $d = 2.41$ is a large effect size, indicating a transformation of the motivational sphere of students under the influence of systematic experience with modular electronic technologies during the semester (see Table 7).

Table 7. Changes within the group from pretest to posttest

Component	Group	Pre M (SD)	Post M (SD)	Diff	t(80)	p	d
RMETQ	Experimental	52.4 (9.3)	74.6 (8.7)	+22.2	21.6	< .001	2.41
	Control	51.8 (9.1)	57.3 (9.2)	+5.5	5.4	< .001	0.60
KMELT	Experimental	12.3 (3.1)	22.4 (3.8)	+10.1	26.8	< .001	2.99
	Control	12.1 (3.4)	14.7 (3.5)	+2.6	6.1	< .001	0.68
ARMECD	Experimental	7.8 (2.4)	15.9 (2.6)	+8.1	30.4	< .001	3.39
	Control	7.6 (2.3)	9.1 (2.4)	+1.5	5.8	< .001	0.65

To determine the effect of pedagogical intervention depending on the year of study, an independent t-test was conducted between subgroups separately for 2nd, 3rd and 4th year students. Senior year students had a greater gain from the use of electronic technologies, probably due to more developed self-organization skills. For the activity-practical component, the effect increased from $d = 2.19$ (2nd year) to $d = 3.24$ (4th year) - the difference is 1.05 units. Detailed results are presented in Table 8.

Table 8. Intergroup comparisons after testing by year of study

Component	Year	Exp M (SD)	Ctrl M (SD)	t	df	p	d
RMETQ	2nd	70.2 (8.9)	54.1 (9.4)	7.14	52	< .001	1.76
	3rd	74.8 (8.4)	57.6 (9.0)	7.96	52	< .001	1.96
	4th	78.9 (8.1)	60.2 (9.1)	8.72	52	< .001	2.15
KMELT	2nd	20.4 (3.9)	13.8 (3.6)	6.98	52	< .001	1.72
	3rd	22.6 (3.7)	14.9 (3.4)	8.62	52	< .001	2.12
	4th	24.3 (3.4)	15.4 (3.5)	10.18	52	< .001	2.50
ARMECD	2nd	14.2 (2.7)	8.4 (2.5)	8.89	52	< .001	2.19
	3rd	16.1 (2.5)	9.2 (2.3)	11.42	52	< .001	2.81
	4th	17.4 (2.3)	9.7 (2.4)	13.16	52	< .001	3.24

Note. $n = 27$ per subgroup. Progressive increase in effect sizes across years of study (e.g., ARMECD: $d = 2.19 \rightarrow 2.81 \rightarrow 3.24$)

One-way ANOVA indicated statistically significant differences between students of different courses within the experimental group: RMETQ — $F(2, 78) = 13.42$, $p < .001$, $\eta^2 = .254$; KMELT — $F(2, 78) = 24.61$, $p < .001$, $\eta^2 = .387$; ARMECD — $F(2, 78) = 20.14$, $p < .001$, $\eta^2 = .341$. Tukey's post hoc test indicated significant pairwise differences between all three courses for KMELT and ARMECD ($p < .05$), while for RMETQ, the differences were significant between the 2nd and 4th courses ($MD = 8.7$, $p < .001$) and between the 2nd and 3rd ($MD = 4.6$, $p = .042$), but not between the 3rd and 4th ($MD = 4.1$, $p = .061$). The dynamics of the effects by course are presented in Figure 3.

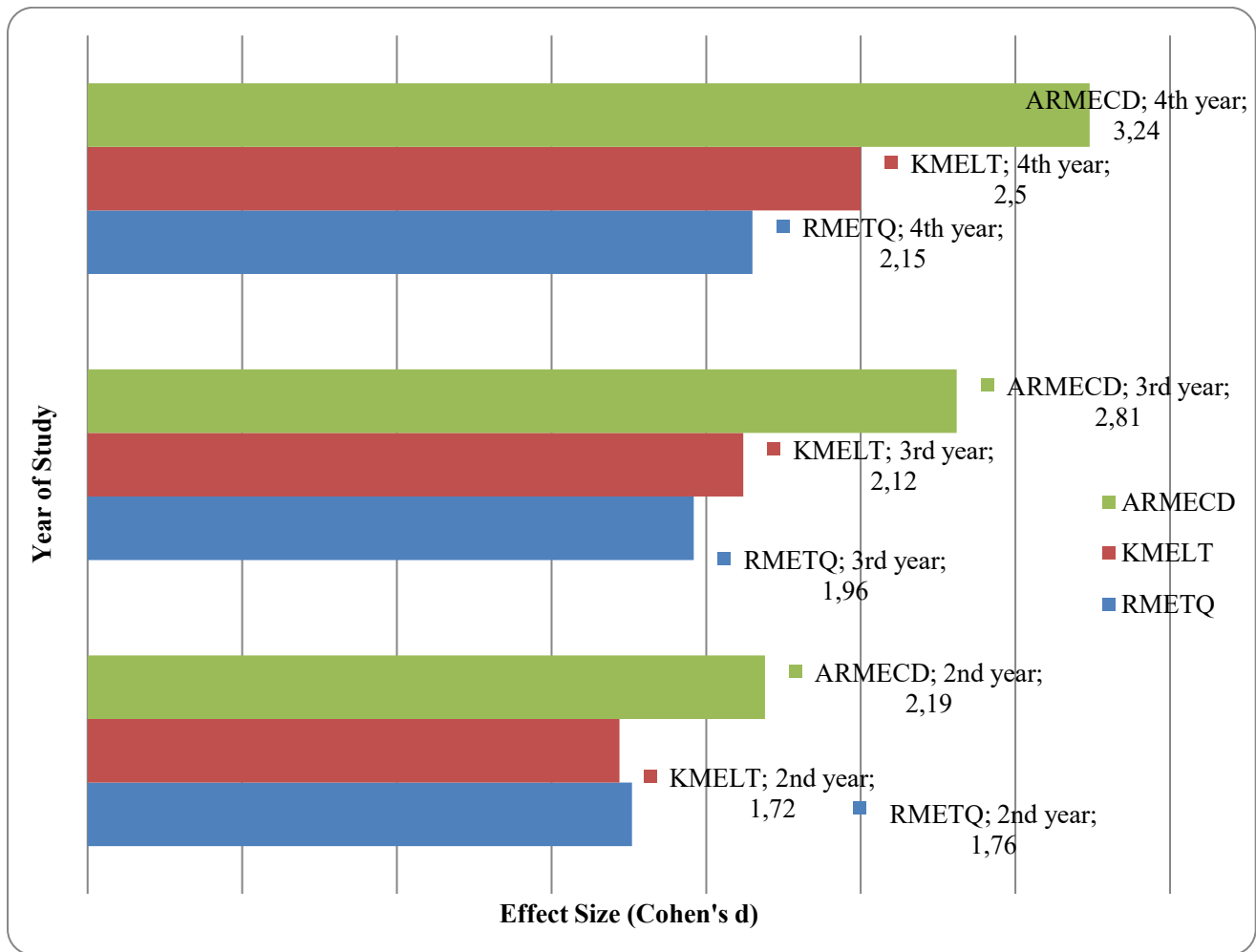


Figure 3. Dynamics of between-group effect sizes (Cohen's d) depending on the year of study and the readiness component

Subgroup analysis by specialty indicated that the effect of the pedagogical intervention was stable and statistically significant for students of all three pedagogical specialties, but with certain differentiated patterns. Students of the specialty "Mathematics and Computer Science" had slightly higher post-test scores compared to other specialties, especially in the activity-practical component: $M = 16.5$ ($SD = 2.4$) versus $M = 15.4$ ($SD = 2.7$) for "Primary Education" and $M = 15.9$ ($SD = 2.6$) for "Ukrainian Language and Literature" (See Table 9).

Table 9. Between-Group Post-Test Comparisons by Field of Specialization

Component	Specialization	Exp M (SD)	Ctrl M (SD)	t	df	p	d
RMETQ	Primary Education (n=55)	73.8 (8.9)	56.4 (9.1)	8.82	53	< .001	1.94
	Ukrainian Language (n=54)	74.9 (8.6)	57.8 (9.3)	8.52	52	< .001	1.93
	Math & Informatics (n=53)	75.2 (8.5)	57.7 (9.2)	8.68	51	< .001	1.96
KMELT	Primary Education	21.8 (3.9)	14.2 (3.6)	9.06	53	< .001	2.00
	Ukrainian Language	22.3 (3.7)	14.9 (3.4)	9.14	52	< .001	2.09
	Math & Informatics	23.2 (3.6)	15.1 (3.5)	9.93	51	< .001	2.27
ARMECD	Primary Education	15.4 (2.7)	8.8 (2.5)	11.21	53	< .001	2.55
	Ukrainian Language	15.9 (2.6)	9.1 (2.4)	11.94	52	< .001	2.74
	Math & Informatics	16.5 (2.4)	9.4 (2.3)	13.32	51	< .001	3.02

Note: Sample sizes reflect proportional distribution across majors (see Table 1). A one-way analysis of variance (ANOVA) in the experimental group did not confirm significant differences between majors for the RMETQ ($F(2,78) = 0.24, p = 0.787$) and marginal significance for the ARMECD ($F(2,78) = 3.12, p = 0.049, \eta^2 = 0.074$), suggesting that the intervention effect is largely uniform across majors.

3.3. Comparison of growth across readiness components

According to the results of the dependent t-test (Table 9), the within-group effect in the experimental group increased from the motivational-value component ($d = 2.41$) through the cognitive component ($d = 2.99$) to the activity-practical component ($d = 3.39$).

To determine the difference between the effect sizes, Steiger's Z-test for dependent correlations was used. The results showed that the difference between the effects for the activity-practical and motivational-value components was significant ($Z = 3.14, p = 0.002$).

According to the results of the normality test, Pearson's r coefficient, where the distribution was normal ($p > 0.05$ by the Shapiro-Wilk test), and Spearman's ρ coefficient were used for correlation analysis. The data are presented in Table 10.

Table 10. Relationships between the components of readiness before and after testing by groups

Comparison	Group	Stage	RMETQ–KMELT	RMETQ–ARMECD	KMELT–ARMECD
	Experimental	Pre-test	$r = .28^*$	$r = .24^*$	$r = .31^*$
		Post-test	$r = .61^{***}$	$r = .67^{***}$	$r = .72^{***}$
	Control	Pre-test	$r = .26^*$	$r = .22^*$	$r = .29^*$
		Post-test	$r = .31^*$	$r = .27^*$	$r = .33^*$

Note. $*p < .05$; $**p < .01$; $***p < .001$.

At the pre-test stage, both groups had weak, but statistically significant correlations between all three components of readiness: the r values ranged from .22 to .31, which corresponds to a weak level of connection. At the post-test stage, the situation changed, but radically only in the experimental group. All three intercomponent correlations significantly increased: RMETQ–KMELT increased from $r = .28$ to $r = .61$; RMETQ–ARMECD — from $r = .24$ to $r = .67$; KMELT–ARMECD — from $r = .31$ to $r = .72$. The strongest was the relationship between the cognitive and activity-practical components ($r = .72, p < .001$). Thus, the systematic assimilation of theoretical knowledge about modular e-technology in the conditions of the Moodle LMS was directly supported by practical tasks. This created conditions for close integration of knowledge and skills. In the control group, the post-test correlations between the components remained at a level comparable to the pre-test: $r = .27$ – $.33$, which corresponds to a weak relationship. The lack of growth in intercomponent correlations in the control group indicates that traditional training does not ensure the integration of different aspects of readiness into a single systemic structure - each component develops relatively isolated without the formation of synergistic relationships between them.

To determine the difference between the correlations of the two groups at the post-test, Fisher's r -to- z transformation was used. All three pairwise comparisons were significant: RMETQ–KMELT: $z = 3.42, p < .001$; RMETQ–ARMECD: $z = 4.18, p < .001$; KMELT–ARMECD: $z = 4.61, p < .001$. (See Table 11).

Table 11. Fisher's r - z test: comparison of intercomponent correlations between groups after testing

Correlation Pair	Exp Post-Test r	Ctrl Post-Test r	z	p
RMETQ – KMELT	.61	.31	3.42	$< .001$
RMETQ – ARMECD	.67	.27	4.18	$< .001$
KMELT – ARMECD	.72	.33	4.61	$< .001$

Thus, the activity-practical component had the largest increase in indicators under the influence of modular e-technology ($d = 3.39$ within the group; $\eta^2p = .622$ in ANCOVA). At the same time, in the experimental group after the intervention, a qualitatively new structure of readiness was formed: intercomponent correlations increased from weak ($r = .22-.31$) to strong ($r = .61-.72$).

3.4. Discussion

This study was designed to investigate the pedagogical conditions for the formation of future teachers' readiness to use modular e-learning technology in university environments. The proposed results made it possible to interpret the revealed patterns in the context of the available scientific literature, to comprehend their theoretical and practical implications.

Initial level of readiness and its interpretation. The answer to RQ1 demonstrated that at the beginning of the study, future teachers of both groups had mainly low and medium levels of readiness in all three components. In addition, the lowest indicators were recorded in the field of the activity-practical component ($M = 7.8$ and $M = 7.6$, respectively). This result was consistent with the findings of previous researchers, who stated that traditional pedagogical training, focused mainly on classroom forms of work, was unable to fully ensure a sufficient level of practical readiness of future teachers to work with digital learning environments [29], [30]. At the same time, a moderate level of the motivational and value component ($M \approx 52$ points out of 100) indicated the existence of an initial positive attitude towards e-learning. However, without sufficient reinforcement with operational knowledge, a positive attitude towards technology did not yet guarantee readiness for pedagogical application [31], [32].

Effectiveness of modular e-technology: confirmation of H1 and H2. The results of the comparative analysis provided an exhaustive answer to RQ2 and confirmed both hypotheses of the study. Hypothesis H1 was confirmed: after controlling for baseline (ANCOVA), the pedagogical condition explained 43.9% of the variance in the motivational-value component ($\eta^2p = .439$, $p < .001$). At the same time, the difference between the groups on the post-test was 17.3 points in favor of the experimental group ($d = 1.77$). The proposed results showed that systematic work in the modular e-technology environment was an important factor for the further development of intrinsic motivation, the gradual evolution of the value understanding of digital technologies in future pedagogical practice. The proposed data confirmed the conclusions of Rajabalee and Santally [33], that the modularly structured e-environment had a significant positive impact on the learning motivation of education seekers. Hypothesis H2 was also confirmed. The proposed results prove that the increase in the activity-practical component in the experimental group (+103.8%, $d = 2.58$) was greater than the increase in the cognitive (+82.1%, $d = 2.18$). Such a development emphasized the special effectiveness of modular e-technology in the formation of practical skills. This phenomenon was explained by the fact that the authentic task of designing an e-course in the LMS Moodle required higher education students to reproduce theoretical knowledge and its transformative application in a real technological environment simultaneously [34], [35]. The progressive increase in the effect size from the motivational-value ($d = 1.77$) through the cognitive ($d = 2.18$) to the activity-practical component ($d = 2.58$) testified to the existence of a hierarchical logic of readiness formation. In particular, the motivational basis opened access to the acquisition of knowledge, and knowledge became an important basis for the further formation of practical skills.

Among the three components of readiness, the greatest increase was in the activity-practical component, which was a theoretically significant result. This conclusion was consistent with the conclusions of other researchers [36], [37]. In the article, it was about effective training of teachers for technologically enriched teaching, which could not be limited to cognitive assimilation of theory. That is, it required the integration of technological, pedagogical and subject knowledge in real practical activities.

The share of students with a high level of practical readiness in the experimental group increased from 1.2% to 61.7%. Such a qualitative transition was practically significant from the point of view of real pedagogical training [38], [39].

Subgroup analysis made it possible to establish that the effect of pedagogical intervention increased with the increase during study: for the activity-practical component, the effect size increased from $d = 2.19$ (2nd year) to $d = 3.24$ (4th year). This can be explained by more developed self-organization skills, academic maturity and broader background experience with digital tools among higher-year students. At the same time, even among 2nd-year students, the effect was noticeable ($d = 2.19$), which was confirmed by the feasibility of introducing modular e-technology from the initial courses of pedagogical training. The proposed analysis by specialties demonstrated a statistically significant effect of the intervention in all three groups [40], [41]. Students of the

specialty "Mathematics and Informatics" showed slightly higher indicators in the activity-practical component ($d = 3.02$ versus $d = 2.55$ for "Primary Education"), which could also indicate a more developed technological base of this group. However, a one-way ANOVA did not show statistically significant differences between specialties for RMETQ ($p = 0.787$). Further, for ARMECD, the differences were only marginally significant ($\eta^2 = .074$). This demonstrated that modular e-technology was a pedagogically universal tool, effective regardless of the subject specialization of future teachers [42], [43]. The conclusion obtained expanded the possibilities of scaling up such experiments in the teacher education system.

Despite the results obtained, the study had several limitations that should be considered during the subsequent interpretation of the findings. First, the quasi-experimental design with group (rather than individual) distribution of participants could not ensure the full effect of contamination between groups. Second, the study was conducted within the framework of one academic discipline and one semester. This situation somewhat limited the possibility of broader generalization of the findings. Third, the self-report nature of the RMETQ questionnaire provided for the possibility of socially desirable answers. Although the convergent validity of the instrument was demonstrated ($r = 0.71$ with the TAM-EDU scale), this only partially eliminated this risk.

4. Conclusions

Therefore, the ascertainment stage revealed that most future teachers were at low and medium levels of readiness before the intervention, with the lowest indicators in the activity-practical component (51.9–53.1% of students at a low level). This indicated a systemic insufficiency of traditional pedagogical training through the prism of forming readiness for e-learning.

However, the systematic use of modular e-learning technology made it possible to achieve a significant increase in readiness for all three components ($p < .001$). The effect sizes are large: between groups $d = 1.77$ – 2.58 , after controlling for input indicators $\eta^2 p = .439$ – $.622$, within the experimental group $d = 2.41$ – 3.39 . The increase in the experimental group is 3.5–5.2 times higher than the increase in the control group.

The study established a differentiated nature of the intervention's effectiveness: the activity-practical component had the largest increase ($d = 3.39$; +103.8%), somewhat smaller — cognitive ($d = 2.99$; +82.1%) and motivational-value ($d = 2.41$; +42.4%). The difference between the effect sizes for the extreme components was significant (Steiger's $Z = 3.14$, $p = .002$). This indicated a higher effectiveness of modular e-technology in the formation of practical skills compared to motivational changes. The study recorded a qualitative transformation of the readiness structure in the experimental group: intercomponent correlations increased from weak ($r = .22$ – $.31$) to strong ($r = .61$ – $.72$). Analysis among subgroups indicated two important differentiated patterns. The effect of pedagogical intervention was cumulative with respect to the course of study — the effect sizes consistently increased from the 2nd to the 4th year (ARMECD: $d = 2.19 \rightarrow 2.81 \rightarrow 3.24$). This situation indicated a higher sensitivity of senior students to modular e-learning. At the same time, the effect was universal with respect to the pedagogical specialty — no statistically significant differences between specialties within the experimental group were found.

Theoretically, the study expanded the understanding of the mechanisms of formation of professional readiness of future teachers for e-learning. In particular, the article showed that modular e-technology ensured the growth of individual components and their systemic integration. In practical terms, the results determined the feasibility of introducing modular e-technology of education as a mandatory element of the system of training future teachers in pedagogical universities.

Declaration of competing interest

The authors declare that they have no conflicts of interest.

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Author contribution

The contribution to the paper is as follows: B. Kylyshpai, I. Yusupova: study conception and design; R. Skakova, K. Medeubayeva: data collection; B. Kylyshpai, I. Yusupova, S. Seitenova: analysis and interpretation

of results; S. Seitenova, K. Medeubayeva: draft preparation. All authors approved the final version of the manuscript.

References

- [1] Y. K. Al-Rikabi and G. A. Montazer, "Designing an E-learning Readiness Assessment Model for Iraqi Universities Employing Fuzzy Delphi Method," *Education and Information Technologies*, 2023, <https://doi.org/10.1007/s10639-023-11889-0>
- [2] A. T. Balcı, "Rethinking social transformation from informal learning to political learning in the Covid-19 pandemic," in *Critical Pedagogy and the Covid-19 Pandemic*, Bloomsbury Academic, 2022, <https://doi.org/10.5040/9781350274914.ch-015>
- [3] Y. Tsekhmister, "War, education and development: A pedagogical response to the challenges of modernity," *Academia*, no. 35-36, pp. 1–8, 2024. [Online]. Available: <https://doi.org/10.26220/aca.4999>
- [4] "Kazakhstan," in *Education Policy Outlook*, OECD, 2019, pp. 413-419, <https://doi.org/10.1787/e765dfb7-en>
- [5] D. Amirbekova, A. Makhanova, and M. Kussaiyn, "Aligning Higher Education Toward the Development of an Educational Hub: The Case of Kazakhstan," *Education Sciences*, vol. 15, no. 12, p. 1597, 2025, <https://doi.org/10.3390/educsci15121597>
- [6] Y. Tsekhmister, T. Konovalova, B. Tsekhmister, T. Pushkarova, and S. Nahorniak, "Contemporary education: globalization and transformation process under the influence of artificial intelligence," *Int. J. Eval. Res. Educ. (IJERE)*, vol. 13, no. 5, p. 3443, Oct. 2024. Accessed: Jul. 7, 2026. [Online]. Available: <https://doi.org/10.11591/ijere.v13i5.29016>
- [7] Y. Tsekhmister, T. Konovalova, and B. Tsekhmister, "Utilizing predictive analytics to identify at-risk students in digitalized medical education: A motivational perspective," *Academicus Int. Scientific J.*, no. 29, pp. 112–125, 2024. [Online]. Available: <https://doi.org/10.26220/aca.5051>
- [8] A. Y. Niyazova, A. A. Chistyakov, N. Y. Volosova, J. A. Krokhina, N. L. Sokolova, and S. E. Chirkina, "Evaluation of pre-service teachers' digital skills and ICT competencies in context of the demands of the 21st century," *Online Journal of Communication and Media Technologies*, vol. 13, no. 3, Art. no. e202337, 2023, <https://doi.org/10.30935/ojcm/13355>
- [9] B. Maksymchuk, I. Maksymchuk, V. Frytsiuk, T. Matviichuk, I. Demchenko, I. Babii, I. Savchuk, "Developing pedagogical mastery of future physical education teachers in higher education institutions," *J. Physical Educ. Sport*, vol. 18, no. 2, pp. 810–815, 2018. [Online]. Available: <https://doi.org/10.7752/jpes.2018.02119>
- [10] Z. Ibrayeva, A. Maimakova, Y. Gavrilova, A. Akerke, and Y. Akimbayev, "Problems and prospects for the implementation of artificial intelligence in the educational process of Kazakhstani Universities," *Periodicals Eng. Natural Sci. (PEN)*, vol. 13, no. 1, pp. 83–96, Apr. 2025. Accessed: Jul. 7, 2026. [Online]. Available: <https://doi.org/10.21533/pen.v13.i1.251>
- [11] B. Nagima, N. Saniya, Y. Gulden, Z. Saule, S. Aisulu, and M. Nazigul, "Influence of Special Learning Technology on the Effectiveness of Pedagogical Ethics Formation in Future Teachers," *Journal of Education and e-Learning Research*, vol. 10, no. 1, pp. 1-6, 2022, <https://doi.org/10.20448/jeelr.v10i1.4313>
- [12] S. Qiqieh and S. Dukmak, "The influence of online education on pre-service teachers' academic experiences at a higher education institution in the United Arab Emirates," *Frontiers in Education*, vol. 9, 2024, <https://doi.org/10.3389/feduc.2024.1398642>

-
- [13] G. Yerzhanova, A. Autayeva, B. Mazhinov, M. Iralina, and S. Nishanbayeva, "Features of the development of research competence in future special education teachers," *Frontiers in Education*, vol. 10, 2025, <https://doi.org/10.3389/feduc.2025.1610757>
- [14] M. Zhanarstanova, Y. Alimzhanov, Y. Dossymkhan, and A. Kaldybekova, "The Role of Learning Analytics in Assessing the Effectiveness of Blended Education: A Case Study of Astana IT University," in *2024 IEEE 4th Int. Conf. Smart Inf. Syst. Technol. (SIST)*, Astana, Kazakhstan, May 15–17, 2024. IEEE, 2024, pp. 447–454. Accessed: Jul. 7, 2026. [Online]. Available: <https://doi.org/10.1109/sist61555.2024.10629415>
- [15] S. Sharov, M. Vorovka, T. Sharova, and A. Zemlianska, "The Impact of Social Networks on the Development of Students' Social Competence," *International Journal of Engineering Pedagogy (iJEP)*, vol. 11, no. 3, pp. 84–98, 2021. Accessed: Jul. 7, 2026. [Online]. Available: <https://doi.org/10.3991/ijep.v11i3.20491>
- [16] S. Sharov, V. Kolmakova, T. Sharova, and A. Pavlenko, "Analysis of MOOC on Programming for IT Specialist Training," *TEM Journal*, vol. 10, no. 4, pp. 1884–1894, 2021. Accessed: Jul. 7, 2026. [Online]. Available: <https://doi.org/10.18421/TEM104-52>
- [17] O. Prokopenko, V. Matviienko, T. Chunikhina, V. Ohol, and A. Jasurkova, "Transforming Teacher Education: The Influence Of Artificial Intelligence On Educational Practices And Human Resource Dynamics," in *ICAITE '24: 2024 Int. Conf. Artif. Intell. Teacher Educ. (ICAITE)*, Beijing China. New York, NY, USA: ACM, 2024, pp. 35–42. Accessed: Jul. 7, 2026. [Online]. Available: <https://doi.org/10.1145/3702386.3702389>
- [18] C. B. Mpungose, "Is Moodle or WhatsApp the preferred e-learning platform at a South African university? First-year students' experiences," *Education and Information Technologies*, vol. 25, no. 2, pp. 927–941, 2019, <https://doi.org/10.1007/s10639-019-10005-5>
- [19] R. R. Saqr, S. A. Al-Somali, and M. Y. Sarhan, "Exploring the Acceptance and User Satisfaction of AI-Driven e-Learning Platforms (Blackboard, Moodle, Edmodo, Coursera and edX): An Integrated Technology Model," *Sustainability*, vol. 16, no. 1, p. 204, 2023, <https://doi.org/10.3390/su16010204>
- [20] M. Yermekova, N. Yrymbayeva, P. Rakhimgalieva, and A. Akbidash, "Bridging the digital divide: Assessing future educators' competence in Kazakhstan's higher education through the DigCompEdu framework," *International Journal of Innovative Research and Scientific Studies*, vol. 8, no. 1, pp. 1224–1238, 2025, <https://doi.org/10.53894/ijirss.v8i1.4572>
- [21] O. Arek-Bawa and S. Reddy, "Preparing Pre-Service Teachers for Teaching in the Digital Age," *Athens Journal of Education*, vol. 12, no. 1, pp. 77–98, 2025, <https://doi.org/10.30958/aje.12-1-5>
- [22] L. L. D. Mallillin, L. C. Mendoza, J. B. Mallillin, R. C. Felix, and I. C. Lipayon, "Implementation and readiness of online learning pedagogy: A transition to covid 19 pandemic," *European Journal of Open Education and E-Learning Studies*, vol. 5, no. 2, 2020, <https://doi.org/10.46827/ejoe.v5i2.3321>
- [23] "Education in Eastern Europe and Central Asia," OECD, 2021, <https://doi.org/10.1787/ebeeb179-en>
- [24] M. Schulz, "E-Learning as a Development Tool," *Sustainability*, vol. 15, no. 20, p. 15012, 2023, <https://doi.org/10.3390/su152015012>
- [25] A. Abiltayeva, K. Zhumagulova, M. Satayev, T. Yechshzhanov, A. Maimatayeva, and N. Balta, "Teacher competencies and digital integration into teaching practices: perceptions from pre-service biology teachers in Kazakhstan," *Frontiers in Education*, vol. 10, 2025, <https://doi.org/10.3389/feduc.2025.1628034>
- [26] M. Gulmira, Z. G. Nurbolatovna, Z. Nazym, M. G. Zholdasbekovna, S. Aigerim, and S. Dilyara, "Background to the development of technology of formation of teachers readiness for distance learning,"
-

-
- World Journal on Educational Technology: Current Issues, vol. 14, no. 3, pp. 855-874, 2022, <https://doi.org/10.18844/wjet.v14i3.7367>
- [27] A. Parasuraman, "Technology readiness index (TRI): A multiple-item scale to measure readiness to embrace new technologies," *Journal of Service Research*, vol. 2, no. 4, pp. 307-320, 2000, <https://doi.org/10.1177/109467050024001>
- [28] J. Tondeur, J. van Braak, P. A. Ertmer, and A. Ottenbreit-Leftwich, "Understanding the relationship between teachers' pedagogical beliefs and technology use in education: a systematic review of qualitative evidence," *Educational Technology Research and Development*, vol. 65, pp. 555-575, 2017, <https://doi.org/10.1007/s11423-016-9481-2>
- [29] Z. Bakirova, A. Tasova, M. Absatova, D. Sadirbekova, B. Auezov, and G. Meirbekova, "Enhancing digital competence and learning motivation of master's students: a new educational model for Kazakhstan's higher education system," *Frontiers in Education*, vol. 11, 2026, <https://doi.org/10.3389/feduc.2026.1675872>
- [30] C. Lopes, Ó. Bernardes, M. J. A. Gonçalves, A. L. Terra, M. M. Silva, C. Tavares, and I. Valente, "E-Learning Enhancement through Multidisciplinary Teams in Higher Education: Students, Teachers, and Librarians," *Education Sciences*, vol. 12, no. 9, p. 601, 2022, <https://doi.org/10.3390/educsci12090601>
- [31] I. Borysiuk, O. B. Haioshko, O. Korniiichuk, Y. Tsekhmister, and M. Demianchuk, "Alternative Approaches to Clinical Practice in Medical Education During the Covid-19 Pandemic," *J. Curriculum Teaching*, vol. 11, no. 2, p. 75, Feb. 2022. Accessed: Jul. 7, 2026. [Online]. Available: <https://doi.org/10.5430/jct.v11n2p75>
- [32] S. Nurzhanova, A. Stambekova, K. Zhaxylikova, G. Tatarinova, E. Aitenova, and Z. Zhumabayeva, "Investigation of Future Teachers' Digital Literacy and Technology Use Skills," *International Journal of Education in Mathematics, Science and Technology*, vol. 12, no. 2, pp. 387-405, 2023, <https://doi.org/10.46328/ijemst.3826>
- [33] Y. B. Rajabalee and M. I. Santally, "Learner satisfaction, engagement and performances in an online module: Implications for institutional e-learning policy," *Education and Information Technologies*, 2020, <https://doi.org/10.1007/s10639-020-10375-1>
- [34] J. C. S. Santiago, M. L. P. Ulanday, Z. J. R. Centeno, M. C. D. Bayla, and J. S. Callanta, "Flexible learning adaptabilities in the new normal: E-learning resources, digital meeting platforms, online learning systems and learning engagement," *Asian Journal of Distance Education*, vol. 16, no. 2, 2021, <https://doi.org/10.5281/zenodo.5762474>
- [35] Y. Tsekhmister, T. Konovalova, L. Bashkirova, M. Savitskaya, and B. Tsekhmister, "Virtual reality in EU healthcare: Empowering patients and enhancing rehabilitation," *Journal of Biochemical Technology*, vol. 14, no. 1, pp. 1–7, 2023, doi: [10.51847/r5WJFVz1bj](https://doi.org/10.51847/r5WJFVz1bj)
- [36] A. Sharimova, N. Durrani, and G. Jumamuratova, "Mapping the Field: A Scoping Review of Initial Teacher Education Research in Central Asia," *Education Sciences*, vol. 15, no. 10, p. 1381, 2025, <https://doi.org/10.3390/educsci15101381>
- [37] A. A. Genbach, D. Yu. Bondartsev, and H. Beloev, "Study of the heat transfer ability of a capillary-porous cooling system in heat power installations," *Journal of Engineering Science and Technology Review*, special issue, pp. 143–144, 2020, <http://jestr.org/downloads/SpecialIssue2020/fulltext29SE.pdf>
- [38] Ł. Tomczyk, K. Potyrała, A. Włoch, J. Wnęk-Gozdek, and N. Demeshkant, "Evaluation of the Functionality of a New E-Learning Platform vs. Previous Experiences in E-Learning and the Self-Assessment of Own Digital Literacy," *Sustainability*, vol. 12, no. 23, p. 10219, 2020, <https://doi.org/10.3390/su122310219>
-

-
- [39] M. Toprak, Y. Bayraktar, S. Yorgun, and A. Özyılmaz, "Digital Transformation, Research University and Restructuring of Higher Education: A Model Proposal for Istanbul University Faculty of Economics," *Journal of Economy Culture and Society*, 2021, <https://doi.org/10.26650/jecs2020-801234>
- [40] H. Mazur, V. Bolhov, I. Akhnovska, O. Dluhopolskyi, and S. Kozlovskyi, "The impact of educational development on the countries' competitiveness in the knowledge economy, " *Nauk. Visnyk Natsionalnoho Hirnychoho Universytetu*, no. 1, pp. 140-146, 2025, <https://doi.org/10.33271/nvngu/2025-1/140>
- [41] J. N. Nabayra and C. R. Tambong, "Readiness Level, Satisfaction Indicators, and Overall Satisfaction towards Flexible Learning through the Lens of Public University Teacher Education Students," *International Journal of Information and Education Technology*, vol. 13, no. 8, pp. 1230-1241, 2023, <https://doi.org/10.18178/ijiet.2023.13.8.1925>
- [42] S. Sharov, V. Kolmakova, T. Sharova, and A. Pavlenko, "Analysis of MOOC on Programming for IT Specialist Training," *TEM Journal*, vol. 10, no. 4, pp. 1884–1894, 2021. Accessed: Jul. 7, 2026. [Online]. Available: <https://doi.org/10.18421/TEM104-52>
- [43] C. James-Springer and K. Cennamo, "e-Learning readiness," in *A Tool for Determining e-Learning Readiness*, Springer International Publishing, 2021, pp. 5-10, https://doi.org/10.1007/978-3-030-76994-9_2

Appendices

Appendix A

Analytic Rubric for Modular E-Course Design (ARMECD)

Maximum Total Score: 20 points | Scoring Scale per Criterion: 0 (Unacceptable) — 1–2 (Developing) — 3 (Proficient) — 4 (Exemplary)

Part I. Scoring Rubric (ARMECD)

Criterion	Unacceptable (0 pts)	Developing (1–2 pts)	Proficient (3 pts)	Exemplary (4 pts)	Score (0–4)
1. Clarity and Measurability of Learning Objectives	Learning objectives are absent or too vague to assess; no alignment with Bloom's taxonomy.	Objectives are stated but partially measurable; limited use of action verbs from Bloom's taxonomy.	Objectives are clear and measurable; appropriate action verbs are used; mostly aligned with a specific cognitive level.	Objectives are precisely formulated, fully measurable, clearly aligned with a specific level of Bloom's taxonomy, and directly linked to assessment tasks.	
2. Logical Structuring and Sequencing of Content	Content is presented in a random or incoherent order; no logical progression is evident.	General sequencing is present but transitions between content sections are unclear or illogical in places.	Content is logically structured; sequence from simple to complex is generally maintained; navigation between sections is clear.	Content demonstrates a clearly planned didactic sequence; each section builds directly on the previous one; navigation is intuitive and purposeful.	
3. Variety and Pedagogical Justification of Learning Activities	Only one type of learning activity is used (e.g., reading only); no pedagogical justification provided.	Two or more activity types are included, but the selection appears arbitrary rather than intentionally designed.	A range of activity types is used (lectures, tasks, forums); their inclusion reflects awareness of different learning modes.	Activities are diverse, deliberately selected, and pedagogically justified in relation to learning objectives; balance of individual, collaborative, and reflective tasks is evident.	
4. Quality of Assessment Design (Self-Test and Final Assessment)	Assessment tasks are absent or consist solely of basic recall questions; no connection to learning objectives.	Some assessment tasks are present but are limited in scope or cognitive demand; partial alignment with objectives.	Assessment includes both self-test and final tasks; questions cover more than one cognitive level and relate to stated objectives.	Assessment is multi-level (formative and summative), cognitively diverse, aligned with all stated objectives, and includes clear feedback	

Criterion	Unacceptable (0 pts)	Developing (1– 2 pts)	Proficient (3 pts)	Exemplary (4 pts)	Score (0– 4)
				mechanisms or answer keys.	
5. Technical Implementation in LMS Moodle	The module structure is not implemented in LMS Moodle, or significant technical errors prevent access or navigation.	The module is uploaded to LMS Moodle but contains navigation errors, broken links, or incomplete settings.	The module is fully accessible in LMS Moodle; key settings (visibility, deadlines) are configured; minor technical issues may be present.	The module is technically complete, fully functional, and professionally configured in LMS Moodle; all resources are properly linked and accessible to students.	
TOTAL SCORE:					/ 20

Evaluator instructions: Assign a score from 0 to 4 for each criterion. Base your evaluation on the submitted PDF report and the live Moodle module. In cases of unclear evidence, assign the lower of the two adjacent scores. Total score is the sum of five criterion scores (max = 20).

Readiness level thresholds: Low: 0–7 pts | Medium: 8–14 pts | High: 15–20 pts

Appendix B.

Distribution of Participants by Readiness Level at Pre-Test and Post-Test (%)

Component	Group	Pre-Test Low	Pre-Test Mid	Pre-Test High	Post-Test Low	Post-Test Mid	Post-Test High	
RMETQ (Motivational- Value)	Experimental	44.4%	51.9%	3.7%	4.9%	46.9%	48.1%	7.4%
	Control		45.7%	50.6%	3.7%	39.5%	53.1%	
KMELT (Cognitive)	Experimental	46.9%	50.6%	2.5%	3.7%	39.5%	56.8%	3.7%
	Control		49.4%	48.1%	2.5%	42.0%	54.3%	
ARMECD (Activity- Practical)	Experimental	51.9%	46.9%	1.2%	2.5%	35.8%	61.7%	1.2%
	Control		53.1%	45.7%	1.2%	46.9%	51.9%	

Note. Level thresholds — RMETQ (max = 100): Low 20–46, Mid 47–73, High 74–100; KMELT (max = 30): Low 0–10, Mid 11–20, High 21–30; ARMECD (max = 20): Low 0–7, Mid 8–14, High 15–20. Chi-square tests (Table III in the main text) confirmed that shifts in experimental group distributions were statistically significant ($p < .001$), whereas control group distributions remained stable across measurement points.