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The Use of Technology-Based Model of Critical Thinking Development to Reshape Students' Self-Study Process

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Abstract: The aim of this study was to investigate how the use of the technologized model of critical thinking development affected the self-study process of students of higher educational institutions (HEIs). The research methodology was based on a combination of qualitative and quantitative empirical methods, as well as a descriptive approach to data analysis. The study involved a quasi-experimental model supposed to influence the variables under study. The technology-based educational model of autonomous learning with a focus on the critical thinking development in students of HEIs consisted of the following processes, such as: communication, analysis, synthesis, problem-solving, evaluation, and reflection. The Watson Glaser Test was adapted to monitor the level of students' critical thinking. The average score on the final control of students' knowledge was used to monitor the experimental group students' performance. By monitoring the development of students' critical thinking and the dynamics of their performance in the course of training, where 90% of the time students studied independently, it was established that the use of a technological educational model had a positive effect on the critical thinking of students of HEIs, and as a result, the effectiveness of their self-study.

Keywords: *Critical thinking, higher education, self-study, student performance, technologies.*

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Introduction

The developed critical thinking of students of higher educational institutions (HEIs) is considered the main prerequisite and integral component of their success in education and further professional activity (Academy of Nutrition and Dietetics, 2020; Dehghani et al., 2011). The student's developed critical thinking is an expected result of realization of modern paradigmatic principles of higher education, in particular such as constructivist paradigm of education, and the 21st century skills defining critical thinking skills in terms of active learning aimed at self-improvement (Abrami et al., 2015; Dagar & Yadav, 2016; Hitchcock, 2015; Tan et al., 2017). At the World Economic Forum in Davos in 2016, the importance of student mastery of critical thinking strategies and procedures was ranked second in the ranking of the ten most important skills in 2020 that determine a student's success in both education and career (Gray, 2016).

The COVID-19 pandemic-related educational challenges entail the need to organize effective independent work of students in HEIs (Mishra, 2020). Despite the large number of studies on critical thinking development technologies and the results of their application, as well as the role and results of critical thinking development, the issue of the relationship between the critical thinking development technologies and the academic performance of students during their independent work is poorly studied. Therefore, the aim of this research was to identify the impact of technologies for the development of critical thinking on the students' performance, mainly achieved through self-study.

The aim was achieved through the fulfilment of the following research objectives:

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1) study how the application of the developed technological educational model affects students' critical thinking;

2) establish how the level of critical thinking affects the effectiveness of students' self-study;

3) to find out how students perceive the technological educational model for thinking development.

Literature Review

Critical Thinking and Technologies

Teachers and researchers of different countries and educational systems worked on the search for the critical thinking development technologies. For example, Warsah et al. (2021) studied this issue in the context of Islamic education, multiculturalism and multi-religion.

In academic pedagogical and psychological literature, the terms "critical thinking", "analytical thinking" and "problem-solving thinking" are used interchangeably and refer to "deepening" thinking (Giraldo-García et al., 2015). Besides, critical thinking is seen as a philosophical concept that includes characteristics, traits, inclinations, habits of thinking and inferences of the individual, which is a human phenomenon related to reflection and self-formation (Atabaki et al., 2014; Padmanabha, 2018; Yanchar et al., 2017). That is, such an ambiguous definition of the term "critical thinking" combines individuals' behavioural and cognitive-analytical actions. In a psychological context, this concept is based on an intrinsically motivated process of cognition and an individual-regulated process of making assumptions and judgments that promote a person's emotional intelligence and intrinsic stability (Jackson et al., 2012; Padmanabha, 2018). Psychological science associates critical thinking with a person's cognitive and socio-cognitive activities, which are related to his / her abilities of emotional self-regulation, adaptation and communication in completing educational tasks (Padmanabha, 2018). Analysed diagnostic tools and conceptual literature enabled identifying the components of critical thinking and their characteristics. In particular, the concept of the 21st century skills (Ohio Department of Education, 2006) identify such components as interpretation, analysis, assessment (of ideas, suggestions), inferences, explanations and justifications, and self-regulation. Table 1 summarizes the results of the analysis of conceptual literature and diagnostic tools for the components of critical thinking and their characteristics (manifestations).

Table 1. Components of Critical Thinking and Their Characteristics (Manifestations)

Component	Manifestation
Interpretation	Categorization (selection of relevant information or knowledge) Decoding of content-factual, content-conceptual and content-subtextual sensitivity of written information Clarification of the meaning of certain provisions, facts and content of the information message
Analysis	Analysis and synthesis of ideas Distinguishing arguments Analysis of arguments
Assessment (of ideas, suggestions)	Assessment of assumptions and statements Critical assessment of arguments
Inferences	Cast doubt on evidence Suggestion of alternatives Drawing conclusions
Explanations and justifications	Presentation of results Justification of procedures Presentation of arguments
Self-regulation	Self-analysis Self-esteem Self-correction

It was found that the diagnostic tools, such as the Watson-Glaser Critical Thinking Appraisal (WGCTA) test (Psychometric Success, 2021), the Thurstone Test of Mental Alertness (Kvaal et al., 2001), the Cornell Critical Thinking Test (Hasinger, 2021), and the California Critical Thinking Skills Test (CCTST) (Facione, 2020) are structured according to the components and characteristics set out in Table 1. This indicates the consistency of the concept and diagnostic tools in terms of psychological and educational elements of critical thinking.

Technologies were found to positively affect students' critical thinking, academic performance and career development, as they eliminate the dominance of explanatory-illustrative learning by substituting student-task-outcome-centred approaches to learning (Lupak et al., 2020). The technology-driven learning environment also provides individualisation of learning and increases student learning motivation (Giraldo-García et al., 2015; Gökçearslan et al., 2019; Lychuk et al., 2021; Nozhovnik & Shykhnenko, 2020; Schindler et al., 2017). Lychuk et al. (2021) found that the above environment could be also organised as inquiry-based and learner-centred. In this way, students can collaborate to share the information they collected, which they had evaluated, analysed, and got ready to speculate on or produce a

different interpretation. Furthermore, technology-based environment can contribute to the students' social and intellectual progress which includes decision-making, leadership, and critical judgement of information delivered by the teachers (Nozhovnik & Shykhnenko, 2020).

Student Critical Thinking and Self-Study

The academic literature substantiates that critical thinking is an integral part of the effective self-study of students of HEIs (Dehghani et al., 2011; Lin et al., 2020; Shirazi & Heidari, 2019). Haghparast et al. (2014) note that independent work requires students to use meta-cognitive abilities, which include critical thinking in order to identify problems, evaluate facts and evidence, distinguish relevant information and draw conclusions. Matsumoto (2021) argues that developed critical thinking can reduce students' emotional reactions to difficulties in completing educational assignments while working independently. Shirazi and Heidari (2019) link critical thinking to student learning styles and strategies, which are defined as the method that the student uses to process information. Lau and Yuen (2010) argue that understanding the methods students use to process information and learning styles allows teachers of HEIs to influence student performance by optimizing and improving their critical thinking. At the same time, Romero Uscanga and Torres-Delgado (2022) emphasize the need to develop teacher critical thinking, which has a positive effect on the development of their students' self-study skills. The review of the studies also revealed conflicting results on the relationship between critical thinking and student performance. D'Alessio et al. (2019) found a positive correlation between the above variables, while Partido and Soto (2019) found negative or neutral. Abdollahi Abdi Ansar et al. (2015) and Lun (2010) believe that such polar correlations arise due to differences in the characteristics of the sample of students and their culture. In view of the foregoing, our research found a limited number of studies that cover the effectiveness of technology for the critical thinking development in students of HEIs in the course of self-study, which is relevant in view of the restrictive measures imposed in response to the COVID-19 pandemic.

Methodology

Research Design

The research methodology was based on a combination of qualitative and quantitative empirical methods, and involved a descriptive (interpretive) approach to the analysis of these data (McLeod, 2019). The study lasted from November 2020 to the end of October 2021. The study consisted of the following stages: Stage 1: pre-test to determine the level of students' critical thinking; Stage 2— an experiment; Stage 3— receiving feedback from students on the technological educational model for critical thinking development; Stage 4— analytical. The study involved a quasi-experimental model to influence mixed variables under study (Price et al., 2015). This type of research model was chosen because it combined the non-equivalent type of sample involvement in the experiment and provided pre-experimental and post-experimental testing. That is, this type of study provided that the experimental group (EG) and the control group (CG) were tested before and after the experiment. Both groups of students involved in the experiment (EG and CG) studied Microeconomics and Regional Economics. However, the CG was not involved in the intervention and the students were not trained in critical thinking using the model. The Watson Glaser Test was used to monitor the level of students' critical thinking (Job Test Prep, 2021). The average score of the students' final assessment was used to monitor the performance of the experimental group students. The test included four content-operational components of critical thinking, namely: assessment of the relevance of the conclusion, analysis and assessment (ideas, proposals, assumptions), interferences, and self-regulation (self-assessment, self-correction). It is important to add that given the objective impact of the COVID-19 pandemic on the educational process of HEIs, this study will consider 90% of self-study and take into account student performance inseparably from other forms of their educational activities.

Description of Technological Educational Model

The technology-based educational model of autonomous learning focused on the critical thinking development in students of HEIs consisted of the following processes: communication, analysis, synthesis, problem-solving, evaluation, and reflection. This model was introduced into the curriculum for Microeconomics (8 ECTS) and Regional Economics (3 ECTS). The model was used from February to the middle of June 2021. The students were supposed to dedicate at least 2-3 hours a day to participate in the activities related to the study.

A discussion forum was used to implement and moderate the communication. The False Statement (Rules) technique was used to engage students in a discussion or debate and stimulate their interest — students had to discuss false statements after watching the video. It was supposed that the students were getting a false rule and forcing themselves to use it. In this way, they could find themselves thinking about doing things in a different way than they would normally do (Brainstorming, 2022). To perform this exercise, students were asked to use the discussion function on the Canvas platform (Rutgers, 2021). This technological tool was expected to help students develop self-awareness of their learning. Some of the topics were as follows: a) My idea of the efficient strategy to subsidise small businesses, b) I would measure economic growth using …, c) I would suggest the below marketing strategies for start-ups … c) Retaining regional workforce: My vision of the efficient strategies, d) If I were a governor decision-maker I would

regulate the workforce migration so that it impacts little on the local budgeting …, e) As I see it, the consumption attitudes changed in Ukraine over the last decade like that….

The students were divided into small groups to solve the problem and evaluate the decisions. This form of educational activities enabled students to communicate, solve problems, hear different points of view and collaborate to analyse and synthesize the content of assignments. The students could use the Canvas platform or ZOOM to complete the assignments. Electronic storytelling with the involvement of multimedia (images, audio, video) by students was used to teach students to evaluate, reflect or analyse the content of educational material, and to present information. The following types of stories were used, such as: 1) stories about personal achievements, 2) stories that documented academic and personal events, and 3) stories that informed, disseminated students' experiences and taught (Robin, 2008; Uribe Enciso et al., 2017).

The students told the stories about the benefits of the course material for their future professional life. The stories were to include specific examples of reading and learning activities that they felt were most relevant to their future careers. Students submitted a PowerPoint File, or a link to a presentation in GoReact, or Google.doc to a discussion forum or assignment at Canvas. Exercises and assignments for mutual (anonymous) assessment were used to train the skills of analysis, assessment and communication. Such exercises gave students the opportunity to demonstrate communication skills by giving feedback on each other's work, revealing alternative perspectives to students, and allowing them to ask questions about what they had read or heard. Conducting peer assessment using online tools protected students' anonymity, increasing the likelihood that students provided honest (unbiased) feedback. The reflective component of critical thinking was developed through Google Doc, the Canvas collaboration function, keeping a diary in which, they reflected on what they were studying, described the progress they had made in their studies, and cited course materials that were most relevant to their progress. Students could share a Google document, and teachers could comment on their work. Figure 1 depicts a generalized technological model of the students' critical thinking development and its impact on the results of their self-study.

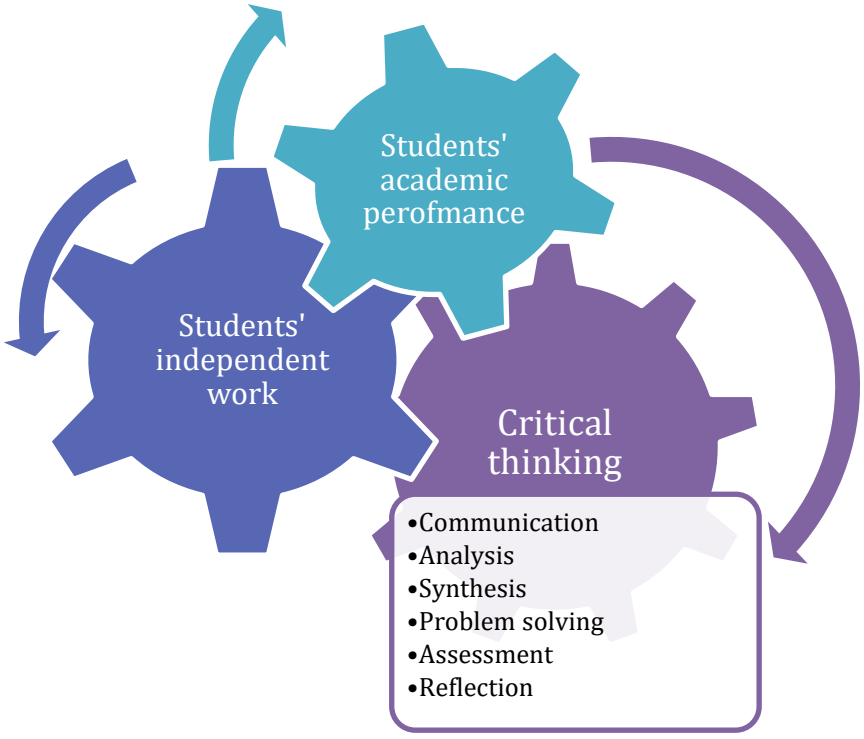

Figure 1. Generalized Technological Educational Model of the Students' Critical Thinking Development and Its Impact on the Results of Independent Work

Sampling

Two sampling methods were used to fulfil the research objectives: the random sampling method and the targeted sampling method. At the time of pre-test, the random sampling method was used to determine the level of students' critical thinking. The link to this test was sent to 249 students of HEIs of Luhansk Taras Shevchenko National University (LTS), Separated Subdivision "Rokytne Professional Medical College" of Municipal Institution of Higher Education "Rivne Medical Academy" of Rivne Region Council (RMA), and T. H. Shevchenko National University "Chernihiv Colehium" (CC), Kyiv National University of Trade and Economics (KNUTE). Tests of 194 respondents were performed in full and their results were used for statistical analysis. Demographic characteristics of respondents are shown in Table 2.

Table 2. Demographic Characteristics of Respondents who Participated in the Validation of the Test ($n = 194$)

Characteristics		LTS, **n (%)**	RMA, **n (%)**	CC, **n (%)**	KNUTE, **n (%)**	**Mean**	**SD**
Age	18-19	12 (19.67%)	9 (14.76%)	18 (29.51%)	22 (30.06%)	18.49	0.499
	20-21	24 (20.08%)	31 (33.69%)	22 (23.92%)	15 (16.31%)	20.30	0.461
	22-23	17 (41.46%)	4 (9.75%)	11 (26,82%)	9 (21.95%)	22.31	0.465
Gender	Male	29 (30.85%)	17 (18.06%)	21 (22.35%)	27 (28.73%)	23.50	4.769
	Female	24 (24.00%)	27 (27.00%)	30 (30.00%)	19 (19.00%)	25.00	4.062

The study involved the targeted sampling method for the formation of experimental and control groups. EG consisted of 27 second-year students (12 women and 15 men, M_{age} = 19.407, $SD = 0.782$) at Luhansk Taras Shevchenko National University, and CG — 24 students (14 women and 10 men, $M_{вік}$ = 19.50, $SD = 0.941$) at T. H. Shevchenko National University "Chernihiv Colehium". The homogeneity of the experimental and control groups was determined not only through the screening of the level of students' critical thinking, but also through measuring of students' academic performance based on the results of the final control. The Watson Glaser Test was used to screen the level of critical thinking of CG and EG students. The average score for the rapid screening test was 7.67, SD=1.211in CG and 7.85, SD = 1.147— in EG. The Grade Point Average (GPA) of EG was 3.47, SD = 0.892, and CG – 3.52, SD = 0.791. Such indicators allowed to consider EG and CG comparable.

A survey of students' perception of the technological educational model for the development of critical thinking and its effectiveness in independent learning was also conducted in EG using a random sampling method. A total of 15 EG students were involved in the survey.

Research Tools

The following research tools were applied to study the problem of how the use of technology for critical thinking development in students of HEIs affect the effectiveness of their self-study: test to determine the level of students' critical thinking and a questionnaire to find out how students perceive technological model of critical thinking development in the course of their self-study. Data collected from tests and questionnaire responses were analysed using the Jamovi software (version 2.0.0) (The Jamovi Project, 2021).

Test to Determine the Level of Students' Critical Thinking

The test (Appendix A) contains 20 situational questions with several (2–5) answer options, where only one is correct. The questions concerned four content-operational components of critical thinking, namely: assessment of the relevance of the conclusion, analysis and assessment (ideas, proposals, assumptions), conclusions, and self-regulation (self-assessment, self-correction). Each correct answer was assessed by one point, and the total score on the test is calculated by summing the number of correct answers. The minimum and maximum possible points are 0 and 20, respectively. The average score on the scale is 10.00, which means that scores below 10.00 reflect relatively weak critical thinking, and scores above 10.00 reflect relatively strong critical thinking. Table 3 presents a scale for measuring the level of critical thinking.

Table 3. Scale for Measuring the Level of Critical Thinking with the Appropriate Scores

Level	**Low**	**Medium**	**High**
Score	1-8	9-15	16-20

There was a time limit of 55 seconds for each question to complete the test — a total of 18.5 minutes per test. Questionnaire to find out students' perception of the technological model of critical thinking development.

The questionnaire (Appendix B) consisted of 12 questions, including 10 close-ended, which provided the following answer options: 1 = Generally ineffective; 2 = Ineffective; 3 = Difficult to assess; 4 = Effective; 5 = Very effective. Two open-ended questions concerned describing students' impressions and receiving their suggestions.

This tool was validated by members of the research team — 5 people — who used the analysis of the general suitability of the questionnaire (external features), its structure and content (Rodrigues et al., 2017). The IL-CVI index was 0.96 and Fleiss's Kappa was .908, indicating almost unquestionable unanimity among evaluators, according to Polit and Beck (2006)

The questionnaire was posted on Google Forms and was distributed to the subjects through messengers. The answers to the first 10 questions were processed in Jamovi (version 2.0.0), and the answers to the 11 and 12 questions were processed manually by members of the research group: key answer topics were identified and their content was analysed. The reliability of analysing qualitative data was ensured by using the strategy of triangulation which was based on involving three volunteer colleagues to analyse the same data (Thakur & Chetty, 2022). This strategy was

supposed to help overcome the research team members' personal biases. The reliability of the obtained results was also verified using the Cronbach's alpha.

Results

The research aimed to fulfil three research objectives, namely: to develop and validate a test to determine the level of students' critical thinking, to study how the application of the developed technological educational model affects students' critical thinking and their self-study performance, and to find out how students perceive the technological educational model for the critical thinking development. The results of the study are presented in the order of the formulated objectives.

Validation Results of the Test to Determine the Level of Students' Critical Thinking

Exploratory and confirmatory factor analysis was used to validate the test. Exploratory factor analysis was based on data obtained after the first experiment. The data obtained for KaiserMeyer Olkin (KMO) ranged from .617 to .795 which were sufficient according to Pallant (2020) and indicated the adequacy of the sample that consisted of 196 test takers. A Bartlett Test of Sphericity showed that p-value less than 0.05 ($p =< .001, \chi^2 = 1135, df = 187$) which indicated that these data were approximately multivariate normal and sufficient for further analysis (Pallant, 2020). The eigenvalues for every factor below were greater than 1.7 which indicated that these could be retained for interpretation.

For its implementation, the method of principal axis factor extraction was used in combination with the varimax rotation to determine the unsatisfactory element. Four-factor analysis of factor load with a factor load of 0.4 was used as a reference value for the acceptance of the variable. Components of critical thinking were used as factors. Factor 1 — "assessment of the relevance of the conclusion", Factor 2 — "analysis and assessment (ideas, proposals, assumptions)", Factor 3 — "inferences", Factor 4 — "self-regulation (self-assessment, self-correction)". The weight of Factor 1 was 14.2% of the total, Factor 2 — 25.2%, Factor 3 — 35.3% and Factor 4 — 45.7%. The model fit measurements are summarized in Table 4.

Table 4. Summarized Model Measurements

CFI	RMSEA	RMSEA 90% CI		TLI	Model Test		
		Lower	Upper		χ^2	df	p
0.929	0.0476	0.0564	0.0608	0.971	147	182	< .001

As Table 4 confirmed, the values of CFI (.929), TLI (.971); and RMSEA (.0476) showed that the test meets the requirements for collecting statistics (Coşkun & Mardikyan, 2016).

Data from the first re-sample were used to perform confirmatory factor analysis. At this stage, the values of model compliance were $\chi^2 = 233.71, df = 174, p < .001$. The results of factor correlation obtained from the confirmatory factor analysis are presented in Table 5.

Table 5. The Results of Factor Correlation Obtained from the Confirmatory Factor Analysis

Factor	1	2	3	4
Assessment of the relevance of the conclusion	1			
Analysis and assessment	.32	1		
Inferences	.58	.26	1	
Self-regulation	.14	–.14	–.22	1

As Table 5 shows, the strongest correlation was found between the components "assessment of the relevance of the conclusion" and "inference" (r = .58). It was found that self-regulation is negatively correlated both with inference, and with the analysis and assessment (r = -.14 and r = -.22, respectively). The model fit measurements summarized in Table 6 indicated that the test showed sufficient overall reliability.

Table 6. Summarized Repeated Model Measurements

CFI	RMSEA	TLI	Model Test		
			χ^2	df	p
0.948	0.0448	0.963	229.66	169	< .001

The data of Table 6, in particular the values of CFI (.948), TLI (.963); and RMSEA (.0448), proved that the test is a valid statistical tool (Coşkun & Mardikyan, 2016). Therefore, the exploratory factor analysis (EFA) and the confirmatory factor analysis (CFA) of the test to determine the level of students' critical thinking proved that it can be used as a reliable tool in this study.

Impact of Technological Educational Model on Critical Thinking and Performance

The Cronbach's alpha was .74. This indicates sufficient reliability of the research tools used.

The ANCOVA test was used to measure how the technology-based educational model influenced the levels of EG students' critical thinking and study performance before and after the use of the above model of self-study. The results of the analysis are presented in Table 7.

Table 7. ANCOVA Test Results of Measurements Drawn Before and After the Use of the Technology-Based Educational Model, EG ($n = 27$), and CG ($n = 24$)

ANCOVA – Post-test	Sum of Squares	df	Mean Square	F	p	η^2	ω^2
Overall model	18771	2	8878.7	155.2	<.001		
Pre-test	17792	1	18844.3	292.6	<.001	0.892	0.894
Intervention	1068	1	1064.7	17.9	<.001	0.059	0.054
Residuals	891	14	59.9				

As can be seen in Table 7, the value for the variability proportion (η^2) for the Pre-test and Post-test is close to 1 which indicates a sufficient relationship between the two (Navarro & Foxcroft, 2021). According to Cohen's guidelines, η^2 represents a medium effect size, (5.9%) of the variance that took place due to the model (Eddy, 2010). As provided in the Post Hoc Comparisons Table (see Table 8), the Mean Difference values ($M_{difference}$ = −7.6, SE = 1.23) showed improvement in the EG students' critical thinking and study performance.

Table 8. Post Hoc Comparisons Based on Tests Mean Values

Comparison		Mean Difference	SE	df	t	p	Cohen's d	95% Confidence Interval	
Treatment	Treatment							Lower	Upper
As usual	Model	-7.6	1.23	14.0	-4.41	<.001	3.277	-2.45	1.21

Note. Comparisons are based on estimated marginal means

The t-value (t = – 4.41; $p = <$ .001) also implied that the EG students experienced a more significant improvement in their critical thinking and study performance compared to CG students. The effect size was significant with $Cohen's\ d = 3.277$ which proved that the technology-based educational model was efficient in developing students' critical thinking and contributed to their academic performance.

The pie chart (Figure 2) supplements Table 7 in terms of the distribution of EG students by levels of critical thinking. Figure 2 clarifies that the level of a significant part of EG students has shifted towards medium and high.

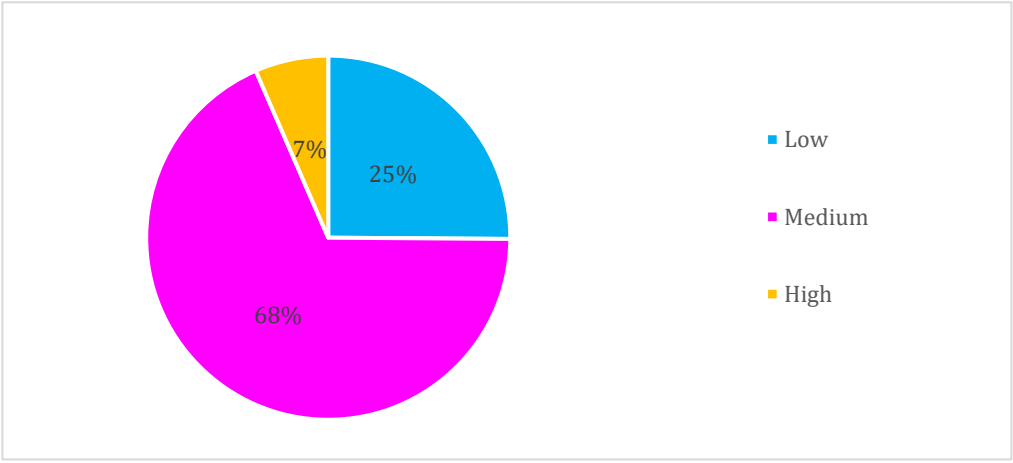

Figure 2. Distribution of EG Students According to the Levels of Critical Thinking

Table 9 presents the results of determining students' performance during the experiment (for one academic year) according to the final control at the end of the academic year in contrast to the year before. As can be noted in Table 9, there was observed a shift in the final scores in both groups, but the shift in the EG was greater.

Table 9. The Results of the Final Control of Students' Performance during the Experiment

Final score	Share of students, %			
	Control group		Experimental group	
	Before	After	Before	After
0-60	0	0	0	0
61-74	58%	54 %	58%	38%
75-89	36 %	39 %	36 %	51%
90-100	6%	7%	6%	11%

Questionnaire on Students' Perception of Technological Model of Students' Critical Thinking Development

A link to the electronic version of the questionnaire was sent to fifteen EG students selected at random to find out the details of the students' learning experience related to their participation in a technological educational environment aimed at developing critical thinking. Descriptive statistics of respondents' answers to 1-10 questions are presented in Table 10.

Table 10. Descriptive Statistics of Respondents' Answers to 1-10 Questions of the Questionnaire

	Questions									
	1	2	3	4	5	6	7	8	9	10
Mean	4.71	4.84	4.67	4.27	4.22	4.88	4.34	4.15	4.94	4.43
SD	1.07	1.14	1.09	0.95	1.08	1.04	1.07	1.14	1.19	1.12
Kurtosis	1.39	1.45	1.43	1.37	1.32	1.46	1.42	1.44	1.46	1.43
Std. error kurtosis	0.221	0.221	0.221	0.221	0.221	0.221	0.221	0.221	0.221	0.221

As Table 10 indicates, the respondents mostly ranked the experience related to their participation in the technological educational environment as "very effective". However, we can note that "intellectual load" were marked by the highest indicators ($M = 4.94, SD = 1.19$), organisation of the self-study process ($M = 4.88, SD = 1.04$), the content of classes with a focus on the critical thinking development ($M = 4.84, SD = 1.14$), and classes focusing on the critical thinking development in general ($M = 4.71, SD = 1.07$). "Additional teacher assistance in technology" ($M = 4.15, SD = 1.14$) and "organization of classes by the teacher" ($M = 4.15, SD = 1.14$) were marked with the lowest scores. The presented results lead to the conclusion that the students insisted on reducing the share of educational autonomy in the educational process.

Discussion

The study sought to investigate, first, how the application of the developed technological educational model affects students' critical thinking, second, how the level of critical thinking affects the effectiveness of students' self-study, and third, how students perceive the technological educational model for thinking development. The novelty of the study is in updating the instructional approaches to fostering critical thinking abilities in students when they self-study by technologizing the process of learning.

Romero Uscanga and Torres-Delgado (2022) prove that the development of critical thinking skills is a prerequisite for improving students' performance. It was also proved that the development of critical thinking does not depend on the previous level of students' knowledge and skills.

This study found that the technology-based educational model influenced the levels of EG students' critical thinking and study performance before and after the use of the above model of self-study. The ANCOVA test showed that the value for the variability proportion (η^2) for the Pre-test and Post-test is close to 1 which indicates a sufficient relationship between the two. According to Cohen's guidelines, η^2 represents a medium effect size, (5.9%) of the variance that took place due to the model. The Mean Difference values ($M_{difference}$ = −7.6, SE = 1.23) drawn from the Post Hoc Comparisons showed improvement in the EG students' critical thinking and study performance. The t-value (t = – 4.41; $p = < .001$) also implied that the EG students experienced a more significant improvement in their critical thinking and study performance compared to CG students. The effect size was significant with $Cohen's\ d = 3.277$ which proved that the technology-based educational model was efficient in developing students' critical thinking and contributed to their academic performance.

The findings of the study are consistent with previous studies. They complement the findings of Hove (2011) and Dichek et al. (2021), who argued that students who develop critical thinking have better learning outcomes. They are consistent with the results of Giraldo-García et al. (2015), Gökçearslan et al. (2019), Lychuk et al. (2021), Nozhovnik and Shykhnenko (2020), Schindler et al. (2017), who found that the use of technology increases students' motivation, provides individualization of learning, improves their time management skills and overall learning satisfaction. The results of the study deepen the provisions introduced by Dehghani et al. (2011), Lin et al. (2020), Shirazi and Heidari (2019). Haghparast et al. (2014), who deal with the fact that independent work with the use of technology encourages

students to use meta-cognitive abilities. Alharbi et al. (2022) proved that the use of collaborative e-learning technology improves students' critical thinking skills. As the study conducted by Sutiani (2021) with the sample consisting of 93 students of Negeri Medan University showed, the introduction of a research approach into the educational process is another technology for the development of critical thinking skills. This enabled the students to reach the level of critical thinking "very good" (72-97%). Wardah et al. (2022) solved the inverse problem to the one set in this work: identifying the impact that students' independent work has on the development of their critical thinking. They established that the higher the level of academic autonomy students have, the higher their level of critical thinking, which is characterized by the ability to choose and use the right strategy for complete and correct problem-solving, and the ability to make predictions about the results and explain them.

The EG students' feedback regarding participation in the experiment was mainly complimentary. The respondents mostly ranked the experience related to their participation in the technological educational environment as "very effective". It can be noted that "intellectual load" was marked by the highest indicators ($M = 4.94, SD = 1.19$), organisation of the self-study process ($M = 4.88, SD = 1.04$), the content of classes with a focus on the critical thinking development ($M = 4.84, SD = 1.14$), and classes focusing on the critical thinking development in general ($M = 4.71, SD = 1.07$). "Additional teacher assistance in technology" ($M = 4.15, SD = 1.14$) and "organization of classes by the teacher" ($M = 4.15, SD = 1.14$) were marked with the lowest scores. The presented results implied that the students insisted on reducing the share of educational autonomy in the educational process.

This study involved indirect methods to establish the relation of the level of students' academic performance achieved in the course of self-study during the 2020 pandemic and the level of their critical thinking. The latter turned out to be dependent on the technologies used for its development.

Conclusions

The application of the technological educational model has a positive effect on the critical thinking of students of HEIs and their self-study performance. It was revealed by monitoring the development of students' critical thinking and their performance before and after the experiment. The study updated the instructional approaches to fostering critical thinking abilities in students when they self-study by technologising the process of learning. It contributed to the previous research on using technology to encourage students to use their meta-cognitive abilities and establishing academic autonomy of the students. The results drawn from the ANCOVA test found medium effect size of the variance that took place due to the model. The Post Hoc Comparisons showed improvement in the EG students' critical thinking and study performance. The t-value also implied that the EG students experienced a more significant improvement in their critical thinking and study performance compared to CG students. The effect size was significant with which proved that the technology-based educational model was efficient in developing students' critical thinking and contributed to their academic performance. It was also found that students were complimentary about the technological educational model for critical thinking development. The results of the survey showed that the respondents mostly ranked the experience related to their participation in the technological educational environment as "very effective".

Recommendations

Teachers should transfer theoretical subjects into the format of pre-recorded lectures and free up time for practical projects, involve technical staff in creating interactive electronic materials, improve the quality of educational materials through the involvement of practitioners. Researchers in the field of education need to study the issue of how to improve the teachers' mastery of technologies, how to optimize the workload of students during their independent work. Further research should be conducted to identify new and improve existing technologies for the development of critical thinking of students of higher education institutions.

Limitations

Monitoring and measuring the latent components of critical thinking can be considered a limitation for our research. Involvement of students in the experimental project only economic specialties can also be considered as a limitation of the study.

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Conflict of Interests

The authors report that there are no legal, financial or commercial conflicts associated with the study.

Authorship Contribution Statement

Kravchenko: Conceptualization, design, reviewing. Dokuchaieva: Data acquisition, data analysis and interpretation, drafting manuscript. Valentieva: Supervision, final approval. Sbitnieva: Data analysis and interpretation, drafting manuscript. Chornobryva: Concept and design, critical revision of manuscript.

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Appendices

Appendix A

Table A1. Test to Determine the Level of Students' Critical Thinking (The Electronic Test Version Is Available at: https://forms.gle/vu6knjxkjbec6kvz8)

Component	No.	Test assignment
Assessment of the relevance of the conclusion	1	According to the 2020 survey, 73% of Ukrainian respondents consider those with a monthly income of less than UAH 6,000 to be "poor", and 52% of respondents consider those with an income higher than UAH 60,000 to be "rich". Those with incomes ranging from UAH 6,000 to UAH 60,000 were classified by most respondents as middle-income. Approximately the same number of respondents classified people with a monthly income of UAH 50,000 as either "rich" or "middle-income". *Interpretation: In order to be considered "rich" in Ukraine, your monthly income must be at least 10 times higher than that of the "poor".* *A) Interpretation is relevant* (correct answer) *B) Interpretation is not relevant*
	2	It has never been proven that children who slowly gain weight in the first few months of their lives usually do not catch up with their peers under 13 years of age. *Interpretation: Children who gain weight slowly tend to catch up with their 13-year-old peers.* *A) Interpretation is relevant* *B) Interpretation is not relevant* ***(correct answer)***
	3	"It's a very interesting piece of household goods," Anna said. "Interesting?" Mykola asked. "It is more than interesting. It is a real antique. It is decorated according to traditions and methods, which is more than 400 years old. I'm sure no one will do it so skilfully now." — But does it allow to call such an item an antique? Anna asked. *Question: Which of the following definitions most fully reflects Mykola's idea of "antiques"?* *A) Antiques are items or decorations, the methods and traditions of which are at least 400 years old, and which are currently no longer made with the same level of skill* ***(correct answer).*** *B) Antiques are items that were made at least 400 years ago.* *C) Antiques are items that have been made according to tradition and using methods that are no longer used, and the decoration of which is more than 400 years old.*
	4	Maria Shevchenko, Dr. of Food Science, is researching the possibility of using food substitutes to lose weight. Interim results of the study showed that so far product A has not significantly affected weight loss in those who used it. However, 12.5% of those who used product B showed significant weight loss results. *Determine which of the following statements is more valid (A) or (B). These statements are underlined and their sources are cited. If you think that none of them is plausible, choose the answer (B).* *(A) One of the tested products did not significantly affect weight loss (from a press release provided by Doctor of Science Maria Shevchenko) (B) Product B showed a more significant result in sample weight loss than product A (as indicated by Dr. of Food Science Maria Shevchenko in the interim report to the Academic Council)* *(C) No statement can be considered plausible or credible* (correct answer).
Analysis and assessment (ideas, proposals, assumptions)	5	Is it appropriate to use the introduction of tariffs on foreign goods as a way to protect the domestic labour market? *Argument: No, because a certain number of domestic jobs are created due to the import of goods from abroad.* *A) Strong argument* (correct answer) *B) Weak argument*
	6	Should employees who have worked for more than five years be required by law to notify employers of their dismissal within 60 days? *Argument:* No, such legislative initiatives in the field of labour law, which are aimed at protecting employers, demotivate employees and reduce their effectiveness in the workplace. *A) Strong argument* (correct answer) *B) Weak argument*
	7	Should the government close power plants that have exhausted their resources and pollute the environment, even if this would lead to increased energy imports? *Argument: No, energy imports are expensive, and the global financial crisis has significantly affected the government's ability to pay for such expensive schemes.* *A) Strong argument* (correct answer) *B) Weak argument*
	8	Obviously, increasing and accelerating the productivity of artificial intelligence will greatly affect business strategy. *Assumption: The higher the speed of artificial intelligence, the more this process will affect business strategy.* *A) The assumption is relevant* (correct answer) *B) The assumption is irrelevant*

Table A1. Continued

Component	No.	Test assignment
	9	This year's Media Innovation Forum was attended by about 330 marketing professionals. This indicates that there is an increase in the use of social networks in marketing, which is becoming an essential component of brand marketing plans. *Proposed assumption: The level of attendance of professional media forums is trend-illustrative.* *A) The assumption is relevant* (correct answer) *B) The assumption is irrelevant*
	10	It is predicted that after the creation of supercomputers, there will be a shortage of people who know how to use their computing power. *Proposed assumption: Creating supercomputers is only a matter of time.* *A) The assumption is relevant* *B) The assumption is irrelevant* (correct answer)
Inferences	11	An international study found behavioural changes among consumers. 41% of respondents said they were "increasingly looking for ways to save money." Although consumers are mostly committed to brands, they are still looking for a good price. Among the above, 12% of consumers began to buy products of cheaper brands (for example, bottled water), while 11%, on the contrary, began to give preference to products of expensive brands, such as cosmetics. There is a massive transition of consumers to online shopping. *Conclusion:* Brand-minded consumers are less likely to save money than those who are not indifferent to brands. *A) Yes* *B) Probably yes.* *C) Lack of information.* *D) Probably not (correct answer)* *E) No.*
	12	2,500 people gathered to protest the proposed 1% sales tax increase. Speakers at the protests spoke not only about reducing the sales tax, but also about reducing the state income tax. Several hundred counter-protesters also came to the protest. Violent clashes ensued, leading to dozens of arrests. *Conclusion:* Counter-protesters do not want the state income tax to be reduced. *A) Yes* *B) Probably yes* (correct answer) *C) Lack of information.* *D) Probably not.* *E) Not.*
	13	One hundred young people aged between 20 and 30 have paid for their recent high-speed dating at a bar in the city centre. At this event, discussions on education and the profession were the most frequently discussed, because it seems that young people today consider these topics most important for finding the perfect partner. *Conclusion:* Most young people have not previously discussed education and profession with their previous potential partners. *A) Yes* *B) Probably yes.* *C) Lack of information.* *D) Probably not* (correct answer) *E) No.*
	14	Bonds and stocks are securities that differ in the following way: shareholders buy them to own a stake in the company, while bondholders lend money to the company's owners. Another difference is that bonds have a fixed term after which the bond is redeemed by the owners, while the shares can be traded indefinitely. That's why I invested in shares of Company C. *Conclusion:* I did not borrow money to Company C. *A) The conclusion is logical* *B) The conclusion is not logical* (correct answer)
	15	All companies strive to maximize their profits. Some companies offer their employees a share in the distribution of profits and thus retain staff. So, the staff retention scheme is a way to maximize the company's profits. *Conclusion:* Not all companies that work to maximize profits retain staff. *A) The conclusion is logical and clear* (correct answer) *B) The conclusion is not logical and not clear*
	16	A waste recycling company that generously rewarded employees for each new customer they hired found that last year, 15% of employees involved three or more new customers. However, the percentage of employees who bribed customers to stay at work was 25%. *Conclusion:* Employees who did not use bribes were able to earn more money than those who gave bribes, because the latter spent their own money to attract new customers. *A) The conclusion is logical* *B) The conclusion is not logical* (correct answer)

Table A1. Continued

Component	No.	Test assignment
	17	Properties are either very large or located in central areas. However, no coincidence was found that both of the above characteristics were present at the same time. Although there is no apartment without air conditioning, all properties with air conditioning are large. *Conclusion:* Properties located in the central areas are not apartments. *A) The conclusion is logical* (correct answer) *B) The conclusion is not logical*
Self-regulation (self-assessment, self-correction	18	Your classmate, whom you can't stand, goes out in front of the audience to make a report, and you notice that her skirt is tucked into tights. She starts talking about a very important topic, and you want to laugh, and you shouldn't. Can you control your laughter? A) Yes, I could control myself in this case without much difficulty (correct answer) B) Yes, however, I would probably blush a little because of holding back my laughter. C) Yes, I could laugh to myself, while refraining from laughing out loud. D) Yes, but if someone other than me would laugh, I would not hold back. E) No, I probably can't help but chuckle. F) No, unfortunately, I would laugh.
	19	Nataliia and Andrii attend the same physical education group. Nataliia runs the fastest in the group. Andrii makes the largest number of pull-ups. Each of them stated that he/she considers himself/herself the best athlete in the group. Roman said that neither of them can be the best, because they are both short, and that usually the best athletes are only those who are tall. After a long conversation, the students agreed to decide which one is the best. *You know that Nataliia ranked second in the pull-up competition, and Andrii was fourth in the run. Andrii is taller than Nataliia. Why are you most likely to find Nataliia the best athlete?* A) In general, Nataliia has better results than Andrii (correct answer). B) You like Nataliia more than Andrii. C) Andrii is too slow to be the best athlete. D) In general, you consider yourself the best athlete.
	20	You were nervous standing on the stage before the performance. As you sang, the students in the hall began to laugh. When you heard the laughter, you sang even louder. When you finished singing, almost everyone laughed. The music stopped, and you smiled at the audience and bowed. When the curtain closed, your teacher wiped away the tears and hugged you tightly. You were glad you finished singing this song. When you returned home, you told your parents that the audience sang along with you. ***Which of the following statements is most true?*** A) Your teacher felt sorry for you. B) Your parents were proud of you. C) You are a bad singer. D) You sang a funny song (correct answer)

Appendix B

Table B1. Questionnaire to Find Out Students' Perception of the Technological Model of Critical Thinking Development (Adapted from https://form.jotform.com/211152017250337) (The Electronic Is Available at: https://forms.gle/wRMMM8pgYohDC5Wr6)

	Question	Assessment				
		1	2	3	4	5
1	In general, classes with a focus on the critical thinking development were:					
2	The content of classes with a focus on the critical thinking development was:					
3	Technologized assignments for the critical thinking development in the process of independent work were:					
4.	The teacher worked:					
5.	The organization of classes by the teacher was:					
6.	The organized self-study process was:					
7.	Feedback from the teacher was:					
8.	Additional technology assistance was provided by the teacher:					
9.	The intellectual load on the student was:					
10.	The performance appraisal system was:					

Note: 1 = "generally ineffective", 2 = "ineffective", 3 = "difficult to assess", 4 = "effective", 5 = "very effective".