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Selection of pedagogical conditions for training STEM teachers to use augmented reality technologies in their work

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Abstract. The focus of the study is on choosing the pedagogical conditions that will best prepare STEM teachers to utilize augmented reality tools in their classrooms. 20 conditions were initially proposed during a brainstorming session and were then sorted into five groups: (1) conditions relating to the material support of the educational process, (2) methods and forms of training, (3) best practices for utilizing augmented reality in education, (4) unique circumstances made in order to achieve the goal of training STEM teachers; and (5) conditions relating to the psychological and pedagogical support of students. A survey was conducted with 94 participants to determine the importance of these conditions. The processing of the survey data allowed for the selection of the following conditions: (a) accessibility of immersive digital educational resources for STEM teachers and mobile hardware for augmented reality (laptops, tablets, smartphones, augmented reality glasses, etc.), (b) inclusion of augmented reality-related topics in STEM teachers' curricula, (c) use of research methodologies and interactive technologies in the STEM classroom, (d) having hands-on experience with the use of augmented reality technologies in STEM instruction.

1. Introduction

The operational plan for the "Strategy for the Development of Higher Education in Ukraine for 2022-2032" [1] implementation in 2022-2024 to achieve strategic goal 3 "Ensuring quality educational and research activities, competitive higher education, which is accessible to different segments of the population" defines operational goal 5 "Taking into account scientific research and innovations when determining the educational programs' content and development", the implementation of which in 2022-2023 provides for the popularization of natural sciences and mathematics for students. To achieve strategic goal 3 and the corresponding operational objectives, a number of tasks are provided, including:

- providing special support to residents of the temporarily occupied territories;

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- supporting modern basic educational laboratories and advanced research laboratories of higher education institutions with equipment for information technologies (digital infrastructure);
- promoting the use of innovative technologies and the latest teaching aids in the educational process, research infrastructures development: "innovation should be realized through the application of new and improved methods and practices (including digital technologies) for teaching, learning and assessment, which should be carried out in close connection with research" [1].

In [1] it is stated that "in general, the higher education system of Ukraine has demonstrated great adaptive potential during the forced transition to distance innovative learning technologies during the quarantine period. At the same time, the limited capabilities of the IT infrastructure of many higher education institutions and the unsatisfactory digital competence level of scientific, scientific-pedagogical and pedagogical workers [2] did not allow to ensure the educational process in distance learning at a sufficient level [3]. Distance innovative learning technologies have become especially important with the Russian Federation armed aggression in 2014 [4] and, in particular, the act of armed aggression against Ukraine on February 24, 2022 [5], which resulted in a large number of temporarily displaced persons, higher education institutions and an increase in number of temporarily occupied territories' residents that have a need in quality educational services [6].

In order to achieve strategic goal 5 "Attractiveness of higher education institutions for study and academic career", it is envisaged to introduce a state program of research and teaching staff continuous professional development, ensuring their digital competencies development [1]. Thus, in 2020, the European Commission approved the "Digital Education Action Plan for 2021-2027", which provides for the following priority areas [7]:

(i) Accelerating the development of effective digital educational ecosystems, which requires:
   - availability of infrastructure, connectivity and digital equipment;
   - effective planning and development of digital potential;
   - trained teachers with digital competencies;
   - high quality educational content, tools and secure platforms that meet privacy and ethical standards and are user-friendly.

(ii) Digital skills and competences development for digital transformation, in particular:
   - basic digital skills and competencies starting from preschool age;
   - digital literacy, including countering misinformation;
   - information education;
   - good data processing technologies, such as artificial intelligence knowledge and understanding;
   - advanced digital skills, more professionals trained in this field;
   - ensuring gender balance.

The scientific and mathematical education (STEM education) development concept [8] determines that in order to ensure its proper quality it is necessary to:

- raising the level of professional teachers' competence;
- updating the content of natural, mathematical and technological educational fields (in particular, teaching aids and electronic educational resources on artificial intelligence, computer modeling, 3D modeling, basics of video technologies, digital art);
- implementation of digital technologies into the educational process.

In detailing the priority areas of the "Digital Education Action Plan for 2021-2027", the European Commission pays special attention to digital education ecosystems based on artificial intelligence technologies, data processing, virtual reality, augmented reality, etc. for which high-speed Internet access is critical [9].

"There is evidence that existing forms of professional development for teachers do not always meet their needs. In particular, there is a need to move from acquiring skills in certain tools or technological competencies to finding ways to adapt technologies to specific subjects, goals and activities. The emergence of new technologies such as artificial intelligence, virtual or augmented reality and social robotics requires teachers to play a more active role in the design and implementation of these tools to ensure their effective, desirable and inclusive use" [10].

Thus, there is a socially defined need to develop the digital competence of STEM teachers [11–13] in the digital educational resources using artificial intelligence [14] and augmented reality technologies design and implementation [15–17].

2. Literature review

In Ukraine, the application of STEM technologies in education was considered in the research works of O. Y. Shagova (pedagogical conditions were determined and a model for the future officers of the Armed Forces of Ukraine readiness formation to use STEM technologies in professional activities was developed [18]), O. S. Kuzmenko (developed the concept of STEM education of a technical higher education institution to ensure the integration of physics and professionally oriented disciplines [19]), L. I. Melnychenko (developed pedagogical conditions for the formation of research skills of future primary school teachers by means of STEM technologies [20]), V. V. Pikalova (determined pedagogical conditions for the use of package GeoGebra as a tool for concept of STEM education implementation in the process of future mathematics teachers training [21]), V. V. Boychenko (the specifics of professional and pedagogical training of STEM teachers of high school in the USA are determined and the corresponding programs at the first (bachelor's) and second (master's) levels of higher education are characterized [22]). N. Valko's dissertation developed the concept of training future teachers of natural and mathematical disciplines for the use of STEM technologies (primarily robotic STEM projects) in professional activities [23]; the author's latest works are devoted to educational applications of artificial intelligence technologies [24].

Since 2000, there have been studies devoted to the electronic educational resources design with the help of virtual and augmented reality [25]: V. G. Li (developed a technology for synthesizing the virtual reality environment [26]), S. M. Danilov (built a virtual reality tools continuum system model as an environment for testing innovative technologies in architecture [27]), O. M. Makoveichuk (developed a technology for the construction and use of visual information structures of augmented reality by constructing and using mosaic stochastic markers [28]), N. M. Gnedko (developed a technology for the future teachers readiness formation to use virtual visualization tools in professional activities [29]).

Among the foreign studies on the use of virtual and augmented reality in STEM education and teacher training, we distinguish the thesis of Wen Huang (it is shown that the effect of novelty in the virtual reality use does not necessarily increase learning success: the key to improving learning achievements is the match between the content and teaching methods [30]), Carolyn F. Pollack (the expediency of using augmented reality for the formation of spatial concepts of students in teaching Earth sciences is shown [31]), K. K. Arcand (the joint usage expediency of programming tools, 3D modeling, 3D printing and virtual reality for the development of spatial concepts in teaching astrophysics and students' professional orientation to the STEM industry [32]), A. M. Villanueva (developed tools that enable teachers and developers to create digital educational resources with augmented reality for collaborative work and distance learning, in particular – for mastering robotics [33]), K. Doty (application of augmented reality simulators to prepare future teachers to work with students in physics lessons [34]).

At the same time, in the studies known to us, there is no holistic methodology for the digital competence of future STEM teachers formation and development in the digital educational resources with augmented reality design and application. Therefore, the task of the study is to select pedagogical conditions for training future STEM teachers to use augmented reality technologies in professional activities.

3. Methodology

Pedagogical conditions are significant circumstances in the educational process (material conditions, methods, forms and real situations, etc.) that have objectively been developed or subjectively created for achieving a specific purpose.

Pedagogical conditions for for training STEM teachers to use augmented reality technologies in their work are material conditions, methods, forms, real situations, etc., of the augmented reality technologies application, which were objectively developed during the training process or subjectively created to achieve the goal.

To identify the pedagogical conditions for training STEM teachers to use augmented reality technologies in their work, a brainstorming session was conducted, during which 20 conditions were proposed and divided into 5 groups:

- Conditions connected to material support of the educational process (the future STEM teachers training, using augmented reality technologies).
  1. Availability of equipped classrooms in higher education institutions (immersive labs, lecture halls with virtual and augmented reality).
  2. Availability of mobile (handheld, portable, partially energy-dependent) augmented reality devices: laptops, tablets, smartphones, augmented reality glasses etc.
  3. Availability of subject-specific (computer science, physics, mathematics, chemistry, biology, technology, etc.) digital educational resources with augmented reality, specially designed for future STEM teachers.
  4. Availability of interdisciplinary (transdisciplinary) digital educational resources with augmented reality, specially developed for future STEM teachers.
  5. Availability of digital educational resources with augmented reality for the future STEM teachers' psychological and pedagogical training.
- The training methods and forms of future STEM teachers to use augmented reality technologies.
  6. Application of interactive technologies in the training of future STEM teachers.
  7. The use of research and project methods in the training.
  8. Engaging students in adaptation, development, testing and implementation of digital educational resources with augmented reality.
  9. Organization of pedagogical practice using augmented reality technologies.
  10. Organization of independent work using augmented reality technologies.
  11. Organization of distance learning using augmented reality technologies.
  12. Application of learning management systems.
- Real situations regarding the best practices of using augmented reality technologies in training.
  13. Selection, adjustment, adaptation, etc. of digital educational resources with augmented reality for educational activities in STEM disciplines.
  14. Acquisition practical experience in the application of augmented reality technologies in teaching STEM disciplines.
- Specifically created to achieve the purpose of preparing future STEM disciplines teachers for using augmented reality technologies in professional activity.

15. Imposition to the content of the training of future STEM teachers, issues related to the use of augmented reality in teaching STEM disciplines.
16. Imposition to the content of the training of future STEM teachers of the special course on the development of digital educational resources with augmented reality.
17. Creation of a cloud-based educational and methodological complex for the digital educational resources development with the augmented reality for future STEM teachers.
18. Engaging students in the contests on the development of digital educational resources with augmented reality.

- Conditions related to participants in the educational process psychological and pedagogical support.

19. Positive motivation to use augmented reality technologies in teaching STEM disciplines.
20. Maintaining an educational website, blog, channel for STEM teachers on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc.

Taking into account the pedagogical conditions are the most significant circumstances of the educational process, a survey was organized in order to estimate the importance of the proposed conditions (Appendix A).

The questionnaire was developed in Google Forms, and the corresponding link (`https://forms.gle/zNWwY43eRF7pCJcC9`) was distributed through several Facebook and Google groups (in particular, cc_seminar). For answers, the questionnaire was opened for 10 days in the period from 07.22.2022 to 08.05.2022.

4. Results

94 participants replied to the questionnaire, among them there were 69.1% – university teachers, 20.2% – teachers, 16% – researchers and 3.2% – students (figure 1).

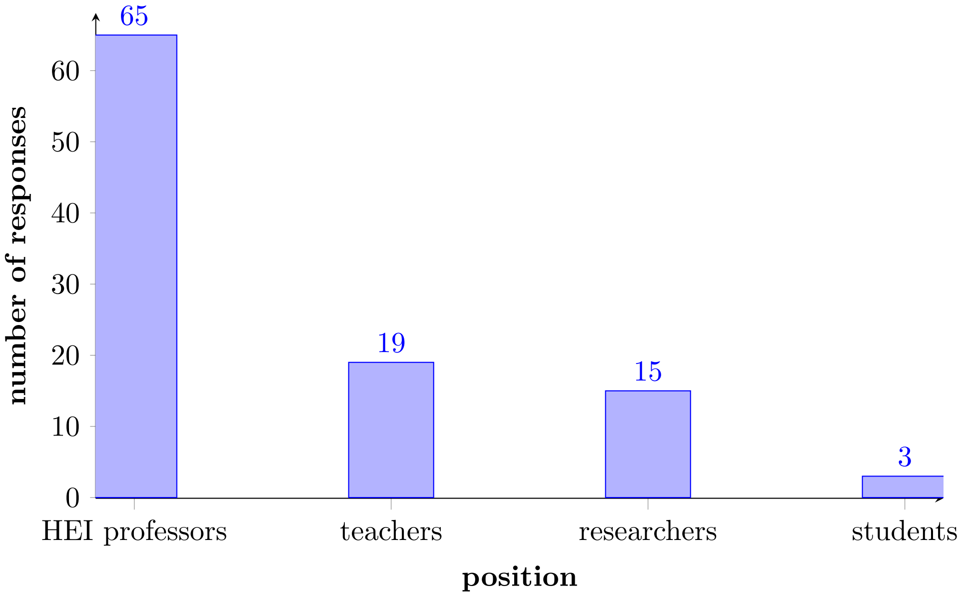

Figure 1. Distribution of answers by positions.

51.1% of respondents are teachers of STEM disciplines (figure 2) – this category of survey participants in the context of the survey topic has the highest level of significance $L_{STEM} = 1$;

for those survey participants who are not STEM disciplines teachers, we will set the level of significance in $L_{STEM} = 0.5$.

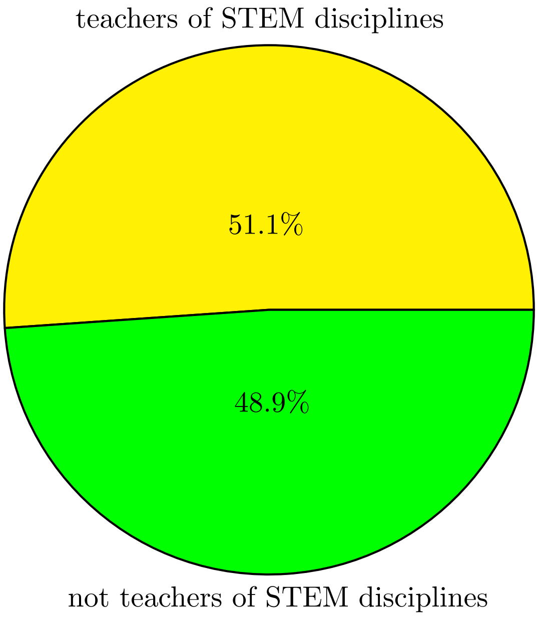

Figure 2. Distribution of answers to the question "Are you a teacher of STEM disciplines?".

In figure 3 shows the distribution of survey participants by the length of service: 10.6% of respondents have experience from 5 to 10 years, 12.8% of respondents have experience from 11 to 15 years, 20.2% of respondents have experience from 16 to 20 years, 31.9% of respondents have experience from 21 to 30 years, that is, more than (75.5%) of the respondents have work experience from 5 to 30 years, which corresponds to a high professional activity level.

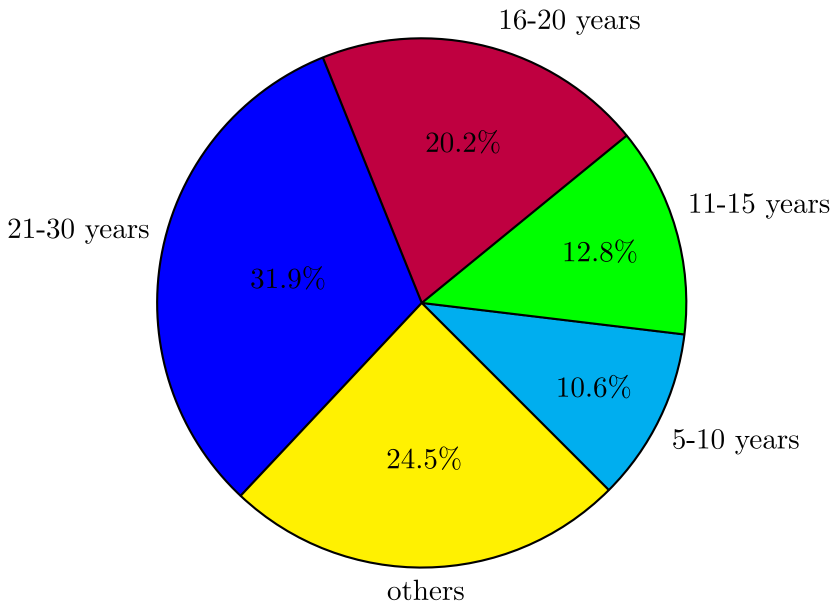

Figure 3. Distribution of answers to the question "Indicate your work experience?".

In the context of the survey, the second significant factor is the augmented reality application level in their professional activity (figure 4): 10.6% of the respondents can develop their means of augmented reality, therefore, the significance level of $L_{AR} = 1$ was set for their answers; 61.7% of respondents use ready-made tools of augmented reality, therefore, the significance level of $L_{AR} = 0.75$ was set for their answers; 27.7% of respondents do not use augmented reality tools in their professional activities but are familiar with them, therefore, the significance level of $L_{AR} = 0.5$ was set for their answers.

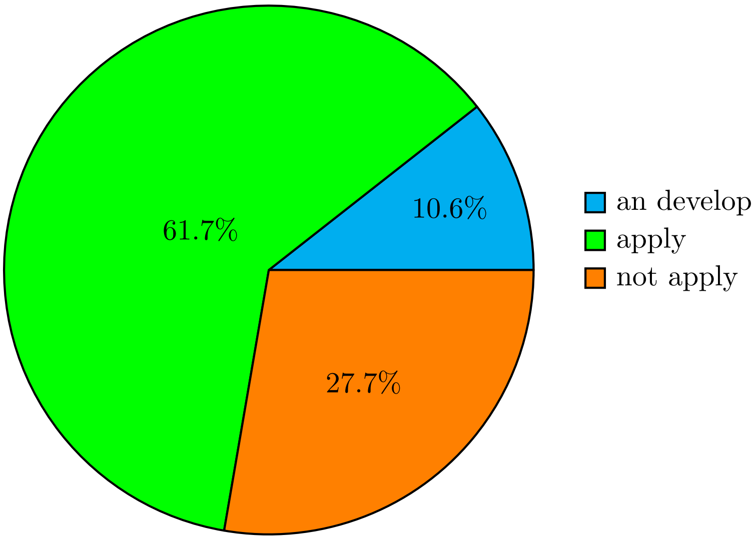

Figure 4. Distribution of survey participants by the level of use of augmented reality in their professional activities.

Proceeding from the questions “Are you a STEM disciplines teacher?” and “Can you rate your level of using augmented reality during your professional activity?” the weight (i) of this answer was established in such a way:

$$W^{(i)} = L^{(i)}_{STEM} \cdot L^{(i)}_{AR} \tag{1}$$

The significance of each of the 20 conditions was proposed to be assessed on a 5-point Likert-type scale: 1 – “very insignificant”, 2 – “insignificant”, 3 – “moderate”, 4 – “significant”, 5 – “very significant”. Considering that the third level corresponded to an uncertain (neutral) answer, the first and second to insignificance, and the fourth and fifth to the significance of the condition, for the convenience of processing the evaluation results, the scale [1, 2, 3, 4, 5] was shifted to the left and transformed on the scale [-2, -1, 0, 1, 2]. Therefore, a negative score indicated the insignificance of the condition, a positive score indicated significance, and a zero score indicated uncertainty.

Let us consider the results of the conditions assessment, related to the educational process material support. Figure 5 shows significance assessment distribution for condition 1 (Availability of equipped classrooms in higher education institutions). 9.5% of the polled consider the availability of equipped classrooms in HEI to be insignificant, 6.4% have not decided on the answer, and 84.1%of the polled consider the availability of equipped classrooms in HEI significant.

Figure 6 shows distribution of significance assessment for condition 2 (Availability of mobile augmented reality devices) 5.3% of respondents consider the mobile tools for augmented reality availability to be insignificant, 4.3% have not decided on the answer, and 90.4% of respondents consider the mobile tools for augmented reality availability to be significant.

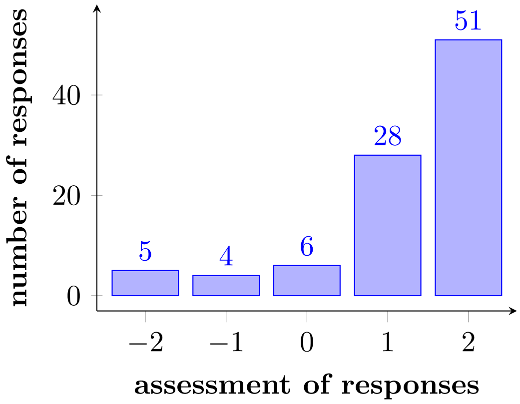

Figure 5. Distribution of significance assessment for condition 1 (Availability of equipped classrooms in higher education institutions).

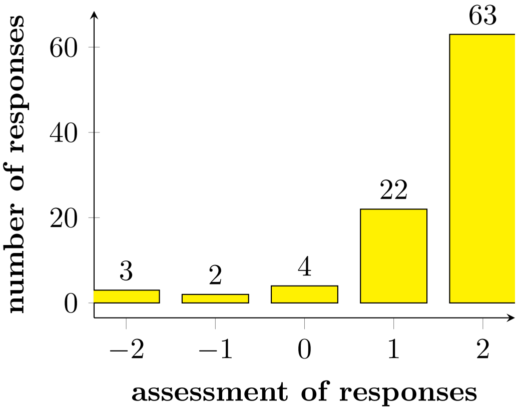

Figure 6. Distribution of significance assessment for condition 2 (Availability of mobile augmented reality devices).

Figure 7 shows the distribution of significance assessment for condition 3 (Availability of subject-specific digital educational resources with augmented reality, specially designed for future STEM teachers). 8.6% of respondents consider the availability of subject-specific digital educational resources with augmented reality specially developed for future STEM disciplines teachers to be insignificant, 7.4% have not decided on the answer, and 84.0% consider the availability of subject-specific digital educational resources with augmented reality specially developed for future STEM disciplines teachers to be significant.

Figure 8 shows the distribution of significance assessment for condition 4 (Availability of interdisciplinary (transdisciplinary) digital educational resources with augmented reality, specially developed for future STEM teachers). 7.5% of respondents consider the availability of cross-curricular digital educational resources with augmented reality specially designed for future STEM disciplines teachers to be insignificant, 5.3% have not decided on the answer, and 87.2% of respondents consider the availability of subject-specific digital educational resources with augmented reality specially designed for future STEM disciplines teachers of to be significant.

Figure 9 shows the distribution of significance assessment for condition 5 (Availability of digital educational resources with augmented reality for the future STEM teachers' psychological and pedagogical training). 14.9% of respondents consider the availability of digital educational resources with augmented reality for future STEM disciplines teachers psychological and pedagogical training to be insignificant, 12.8% have not decided on the answer, and 72.3% of respondents consider the availability of digital educational resources with augmented reality for future STEM disciplines teachers psychological and pedagogical training to be significant.

Figure 10 shows the distribution of significance assessment for condition 6 (Application of interactive technologies in the training of future STEM teachers). 5.3% of respondents consider the use of interactive technologies in the future STEM disciplines teachers training process to be insignificant, 10.6% have not decided on the answer, and 84.1% of respondents consider the use of interactive technologies in the future STEM disciplines teachers training process to be significant.

Figure 11 shows the distribution of significance assessment for condition 7 (The use of research and project methods in the training). 3.2% of respondents consider the application of research

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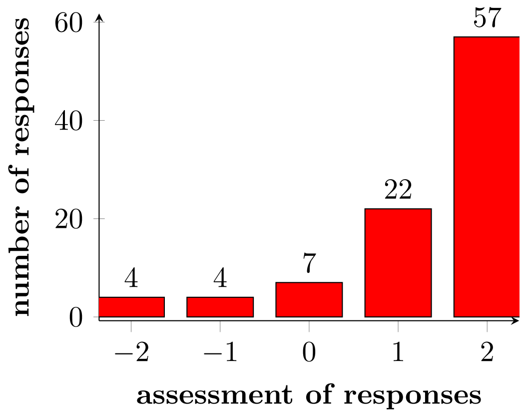

Figure 7. Distribution of significance assessment for condition 3 (Availability of subject-specific digital educational resources with augmented reality, specially designed for future STEM teachers).

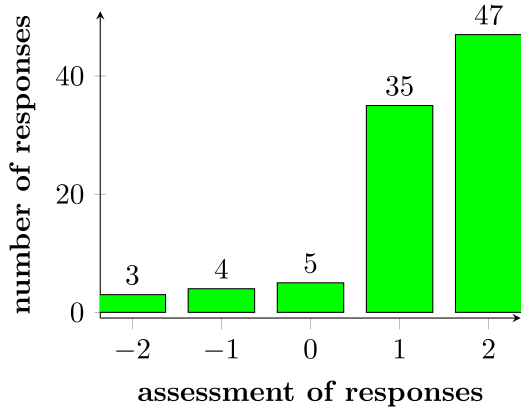

Figure 8. Distribution of significance assessment for condition 4 (Availability of interdisciplinary (transdisciplinary) digital educational resources with augmented reality, specially developed for future STEM teachers).

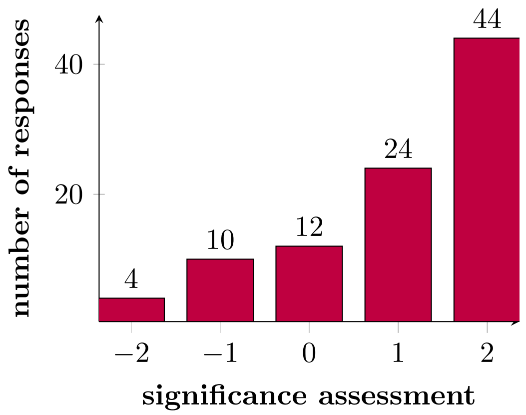

Figure 9. Distribution of significance assessment for condition 5 (Availability of digital educational resources with augmented reality for the future STEM teachers' psychological and pedagogical training).

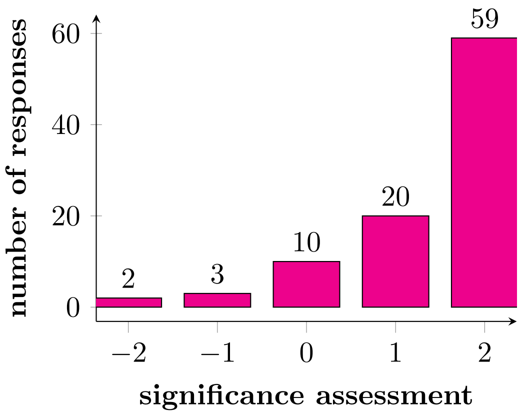

Figure 10. Distribution of significance assessment for condition 6 (Application of interactive technologies in the training of future STEM teachers).

and design methods in the training process to be insignificant, 9.6% have not decided on the answer, and 87.2% of respondents consider the research and design methods application in the training process to be significant.

Figure 12 shows the distribution of significance assessment for condition 8 (Engaging students in adaptation, development, testing and implementation of digital educational resources with augmented reality). 10.7% of respondents consider the digital educational resources with augmented reality involvement of students in the adaptation, development, testing and implementation to be insignificant, 8.5% have not decided on the answer, and 80.8% of respondents consider the involvement of students in the adaptation, development, testing and implementation of digital educational resources with augmented reality to be significant.

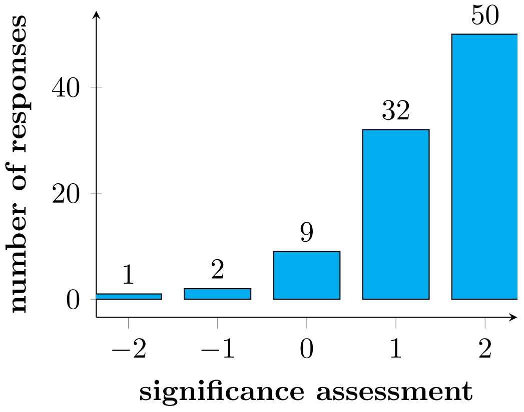

Figure 11. Distribution of significance assessment for condition 7 (The use of research and project methods in the training).

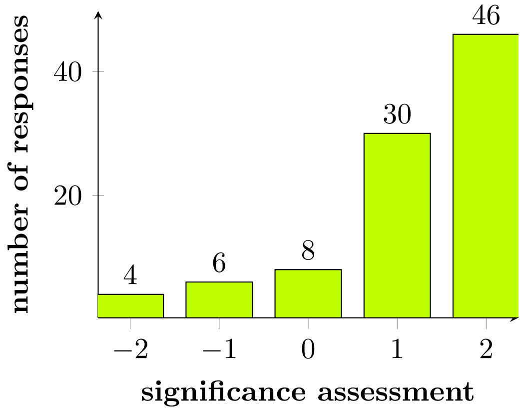

Figure 12. Distribution of significance assessment for condition 8 (Engaging students in adaptation, development, testing and implementation of digital educational resources with augmented reality).

Figure 13 shows the significance assessment for condition 9 distribution (Organization of pedagogical practice using augmented reality technologies). 9.6% of respondents consider the organization of pedagogical practice with the use of augmented reality technologies insignificant, 11.7% have not decided on the answer, and 78.7% of respondents consider the pedagogical practice with the use of augmented reality technologies organization significant.

Figure 14 shows the distribution of condition 10 significance assessment (Organization of independent work using augmented reality technologies). 8.6% of respondents consider the organization of independent work with the use of augmented reality technologies to be insignificant, 13.8% have not decided on the answer, and 77.7% of respondents consider the organization of independent work with the use of augmented reality technologies to be significant.

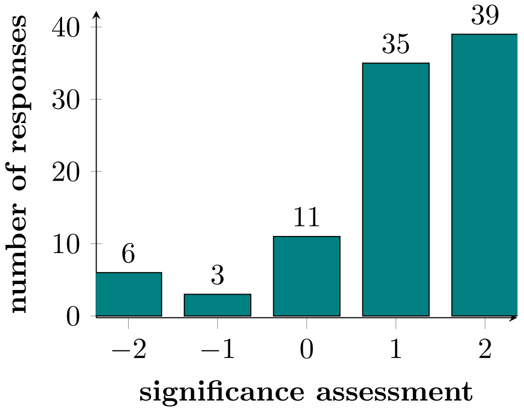

Figure 13. Distribution of significance assessment for condition 9 (Organization of pedagogical practice using augmented reality technologies).

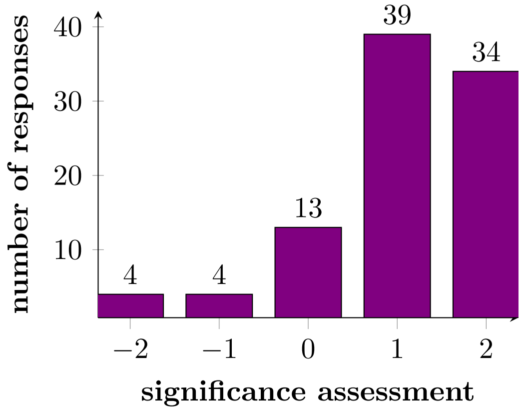

Figure 14. Distribution of significance assessment for condition 10 (Organization of independent work using augmented reality technologies).

Figure 15 shows the condition 11 significance assessment distribution (Organization of distance learning using augmented reality technologies). 10.6% of respondents consider the distance learning organization with the use of augmented reality technologies insignificant, 17% have not decided on the answer, and 72.3% of respondents consider the organization of distance learning with the use of augmented reality technologies significant.

Figure 16 shows the condition 12 significance assessment distribution (Application of learning management systems). 10.6% of respondents consider the use of learning support systems to be insignificant, 14.9% have not decided on the answer, and 74.4% of respondents consider the use of learning support systems to be significant.

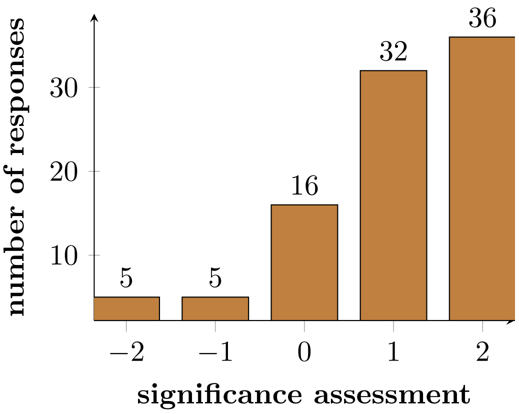

Figure 15. Distribution of significance assessment for condition 11 (Organization of distance learning using augmented reality technologies).

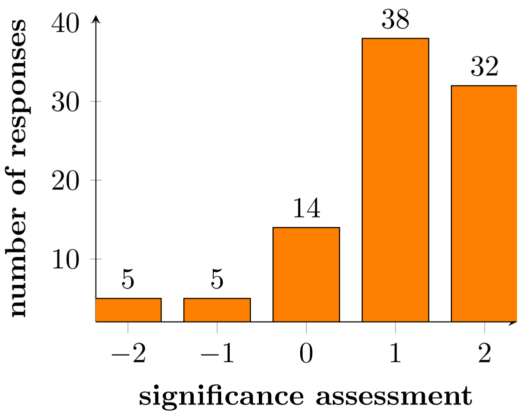

Figure 16. Distribution of significance assessment for condition 12 (Application of learning management systems).

Figure 17 shows the condition 13 significance assessment distribution (Selection, adjustment, adaptation, etc. of digital educational resources with augmented reality for educational activities in STEM disciplines). 6.4% of respondents believe that the selection, adaptation, etc. of digital resources with augmented reality for STEM disciplines is insignificant, 6.4% have not decided on the answer, and 87.3% of respondents believe that the selection, application, adaptation, etc. of digital resources with augmented reality for STEM is significant.

Figure 18 shows the condition 14 significance assessment distribution (Acquisition practical experience in the application of augmented reality technologies in teaching STEM disciplines). 7.4% of respondents believe that gaining practical experience in applying augmented reality technologies in teaching STEM disciplines is insignificant, 1.1% have not decided on the answer, and 91.5% of respondents believe that gaining practical experience in applying augmented reality technologies in teaching STEM disciplines is significant.

Figure 19 shows the distribution of significance assessment of condition 15 (Imposition to the content of the training of future STEM teachers, issues related to the use of augmented reality in teaching STEM disciplines). 5.3% of respondents consider the inclusion of issues related to the augmented reality in teaching STEM disciplines in the future STEM teachers training content to be insignificant, 9.6% have not decided on the answer, and 85.1% of respondents consider the introduction of issues related to the augmented reality in teaching STEM disciplines in the future STEM teachers training content to be significant.

Figure 20 shows the condition 16 significance assessment distribution (Imposition to the content of the training of future STEM teachers of the special course on the development

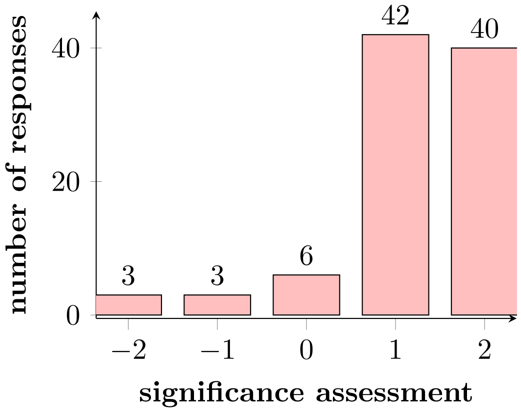

Figure 17. Distribution of significance assessment for condition 13 (Selection, adjustment, adaptation, etc. of digital educational resources with augmented reality for educational activities in STEM disciplines).

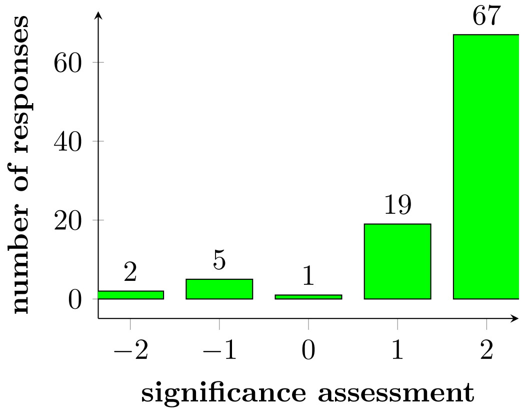

Figure 18. Distribution of significance assessment for condition 14 (Acquisition practical experience in the application of augmented reality technologies in teaching STEM disciplines).

of digital educational resources with augmented reality.). 5.3% of the respondents consider the introduction of a special course on the development of digital educational resources with augmented reality in the content of training of future STEM teachers to be insignificant, 9.6% have not decided on the answer, and 85.1% of respondents consider the inclusion of a special course on the development of digital educational resources with augmented reality in the content of training of future STEM teachers to be significant.

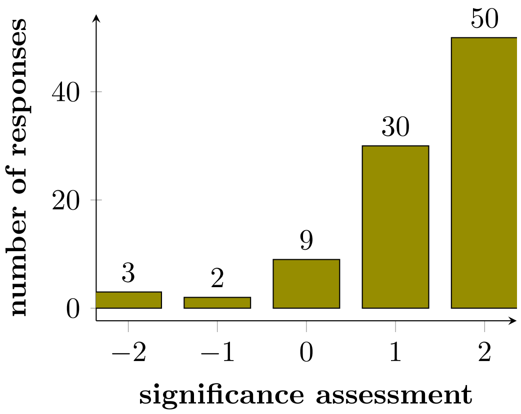

Figure 19. Distribution of significance assessment for condition 15 (Imposition to the content of the training of future STEM teachers, issues related to the use of augmented reality in teaching STEM disciplines).

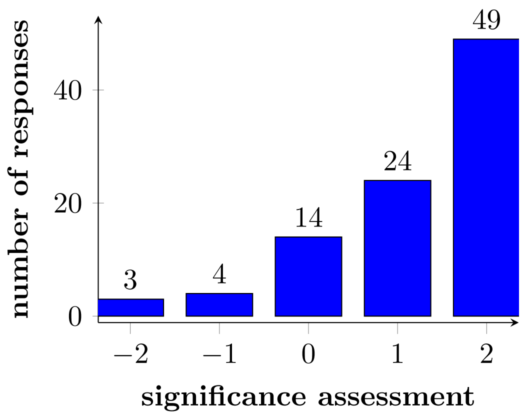

Figure 20. Distribution of significance assessment for condition 16 (Imposition to the content of the training of future STEM teachers of the special course on the development of digital educational resources with augmented reality).

Figure 21 shows the condition 17 significance assessment distribution (Creation of a cloud-based educational and methodological complex for the digital educational resources development with the augmented reality for future STEM teachers). 7.5% of the respondents consider the creation of a cloud-oriented educational and methodological complex for the development of digital educational resources with augmented reality for future STEM disciplines teachers insignificant, 13.8% have not decided on the answer, and 77.8% of respondents consider the creation of a cloud-oriented educational and methodological complex for the development of digital educational resources with augmented reality for future STEM disciplines teachers significant.

Figure 22 shows the condition 18 significance assessment distribution (Engaging students in the contests on the development of digital educational resources with augmented reality). 7.5% of respondents consider the involvement of students in competitions for the development of digital educational resources with augmented reality insignificant, 16% have not decided on the answer, and 76.6% of respondents consider the involvement of students in competitions for the development of digital educational resources with augmented reality significant.

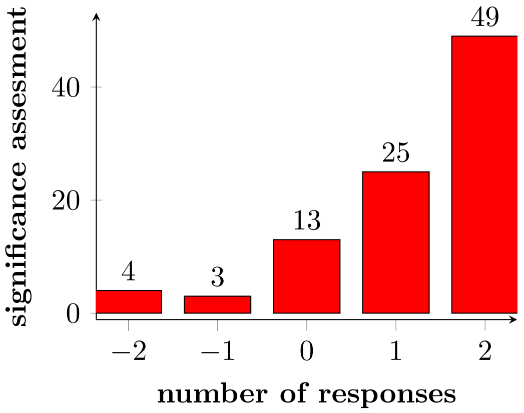

Figure 21. Distribution of significance assessment of condition 17 (Creation of a cloud-based educational and methodological complex for the digital educational resources development with the augmented reality for future STEM teachers).

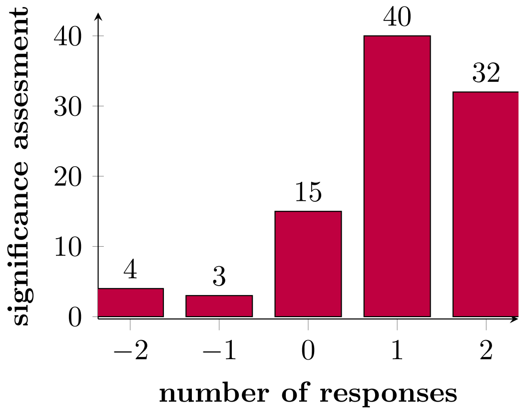

Figure 22. Distribution of significance assessment of condition 18 (Engaging students in the contests on the development of digital educational resources with augmented reality).

Figure 23 shows the condition 19 significance assessment distribution (Positive motivation to use augmented reality technologies in teaching STEM disciplines) 6.4% of respondents believe that the positive motivation to use augmented reality technologies in teaching STEM disciplines is insignificant, 10.6% have not decided on the answer, and 83.0% of respondents believe that positive motivation to use augmented reality technologies in teaching STEM disciplines is significant.

Figure 24 shows the condition 20 significance assessment distribution (Maintaining an educational website, blog, channel for STEM teachers on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc.) 10.6% of respondents consider maintaining an educational website, blog, channel for teachers of STEM disciplines on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc. to be insignificant, 21.3% have not decided on the answer, and 68.1% of respondents consider maintaining an educational website, blog, channel for teachers of STEM disciplines on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc. to be significant.

The following values were calculated for each condition in table 1:

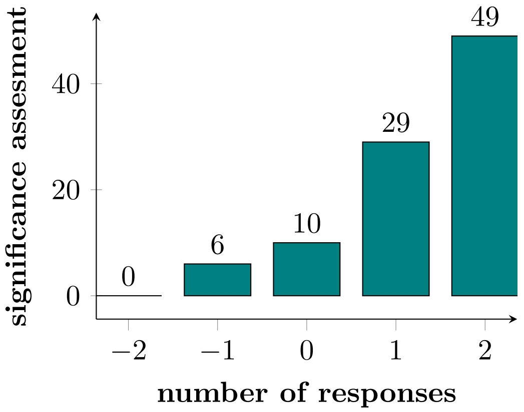

Figure 23. Distribution of significance assessment of condition 19 (Positive motivation to use augmented reality technologies in teaching STEM disciplines).

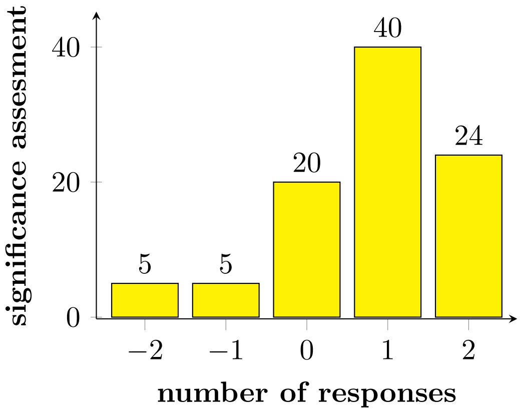

Figure 24. Distribution of significance assessment of condition 20 (Maintaining an educational website, blog, channel for STEM teachers on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc.)

- $AVG_k = \frac{1}{n}\sum_{i=1}^{n} S_k^i$ – average significance assessment of pedagogical condition without taking into account the weight of answers, where $k = \overline{1,20}$ – is the number of the evaluated pedagogical condition, $n = 94$ – number of respondents, $i = \overline{1,n}$ – number of the answer, S_k^i–is the significance assessment of the k-th condition by the i-th respondent;
- $WAVG_k = \frac{1}{n}\sum_{i=1}^{n} W^i S_k^i$ – average significance assessment of pedagogical condition with taking into account the weight of answers, where $k = \overline{1,20}$ is the number of the evaluated pedagogical condition, $n = 94$ – number of respondents, $i = \overline{1,n}$ – number of the answer, W^i – weight of the i-th answer (according to formula (1)), S_k^i – is the significance assessment of the k-th condition by the i-th respondent.

Table 1: Selection of pedagogical conditions.

Condition	AVG	WAVG	Experts pay more attention	Experts pay less attention	Selection by AVG	Selection by WAVG
Availability of equipped classrooms in higher education institutions (immersive labs, lecture halls with virtual and augmented reality)	1.234	1.198		*	0	0

Continued from Table 1

Condition	AVG	WAVG	Experts pay more attention	Experts pay less attention	Selection by AVG	Selection by WAVG
Availability of mobile (handheld, portable, partially energy-dependent) augmented reality devices: laptops, tablets, smartphones, augmented reality glasses etc.	1.489	1.498	+		**1**	**1**
Availability of subject-specific (computer science, physics, mathematics, chemistry, biology, technology, etc.) digital educational resources with augmented reality, specially designed for future STEM teachers	1.319	1.314		*	**1**	0
Availability of interdisciplinary (transdisciplinary) digital educational resources with augmented reality, specially developed for future STEM teachers	1.266	1.261		*	0	0
Availability of digital educational resources with augmented reality for the future STEM teachers' psychological and pedagogical training	1.000	0.998		*	0	0
Application of interactive technologies in the training of future STEM teachers	1.394	1.394	+		**1**	**1**
The use of research and project methods in the training	1.362	1.454	+		**1**	**1**
Engaging students in adaptation, development, testing and implementation of digital educational resources with augmented reality	1.149	1.179	+		0	0
Organization of pedagogical practice using augmented reality technologies	1.043	1.019		*	0	0
Organization of independent work using augmented reality technologies	1.011	1.012	+		0	0
Organization of distance learning using augmented reality technologies	0.947	0.940		*	0	0
Application of learning management systems	0.926	1.007	+		0	0
Selection, adjustment, adaptation, etc. of digital educational resources with augmented reality for educational activities in STEM disciplines	1.202	1.205	+		0	0
Acquisition practical experience in the application of augmented reality technologies in teaching STEM disciplines	1.532	1.551	+		**1**	**1**
Imposition to the content of the training of future STEM teachers, issues related to the use of augmented reality in teaching STEM disciplines	1.298	1.338	+		0	**1**

Continued from Table 1

Condition	AVG	WAVG	Experts pay more attention	Experts pay less attention	Selection by AVG	Selection by WAVG
Imposition to the content of the training of future STEM teachers of the special course on the development of digital educational resources with augmented reality	1.191	1.242	+		0	0
Creation of a cloud-based educational and methodological complex for the digital educational resources development with the augmented reality for future STEM teachers	1.191	1.200	+		0	0
Engaging students in the contests on the development of digital educational resources with augmented reality	0.989	1.048	+		0	0
Positive motivation to use augmented reality technologies in teaching STEM disciplines	1.287	1.309	+		0	0
Maintaining an educational website, blog, channel for STEM teachers on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc.	0.777	0.831	+		0	0
	1.180	1.200				
	1.298	1.320				

The weighted average value of $WAVG_k$, unlike AVG_k, reflects the opinion of the specialists to whom STEM discipline teachers who actively use augmented reality technologies in their professional activities are referred. Therefore, if the value of $WAVG_k > AVG_k$, for the k-th pedagogical condition, then the column "Specialists pay more attention" was entered as "+", otherwise the column "Specialists pay less attention" was entered as "*".

Further calculations were made $TAVG = \frac{1}{20}\sum_{k=1}^{20} AVG_k = 1.180$ – average value AVG for all conditions and $TWAVG = \frac{1}{20}\sum_{k=1}^{20} WAVG_k = 1.200$ – is the average $WAVG$ value for all conditions. The values obtained were the starting point for selecting pedagogical conditions by the conventional (AVG) and weighted ($WAVG$) mean significance values.

If take these values as thresholds (i.e. compare the each condition's significance level with them – if it is less than the threshold, the condition is discarded (0), otherwise the condition is accepted (1)), then there are 12 conditions selected for AVG (1, 2, 3, 4, 6, 7, 13, 14, 15, 16, 17, 19), and 11 for $WAVG$ (the same as for AVG, except 1). This number of conditions is excessive, so an empirically sampled multiplier (1.1) was introduced and applied to $TAVG$ and $TWAVG$, giving such limit values $1.1TAVG = 1.298$ and $1.1TWAVG = 1.320$ "Selection by AVG" and "Selection by WAVG" (1 – condition sampled, 0 – condition not sampled).

Conditions 2, 6, 7, and 14 are selected for AVG and $WAVG$ at the same time. Condition 15, selected only at $WAVG$, is of great significance for specialists, and condition 3, selected only at AVG, is of significance for the general public:

- 2, 3 – conditions related to the the educational process material support;
- 6, 7 – methods, forms of future STEM disciplines teachers training to apply augmented reality technologies;
- 14 – real situations concerning the best practices of augmented reality technology application in training;
- 15 – specifically created to achieve the goal of preparing future STEM disciplines teachers to apply augmented reality technologies in professional activities;
- conditions related to psychological and pedagogical support of educational process participants are not selected.

5. Conclusions
Thus, after combining, we obtain the following *pedagogical conditions for training STEM teachers to use augmented reality technologies in their work*:

(i) Availability of mobile augmented reality hardware (laptops, tablets, smartphones, augmented reality glasses, etc.) and immersive digital educational resources for future STEM disciplines teachers.
(ii) Supplementing the learning content with topics related to the use of augmented reality in teaching STEM disciplines.
(iii) Application of research approach and interactive technologies in training future STEM disciplines teachers.
(iv) Acquisition of augmented reality technology application practical experience in STEM disciplines training.

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Appendix A. Questionnaire "Conditions for training STEM teachers to use augmented reality technologies in their work"

Dear colleagues!

In order to select conditions for training STEM teachers to use augmented reality technologies in their work, we ask you to evaluate their importance on a 5–point scale (1 – "very insignificant", 2 – "insignificant", 3 – "moderate", 4 – "significant", 5 – "very significant") and provide your recommendations.

Availability of equipped classrooms in higher education institutions (immersive labs, lecture halls with virtual and augmented reality)

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Availability of mobile (handheld, portable, partially energy-dependent) augmented reality devices: laptops, tablets, smartphones, augmented reality glasses etc.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Availability of subject-specific (computer science, physics, mathematics, chemistry, biology, technology, etc.) digital educational resources with augmented reality, specially designed for future STEM teachers.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Availability of interdisciplinary (transdisciplinary) digital educational resources with augmented reality, specially developed for future STEM teachers.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Availability of digital educational resources with augmented reality for the future STEM teachers' psychological and pedagogical training.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Application of interactive technologies in the training of future STEM teachers.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

The use of research and project methods in the training.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Engaging students in adaptation, development, testing and implementation of digital educational resources with augmented reality.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Organization of pedagogical practice using augmented reality technologies.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Organization of independent work using augmented reality technologies.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Organization of distance learning using augmented reality technologies.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Application of learning management systems.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Selection, adjustment, adaptation, etc. of digital educational resources with augmented reality for educational activities in STEM disciplines.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Acquisition practical experience in the application of augmented reality technologies in teaching STEM disciplines.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Imposition to the content of the training of future STEM teachers, issues related to the use of augmented reality in teaching STEM disciplines.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Imposition to the content of the training of future STEM teachers of the special course on the development of digital educational resources with augmented reality.

very insignificant ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 very significant

Creation of a cloud-based educational and methodological complex for the digital educational resources development with the augmented reality for future STEM teachers.

very insignificant ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 very significant

Engaging students in the contests on the development of digital educational resources with augmented reality.

very insignificant ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 very significant

Positive motivation to use augmented reality technologies in teaching STEM disciplines.

very insignificant ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 very significant

Maintaining an educational website, blog, channel for STEM teachers on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc.

very insignificant ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 very significant

What conditions for training STEM teachers to use augmented reality technologies in their work would you suggest?

[optional field for entering your own answer]

Your position

- student
- teacher
- research associate
- HEI Professors

Are you a STEM disciplines teacher?

- yes
- no

Specify your work experience

- up to 3 years
- up to 5 years
- 5-10 years
- 11-15 years
- 16-20 years
- 21-30 years
- 31-40 years
- 41-50 years
- more than 50 years

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Evaluate augmented reality in your own professional activity level

- I don't apply
- I apply ready-made means of augmented reality
- I can elaborate my own means of augmented reality
- other – the possibility of entering your own answer

If you want to follow the development of this research, specify your e-mail address

[optional field for entering your own answer]

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