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Assessment and Development of STEAM Competences of Pre-service and In-service Teachers: Selected Aspects

Abstract
The subject and objectives of the research are conditioned by the topicality of STEAM education and the need for STEAM competences, the integration of science basics, the formation of competences in pre-service teachers and students, the instruction of the scientific method in teaching, the study of STEAM teaching methods, the dynamically developing digital society, gaps in the job market for IT specialists. Adequate hypotheses were developed. The study utilized various research methodologies, such as a review of existing literature, specific experimental studies, and the creation of research instruments like a questionnaire and a self-assessment for STEAM competencies based on the Likert scale from 1 to 5. The participants comprised pedagogy students from the University of Silesia in Poland (US) and Borys Grinchenko Kyiv University in Ukraine (BGKU), along with

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both pre-service and in-service teachers. The findings present key research outcomes and offer recommendations for higher education institutions and pre-service teachers.

Keywords:
digital tools, aspiring teachers, practicing teachers, STEAM competences, survey

1. INTRODUCTION

STEAM education integrates Science, Technology, Engineering, Art, and Mathematics into student instruction. Evidence suggests this method fosters critical thinking, problem-solving abilities, teamwork, creativity, and a willingness to take risks in students. The European Commission recommends that STEM competence should be expanded to include communication in foreign languages, cultural, and social competences (EU Skills Panorama, 2014). To develop STEAM competence, educators must be proficient in foreign languages, which will enable them to access open electronic resources on the internet, communicate effectively and collaborate globally (Kozan et al., 2023). A conceptual model for teaching practices in integrated STEM at the secondary level has been developed, grounded in five fundamental principles: the integration of STEM disciplines, learning centered around problems, inquiry-driven learning, learning through design, and collaborative learning. These guiding principles are anchored in the social constructivist theory of learning.

2. BACKGROUND OF RESEARCH

The integration of STEAM (Science, Technology, Engineering, Arts, and Mathematics) education into the curriculum has become increasingly important in recent years due to the growing need for students to acquire critical thinking, problem-solving, and computational thinking skills. In this article, we highlight some of the most interesting and innovative research in the field of STEAM education, computational thinking, and the use of applications and software in teaching.

One study published in the Journal of Educational Computing Research examined the effectiveness of using game-based learning to teach computational thinking skills to middle school students. The study found that game-based learning significantly improved students' computational thinking abilities compared to traditional classroom instruction (Ketelhut et al., 2015).

Recent research in the field of STEAM education and computational thinking has yielded some interesting findings from various countries around the world. In a study conducted by Li, Gao, & Zhou (2020) in China, it was found that the use of an educational robot helped improve primary school students' computational thinking ability. Similarly, a study conducted by Park and Jang (2020) in South Korea found that students who participated in STEAM education activities showed significant improvements in their problem-solving and critical thinking skills.

In the United States, researchers are exploring the use of mobile apps to enhance STEAM education. A study conducted by Abedi (2023) found that the use of a mobile app that incorporated augmented reality technology helped improve students' understanding of geometric shapes and spatial relationships.

In Europe, researchers are also exploring the use of technology in education. Tomasz Kopczyński (2015) conducted a study in Poland to investigate the effectiveness of STEM education. The study has important implications for education in the STEAM area, as it demonstrates the effectiveness of a constructivist approach to teaching and the use of didactic aids for reinforcing competences. The findings suggest that educators in STEAM fields can benefit from incorporating such aids in their teaching methods to enhance student learning and achievement. The didactic aid used in the study was based on the theory of constructivism, which emphasizes the importance of active learning and the construction of knowledge by the learner. The aid consisted of a set of tasks and exercises designed to reinforce logical and mathematical competencies in students.

STEM and STEAM in contemporary education: challenges, contemporary trends and transformation was analyzed and compared in the international research Basogain et. al. (2020). New technologies in personalization of STEM and STEAM education in international context was described in Glushkova et al. (2022).

2.1. THEORETICAL FOUNDATIONS OF THE RESEARCH

The EU Skills Panorama 2014 defines STEM skills as skills "expected to be possessed by people educated in science, technology, engineering and mathematics at higher education level". These skills were defined as "the ability to produce, understand and analyse empirical data, including arithmetic and critical analysis; understanding of scientific and mathematical principles; the ability to systematically and critically assess complex problems and the ability to implement theoretical knowledge of the subject of problems; ability to convey scientific topics to interested parties and others; creativity, logical reasoning and practical intelligence" (EU Skills Panorama, 2014).

According to Carnevale et al. (2011), skills are competences that allow continuing learning in the field of knowledge. In this context, as seen in Table 1 (Carnevale et al., 2011; p. 8), they grouped STEM competences under three main headings, namely knowledge (e.g. production and processing; computers and electronics; engineering and technology, others), skills (mathematics; science; critical thinking, others), and abilities (problem sensitivity; deductive reasoning; inductive reasoning, others) (Carnevale et al., 2011).

STEAM represents a pedagogical strategy that leverages Science, Technology, Engineering, Art, and Mathematics to steer students towards inquiry, discussion, and critical analysis. This approach cultivates learners who are prepared to embrace risk, engage in experiential learning, tackle problem-solving, collaborate effectively, and navigate the creative process. Such individuals emerge as innovators, educators, leaders, and learners fit for the 21st century (Nagai et. al., 2023).

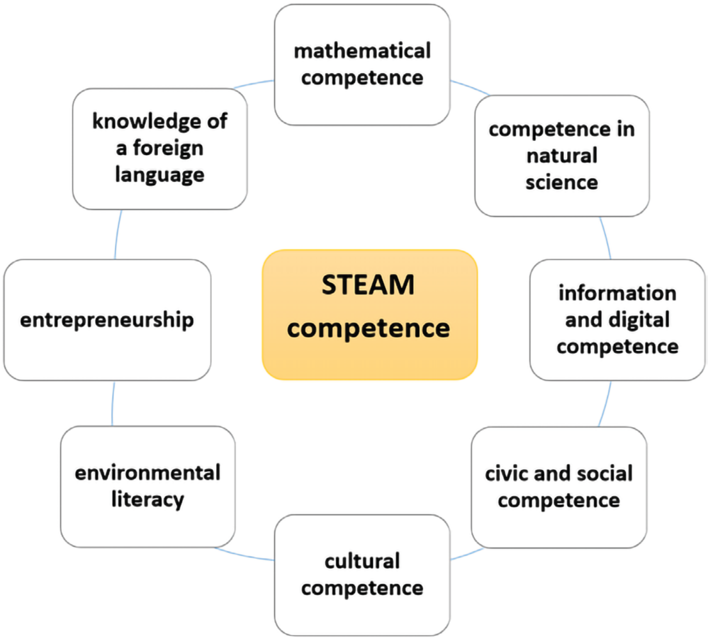
The components of STEAM competence should encompass mathematical competence, competence in natural sciences and technologies, as well as aspects of information and digital competence, and environmental literacy. According to the European Commission's recommendations on the development of scientific education, a shift from STEM competence to STEAM is advised. This implies that STEAM competence can be seen as encompassing all the components of STEM competence, with the addition of foreign language communication skills, cultural competence (awareness and expression in cultural contexts), and social competence.

The researchers in their study (Hrynevych et al., 2020) smartly define the components of STEAM competence (Figure 1).

Foreign language competence is very important for the development of STEAM competence, especially from the point of view of using open electronic resources, which are provided on the Internet in foreign languages and are available in an open space for students and teachers of Ukraine, and effective communication and cooperation in the global world (Hrynevych et al., 2020).

The study by Del Moral Pérez et al. (2023) focused on evaluating the didactic, digital, socio-collaborative, and creative skills of participants as demonstrated in Immersive Literary Environments (ILE), aiming to explore the interplay between digital competence and other related skills. This research integrates STEAM approaches with maker culture by crafting Immersive Literary Environments (ILE) utilizing Augmented Reality (AR) (Del Moral Pérez et al. 2023). Another investigation by Leoste et al. (2022) sought to develop and execute a cost-effective,

Figure 1. Components of STEAM competence



synchronous online training model for early childhood educators. This model facilitates co-design courses centered on STEAM-based learning activities, yielding compelling and motivational findings. Furthermore, Pérez Poch et al. (2022) unveil the intriguing outcomes of a study examining the profiles of attendees in a postgraduate teaching program (15 ECTS) focused on STEAM competencies at a university level. Through qualitative interviews, discussions revolved around their program experiences, future professional aspirations, and the relevance of their unique backgrounds. This research underscores the critical need for enhanced digital skills training in the future (Pérez Poch et al., 2022).

2.2. STEAM TEACHING METHODS

Drawing from the outcomes of the systematic review, a theoretical framework for teaching practices in integrated STEM at the secondary education level was developed. This was achieved by identifying and selecting the five most frequently occurring categories of instructional elements across the reviewed papers (Kozan et al., 2023).

Fan and Yu (2016) contend that the essence of STEM education lies in its ability to encourage students to amalgamate interdisciplinary knowledge, spark their interest in STEM fields, and equip them with the necessary skills for future STEM careers, as well as fostering STEM literacy vital for global citizens in the 21st century. They highlight that successful STEM programs typically share several key characteristics: (1) the application of real-world problems or scenarios; (2) the creation of curricula centered around projects, problems, or inquiries; (3) the establishment of explicit objectives, subject matter, and learning outcomes; (4) the provision of a student-centered learning environment; (5) a focus on the synthesis and integration of STEM disciplines; (6) an emphasis on cultivating advanced cognitive abilities, including logical reasoning, problem-solving, and critical analysis; and (7) a strong linkage between educational content and the job market (Fan & Yu, 2016).

Bybee (2010) proposed that the adoption of STEM as an educational approach could be facilitated by engaging students with challenging tasks or questions, motivating them to apply STEM principles for problem-solving (Bybee, 2010). Moreover, the knowledge gained and skills honed through problem investigation and solution finding can be evaluated against the Common Core Standards or other national competency benchmarks. To support STEM education, researchers have advocated for the use of inquiry-based learning strategies to foster technological advancement, elevate teaching practices to a higher level, and amplify the effectiveness of STEM education (Burke, 2014; Chang & Yang, 2014b; Cheng et al., 2016; Smyrnova-Trybulska et al., 2016, 2017, 2019, 2020). Additionally, the perspectives of teachers and students on employing robots in STEM education for young learners, as well as their views on the role of educational robots in primary education, have been explored in the work of Ye, Shih, & Wang (2022), highlighting the significance and conditions for integrating robotics into STEM learning experiences.

According to the International STEM Education Ranking, Program for International Student Assessment (PISA), Singapore, China and Macau SAR achieved the best results in mathematics, science and problem solving, which may indicate a good quality of STEM education. Europe has also tried to make a difference through action with the PISA test (Auld, Rappleye, & Morris, 2018).

Lin, and Chiang (2019) and Burke (2014) unanimously recommended the adoption of the 6E learning model to improve the effect of STEAM learning. The model is an inquiry-based learning strategy whose main learning procedures include: (1) engagement, (2) exploration, (3) explanation, (4) engineering, (5) enrichment, and (6) evaluation used by Alam (2022).

3. METHODOLOGY AND RESEARCH RESULTS

The subject and objectives of the research are conditioned by the topicality of STEAM education and the need for STEAM competences, the integration of science basics, the formation of competences in pre-service teachers and students, the need for targeted training for future teachers and initial teaching, the instruction of the scientific method in teaching, the study of STEAM teaching methods, the dynamically developing digital society, gaps in the job market for IT specialists. The goal of the article was to investigate attitudes and confidence towards STEAM and awareness of the importance of STEAM issues in the education, development of different kinds of thinking and labour market, as well as the willingness to continue education and development in this direction of university students studying in Poland and Ukraine. The survey was conducted in January and February 2023. Students of the University of Silesia in Katowice, Poland and students of the Borys Grinchenko Kyiv University, Ukraine as well as in-service teachers – were asked to respond. A total of 180 responses were received, 102 of Polish students and 78 Ukrainian students. Some selected results were presented at the ICEDU2023 conference (Morze et al., 2023).

The main Research questions were the following:

RQ1. Is it necessary for teachers to develop STEAM competences according to pre-service and in-service teachers.

RQ2. Is the process of developing STEAM competences the same in primary and secondary school teacher education.

RQ3. What is the degree of importance of the proposed components for shaping teachers' STEAM competences in the opinion of pre-service and in-service teachers?

RQ4. What is the opinion of students and teachers that STEAM education is the basis of 21st century education?

All RQs also include an additional question: What is the opinion of Polish and Ukrainian respondents?

Adequate hypotheses are following:

H1. Developing STEAM competences is necessary for teachers according to the opinion of pre-service and in-service teachers.

H2. The process of developing STEAM competences is the same in the education of primary and secondary school teachers.

H3. The degree of importance of the proposed components for shaping STEAM competences in teachers, in the opinion of future and active teachers and students, is varied (significantly different).

H4. The opinion that STEAM education is the basis of 21st century education in the opinion of students and teachers is similar (3.7), high.

All Hypotheses also include the second part: the opinion of Polish and Ukrainian respondents is similar.

The research examined variables measured on ordinal and nominal scales. To evaluate the differences between variables on the ordinal scale, the Mann-Whitney Test was employed. This analysis utilized two-sided statistical tests with a significance threshold of α = 0.05, conducted in the Dell Inc. (2016) Dell Statistica (data analysis software system), version 13, available at software.dell.com, and Cytel Studio version 11.1.0.

Tables 2–11 show correlation of the chosen variables with the descriptive statistical and comparative analysis.

The Coding (Table 1) was used in statistical analysis.

Table 1. Coding in statistical analysis

Response	Code
Strongly Disagree	101
Disagree	102
Undecided	103
Agree	104
Strongly Agree	105

Tables 2–3 and Figure 2 show correlation of the chosen variables with the descriptive statistical and comparative analysis concerning RQ1 and H1.

Table 2. Descriptive statistics

Variable For specialists of which professions do you consider it necessary to develop STEAM competences?	Aggregate Results Descriptive Statistics (STEAM Poland Ukraine)						
	Country	N valid.	Median	Minimum	Maximum	First Quartile	Third Quartile
3.1.1. [scientists dealing with natural and mathematical sciences]	Poland	102	104	101	105	103	105
3.1.2. [engineers]	Poland	102	104	101	105	104	105
3.1.3. [IT specialists]	Poland	102	104	102	105	104	105
3.1.4. [qualified employees of STEAM professions]	Poland	102	104.5	102	105	104	105

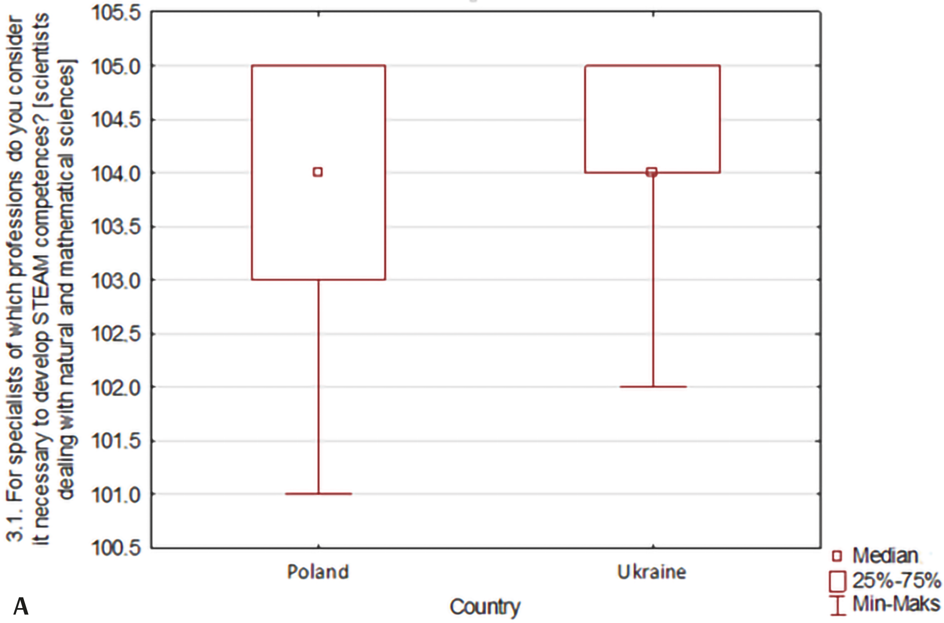
Variable For specialists of which professions do you consider it necessary to develop STEAM competences?	Aggregate Results Descriptive Statistics (STEAM Poland Ukraine)						
	Country	N valid.	Median	Minimum	Maximum	First Quartile	Third Quartile
3.1.5. [primary school teachers]	Poland	102	104	101	105	103	105
3.1.6. [all teachers]	Poland	102	104	101	105	103	104
3.1.1. [scientists dealing with natural and mathematical sciences]	Ukraine	78	104	102	105	104	105
3.1.2. [engineers]	Ukraine	78	105	103	105	104	105
3.1.3. [IT specialists]	Ukraine	78	105	103	105	104	105
3.1.4. [qualified employees of STEAM professions]	Ukraine	78	105	103	105	104	105
3.1.5. [primary school teachers]	Ukraine	78	104	101	105	104	105
3.1.6. [all teachers]	Ukraine	78	104	102	105	104	105

Table 3. Comparative analysis

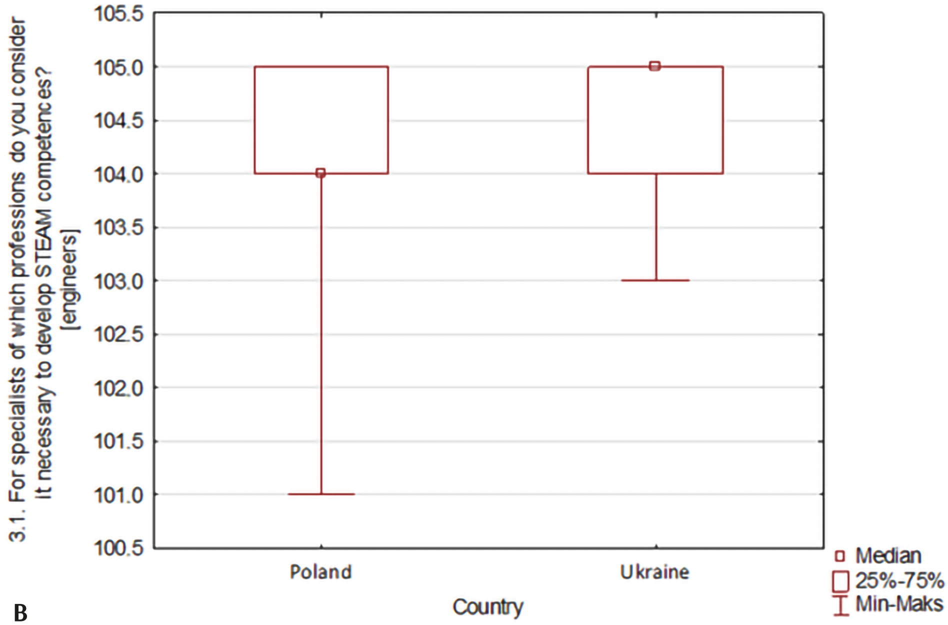
Variable For specialists of which professions do you consider it necessary to develop STEAM competences?	Mann-Whitney U test (continuity corrected) (STEAM Pol Ukraine) Variable: country Marked results are significant with p <.05		
	p	N valid. Poland	N valid. Ukraine
3.1.1. [scientists dealing with natural and mathematical sciences]	0.018	102	78
3.1.2 [engineers]	0.001	102	78
3.1.3 [IT specialists]	0.002	102	78
3.1.4 [qualified employees of STEAM professions]	0.001	102	78
3.1.5 [primary school teachers]	0.053	102	78
3.1.6 [all teachers]	0.003	102	78

RQ1 The Mann Whitney test found a **significant** difference in the parameter: For specialists of which professions do you consider it necessary to develop STEAM competences? In particular, for "scientists dealing with natural and mathematical sciences" $p = 0.018 < 0.05$. We look at the medians and we see that it is similar, but the First Quartile for Ukraine is 104 – according to the code agree, and in Poland the First Quartile is 103, i.e. "Undecided".

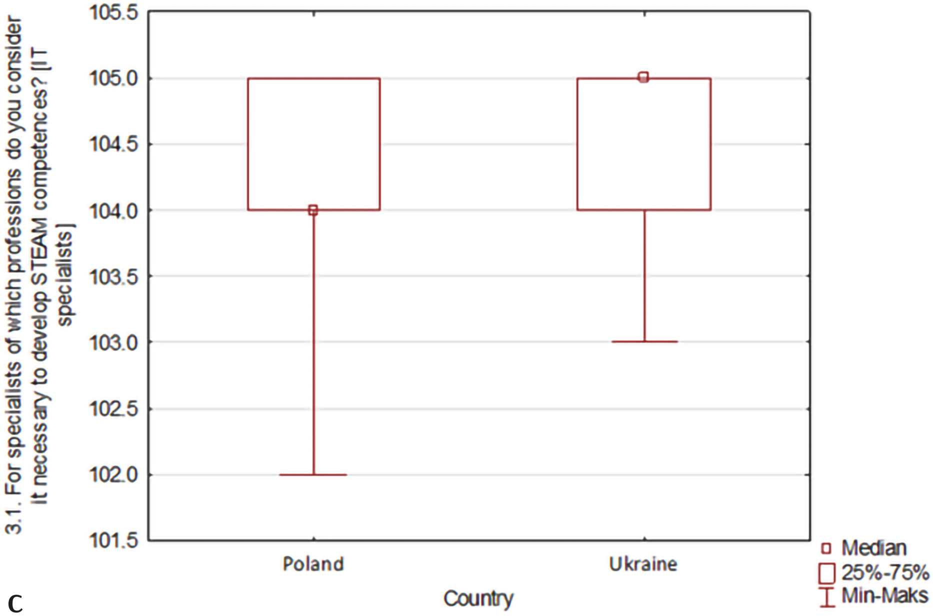
Figure 2. A–F. Comparison of the responses obtained for question "Is it necessary for teachers to develop STEAM competences according to pre-service and in-service teachers. What is the opinion of Polish and Ukrainian respondents?



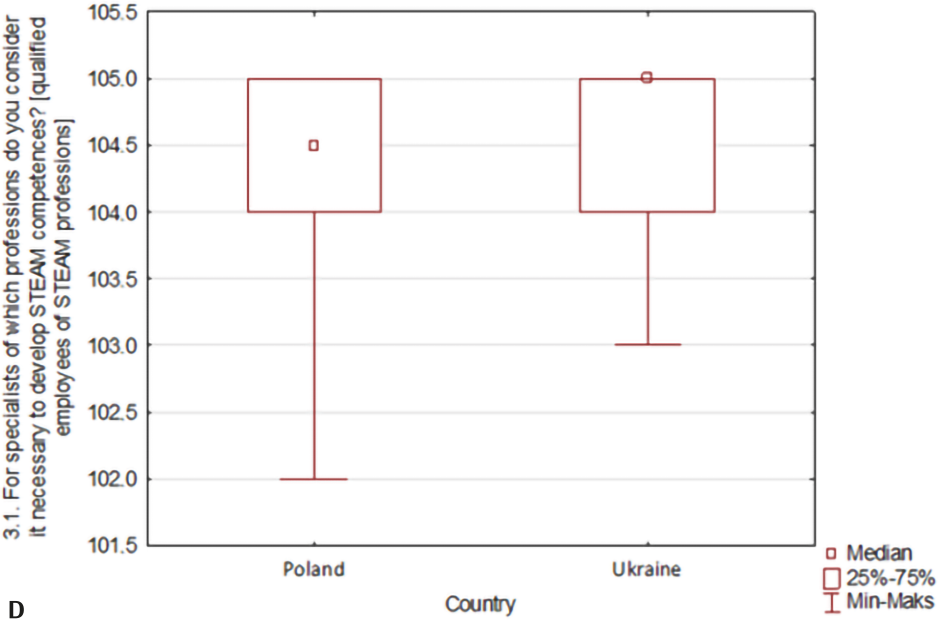
A



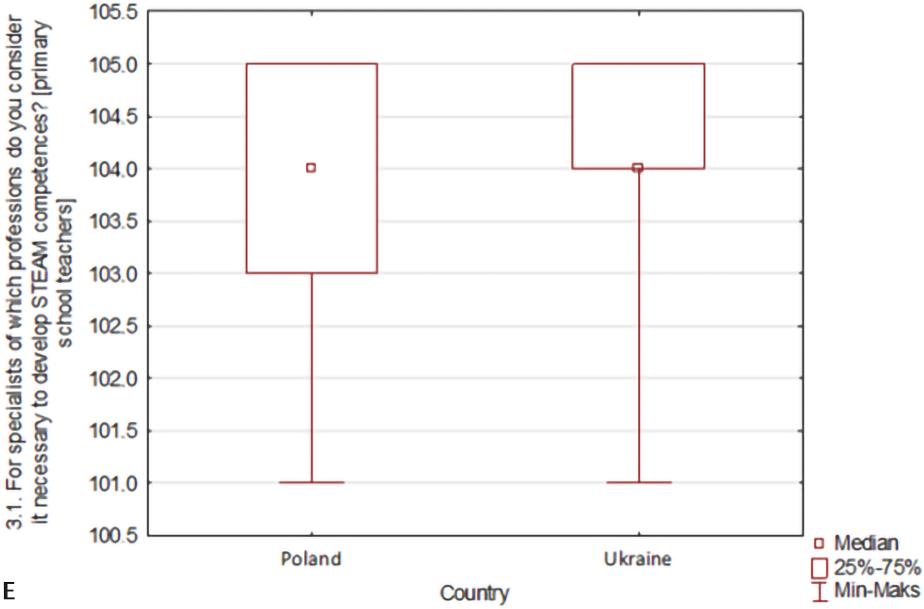
B


3.1. For specialists of which professions do you consider it necessary to develop STEAM competences? [IT specialists]
105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
Poland
Ukraine
Country
Median
25%-75%
Min-Maks

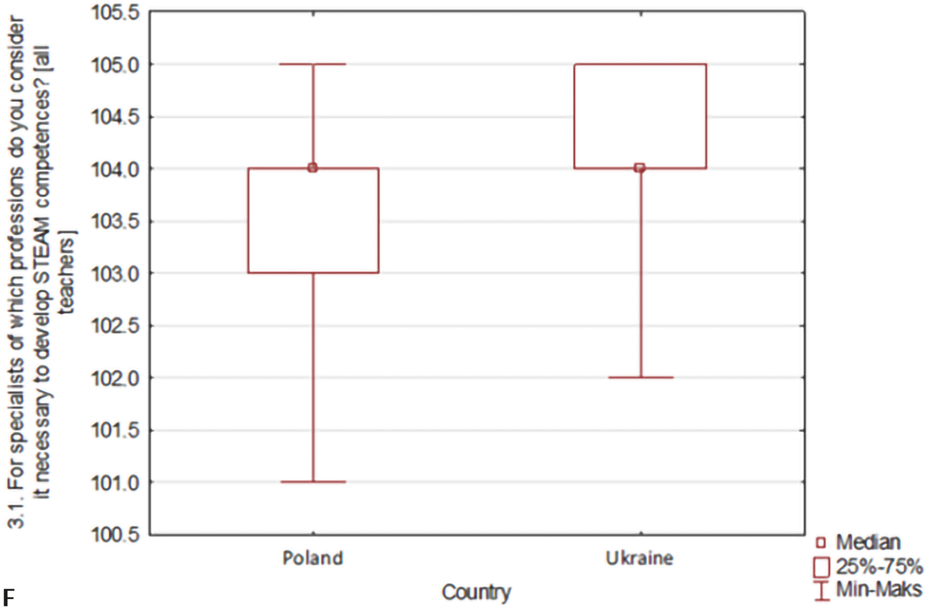
C


3.1. For specialists of which professions do you consider it necessary to develop STEAM competences? [qualified employees of STEAM professions]
105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
Poland
Ukraine
Country
Median
25%-75%
Min-Maks

D


3.1. For specialists of which professions do you consider it necessary to develop STEAM competences? [primary school teachers]
105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0
100.5
Poland
Ukraine
Country
Median
25%-75%
Min-Maks

E


3.1. For specialists of which professions do you consider it necessary to develop STEAM competences? [all teachers]
105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0
100.5
Poland
Ukraine
Country
Median
25%-75%
Min-Maks

F

For “engineers” p = 0.001<0.05. We look at the quartiles and we see that they are similar, but the median for Ukraine is 105 (“Strongly Agree”) and for Poland – 104 – that is, according to the “Agree” code.

For “IT specialists” p = 0.002<0.05. We look at the quartiles and we see that they are similar, but the median for Ukraine is 105 (“Strongly Agree”) and for Poland – 104 – that is, according to the “Agree” code.

For “qualified employees of STEAM professions” p = 0.001<0.05. We look at the quartiles and we see that they are similar 104, but the median for Ukraine is 105 (“Strongly Agree”) and for Poland – 104.5 – that is, according to the “Agree” code.

For primary school teachers, p = **0.053>0.05**. The medians for Poland and Ukraine are partly differ – 104.5 between “Agree” and “Strongly Agree”, and 104 “Agree” for Ukraine. The First Quartile is differ: 103 “Undecided” for Poland and 104 (“Agree”) for Ukraine. Third Quartile for Poland and Ukraine 105 (“Strongly Agree”).

For “all teachers” p = 0.003<0.05. The medians for Poland and Ukraine are similar – 104 “agree”. However, the First quartiles differ: the lower one for Poland is 103 “Undecided”, and for Ukraine 104 “agree”. The Third Quartile for Poland is 104 “agree”, and for Ukraine 105 (“Strongly Agree”). **The Hypothesis H1 was refuted**.

Tables 4–5 show correlation of the chosen variables with the descriptive statistic and comparative analysing concerning RQ2 and H2.

Table 4. Descriptive statistics

Variable	Aggregate Results Descriptive Statistics (STEAM Pol Ukraine)						
	Country	N valid.	Median	Minimum	Maximum	First Quartile	Third Quartile
3.2. Is the process of developing STEAM competences the same in teacher education for primary and secondary schools? [Is the STEAM competency process the same in primary and secondary school teacher	Poland	102	103	101	105	102	104
	Ukraine	78	103	101	105	102	104

RQ2 The Mann-Whitney test did not reveal significant differences in the parameter: *Is the process of developing STEAM competences the same in primary and secondary school teacher the opinion of Polish and Ukrainian respondents?* In particular, p = **0.983>0.05**.

Table 5. Comparative analysis

Variable	Mann-Whitney U test (continuity corrected) (STEAM Pol Ukraine) Variable: country Marked results are significant with p <.05		
	p	N valid. Poland	N valid. Ukraine
3.2. Is the process of developing STEAM competences the same in teacher education for primary and secondary schools? [Is the STEAM competency process the same in primary and secondary school teacher	0.983	102	78

We look at the medians and we see that they are similar – 103 “Undecided”, the First Quartiles for Ukraine and Poland are also similar – 102 “Disagree”, the Third Quartiles are also similar – 104 “Agree”. This suggests that both Polish and Ukrainian respondents have similar attitudes towards the process of developing STEAM competences in primary and secondary school teacher education. Overall, these results provide valuable insights into the attitudes of Polish and Ukrainian respondents towards the process of developing STEAM competences in primary and secondary school teacher education. These findings can inform policy decisions and educational practices in both countries to ensure that STEAM education is effectively integrated into teacher education. **The Hypothesis H2 was confirmed**.

Tables 6–8 and Figure 3 show correlation of the chosen variables with the descriptive statistics and comparative analysis concerning RQ3 and H3.

Table 6. Descriptive statistics

Variable Evaluate the degree of importance of the proposed components for shaping teachers’ STEAM competences:	Aggregate Results Descriptive Statistics (STEAM Pol Ukraine)						
	Country	N valid.	Median	Minimum	Maximum	First Quartile	Third Quartile
3.4.1 [Knowledge in the field of STEAM disciplines]	Poland	102	104	101	105	103	105
3.4.2 [IT (digital) competences.]	Poland	102	104	101	105	104	105
3.4.3 [Research competences]	Poland	102	104	101	105	103	104
3.4.4 [Abilities and inclinations for natural sciences and mathematics]	Poland	102	104	102	105	103	104

Variable Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences:	Aggregate Results Descriptive Statistics (STEAM Pol Ukraine)						
	Country	N valid.	Median	Minimum	Maximum	First Quartile	Third Quartile
3.4.5 [Individual components of "soft skills"]	Poland	102	104	101	105	103	104
3.4.6 [Methodological competences]	Poland	102	104	101	105	103	104
3.4.7 [Social competences]	Poland	102	104	101	105	104	105
3.4.8 [Civic competences]	Poland	102	104	101	105	104	105
3.4.9 [Entrepreneurship]	Poland	102	104	101	105	103	104
3.4.1 [Knowledge in the field of STEAM disciplines]	Ukraine	78	104	102	105	104	105
3.4.2 [IT (digital) competences]	Ukraine	78	105	102	105	104	105
3.4.3 [Research competences]	Ukraine	78	105	102	105	104	105
3.4.4. [Abilities and inclinations for natural sciences and mathematics]	Ukraine	78	104	102	105	104	105
3.4.5 [Individual components of "soft skills"]	Ukraine	78	104	102	105	104	105
3.4.6 [Methodological competences]	Ukraine	78	104	102	105	104	105
3.4.7 [Social competences]	Ukraine	78	104	102	105	104	105
3.4.8 [Civic competences]	Ukraine	78	104	102	105	104	105
3.4.9 [Entrepreneurship]	Ukraine	78	104	102	105	104	105

Table 7. Comparative analysis

Variable Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences:	Mann-Whitney U test (continuity corrected) (STEAM Pol Ukraine) Variable: country Marked results are significant with p <.05000		
	p	N valid. Poland	N valid. Ukraine
3.4.1 [Knowledge in the field of STEAM disciplines]	0.005	102	78
3.4.2 [IT (digital) competences.]	0.006	102	78
3.4.3 [Research competences]	0.000	102	78
3.4.4 [Abilities and inclinations for natural sciences and mathematics]	0.007	102	78
3.4.5 [Individual components of "soft skills"]	0.000	102	78

Variable Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences:	Mann-Whitney U test (continuity corrected) (STEAM Pol Ukraine) Variable: country Marked results are significant with p <.05000		
	p	N valid. Poland	N valid. Ukraine
3.4.6 [Methodological competences]	0.018	102	78
3.4.7 [Social competences]	0.025	102	78
3.4.8 [Civic competences]	0.000	102	78
3.4.9 [Entrepreneurship]	0.091	102	78

Table 8. Descriptive statistics

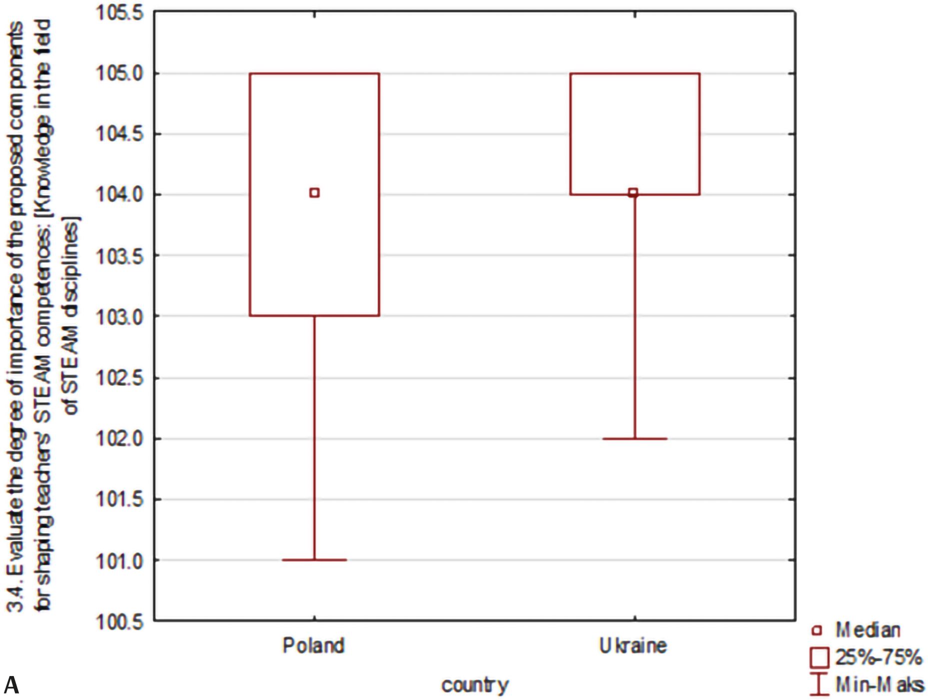
	3.4.1. Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences: [Knowledge in the field of STEAM disciplines]					
Country	**N**	**Median**	**Minimum**	**Maximum**	**First quartile**	**Third quartile**
PL	102	104	101	105	103	105
UA	78	104	102	105	104	105
	3.4.2. Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences: [IT (digital) competences.]					
Country	**N**	**Median**	**Minimum**	**Maximum**	**First quartile**	**Third quartile**
PL	102	104	101	105	104	105
UA	78	105	102	105	104	105
	3.4.3. Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences: [Research competences]					
Country	**N**	**Median**	**Minimum**	**Maximum**	**First quartile**	**Third quartile**
PL	102	104	101	105	103	104
UA	78	105	102	105	104	105
	3.4.4. Evaluate the degree of importance of the proposed components for shaping STEAM competences in teachers: [Abilities and inclinations for natural sciences and mathematics]					
Country	**N**	**Median**	**Minimum**	**Maximum**	**First quartile**	**Third quartile**
PL	102	104	102	105	103	104
UA	78	104	102	105	104	105
	3.4.5. Evaluate the degree of importance of the proposed components for shaping STEAM competences in teachers: [Individual components of "soft skills"]					
Country	**N**	**Median**	**Minimum**	**Maximum**	**First quartile**	**Third quartile**
PL	102	104	101	105	103	104
UA	78	104	102	105	104	105
	3.4.6. Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences: [Methodological competences]					
Country	**N**	**Median**	**Minimum**	**Maximum**	**First quartile**	**Third quartile**
PL	102	104	101	105	104	105
UA	78	104	102	105	104	105

	3.4.7. Evaluate the degree of importance of the proposed components for shaping STEAM competences in teachers: [Social competences]					
Country	**N**	**Median**	**Minimum**	**Maximum**	**First quartile**	**Third quartile**
PL	102	104	101	105	104	105
UA	78	104	102	105	104	105

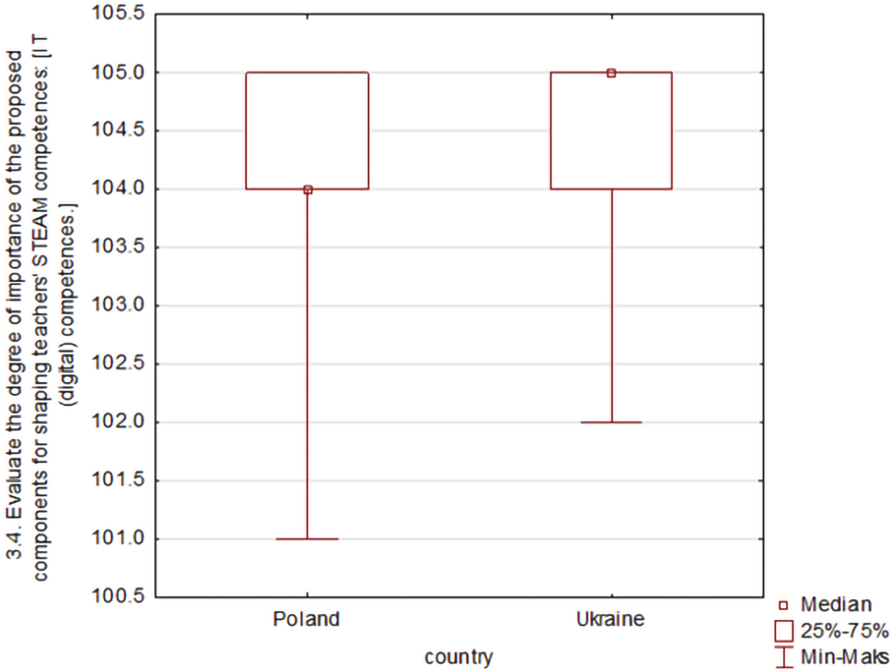
	3.4.8. Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences: [Civic competences]					
Country	**N**	**Median**	**Minimum**	**Maximum**	**First quartile**	**Third quartile**
PL	102	104	101	105	104	105
UA	78	104	102	105	104	105

	3.4.9. Evaluate the degree of importance of the proposed components for shaping STEAM competences in teachers: [Entrepreneurship]					
Country	**N**	**Median**	**Minimum**	**Maximum**	**First quartile**	**Third quartile**
PL	102	104	101	105	103	105
UA	78	104	102	105	104	105

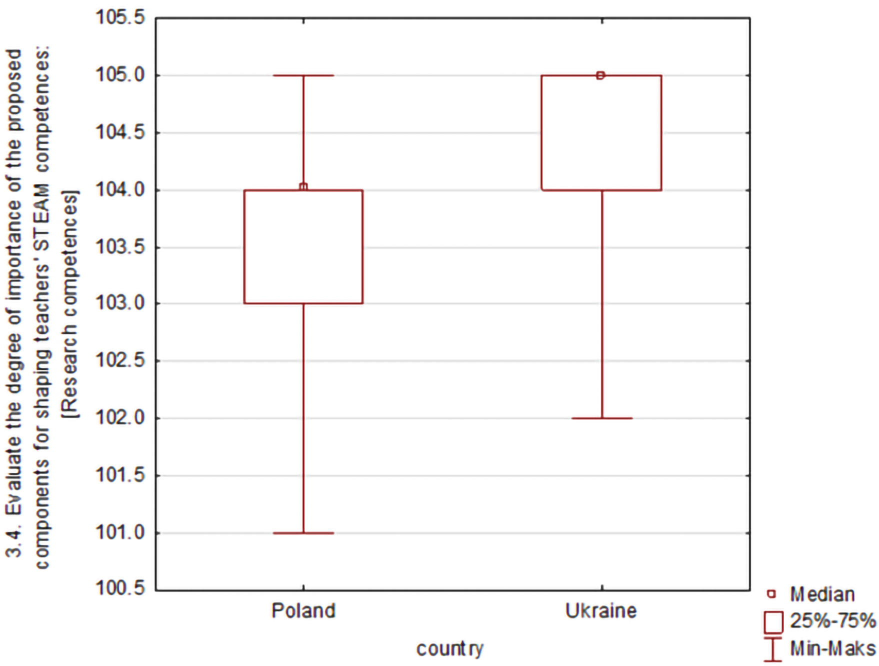
Figure 3. A–I. Comparison of the responses obtained for question "For specialists of which professions do you consider it necessary to develop STEAM competences? (RQ3)



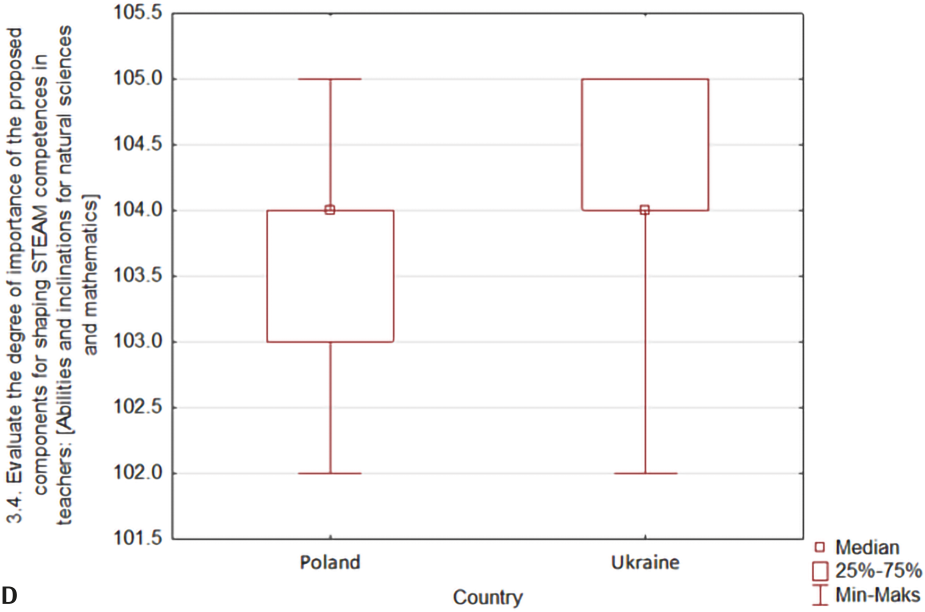
A


105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0
100.5
3.4. Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences: [IT (digital) competences.]
Poland
Ukraine
country
Median
25%-75%
Min-Maks

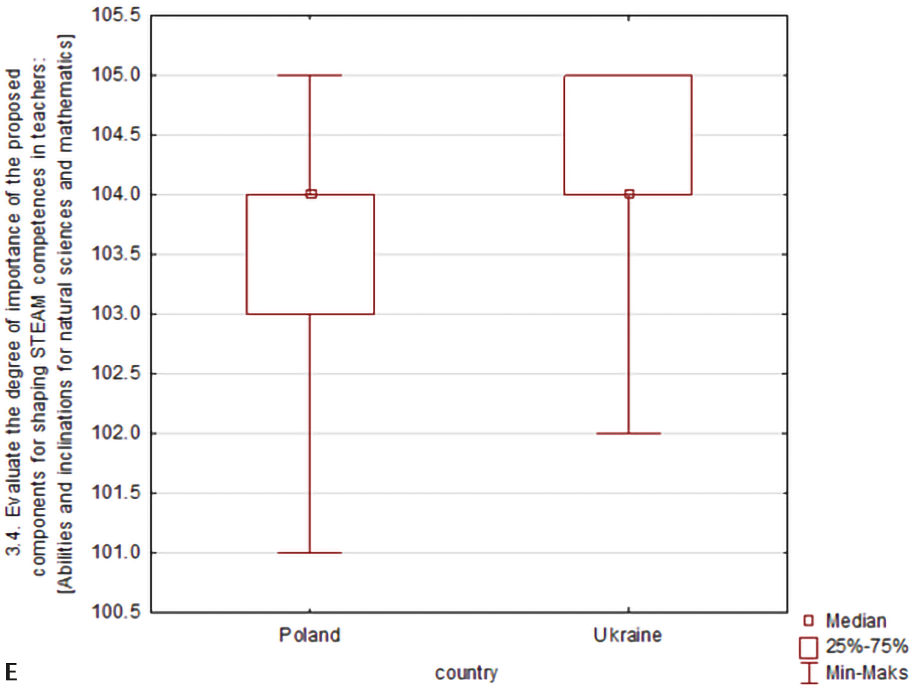
B


105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0
100.5
3.4. Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences: [Research competences]
Poland
Ukraine
country
Median
25%-75%
Min-Maks

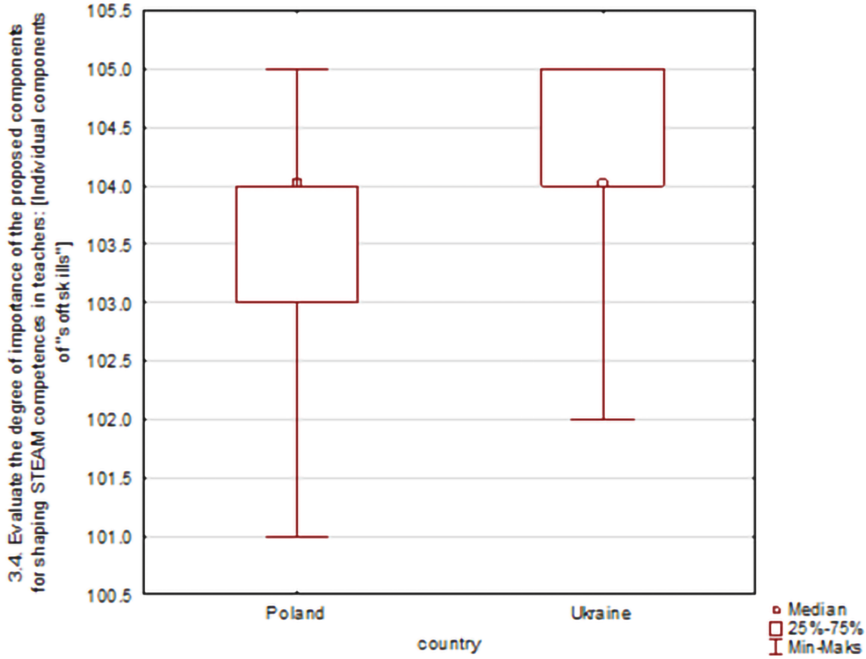
C


3.4. Evaluate the degree of importance of the proposed components for shaping STEAM competences in teachers: [Abilities and inclinations for natural sciences and mathematics]
105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
Poland
Ukraine
Country
Median
25%-75%
Min-Maks

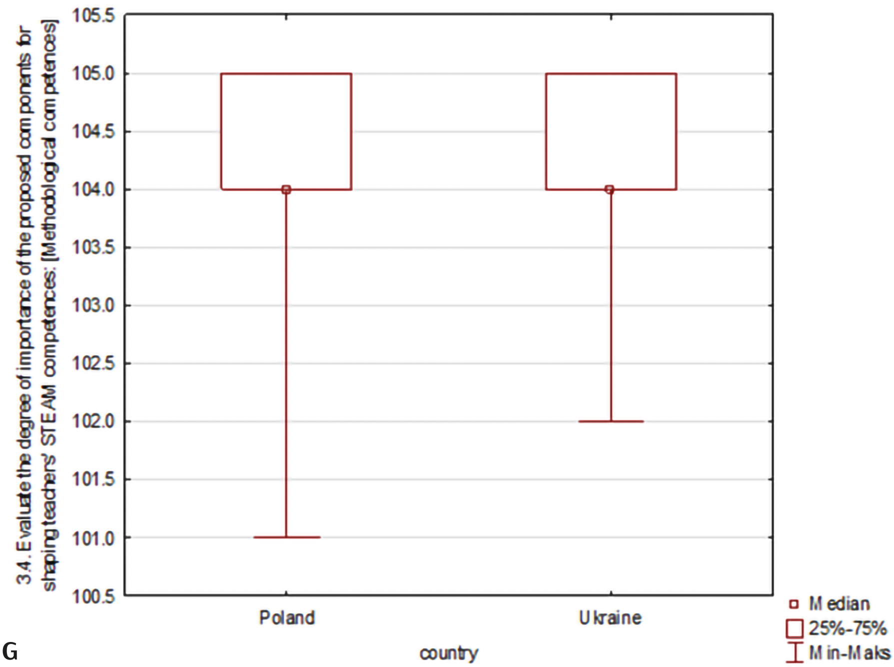
D


3.4. Evaluate the degree of importance of the proposed components for shaping STEAM competences in teachers: [Abilities and inclinations for natural sciences and mathematics]
105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0
100.5
Poland
Ukraine
country
Median
25%-75%
Min-Maks

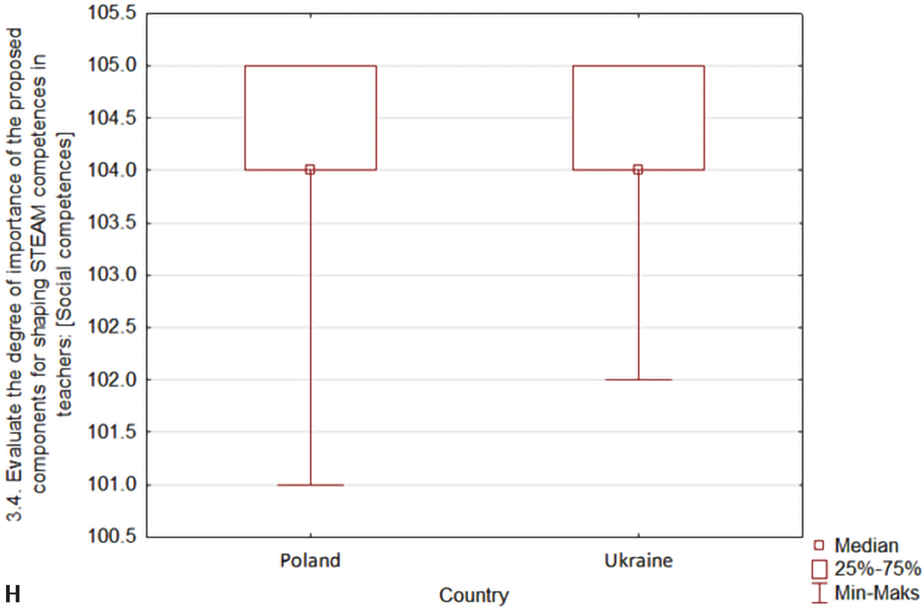
E


3.4. Evaluate the degree of importance of the proposed components for shaping STEAM competences in teachers: [Individual components of "soft skills"]
105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0
100.5
Poland
Ukraine
country
Median
25%-75%
Min-Maks

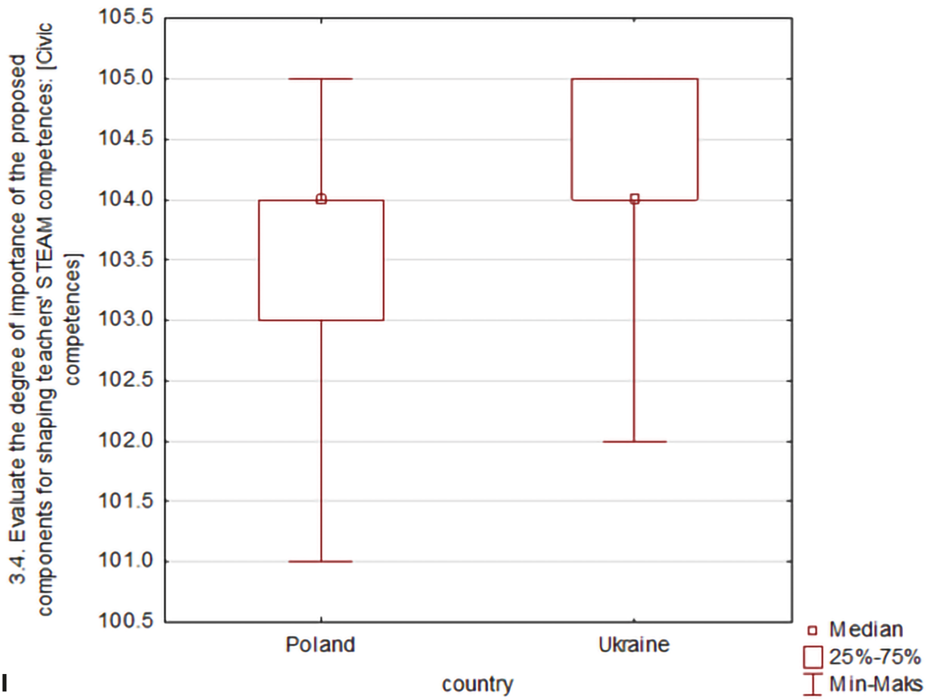
F


3.4. Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences: [Methodological competences]
105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0
100.5
Poland
Ukraine
country
Median
25%-75%
Min-Maks

G


105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0
100.5
3.4. Evaluate the degree of importance of the proposed components for shaping STEAM competences in teachers: [Social competences]
Poland
Ukraine
Country
Median
25%-75%
Min-Maks

H


105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0
100.5
3.4. Evaluate the degree of importance of the proposed components for shaping teachers' STEAM competences: [Civic competences]
Poland
Ukraine
country
Median
25%-75%
Min-Maks

I

RQ3 The Mann Whitney test found a **significant difference** in the parameter: For specialists of which professions do you consider it necessary to develop STEAM competences? For most sub questions: 8 out of 9 showed a **significant difference**.

For “Knowledge in the field of STEAM disciplines” $p = 0.005 < 0.05$. We observe that the medians are similar; both Ukraine and Poland have a median of 104, indicated by the code “Agree”. However, there are differences in the first quartiles: in Ukraine, it is 104 (“Agree”), while in Poland, it is 103 (“Undecided”). The third quartiles are similar, both standing at 105 (“Strongly Agree”).

For “IT (digital) competences,” $p = 0.006 < 0.05$. Upon examining the quartiles, we observe their similarity. However, the median for Ukraine is 105 (“Strongly Agree”), while for Poland, it is 104, corresponding to the “Agree” code.

For “Research competences,” $p = 0.000 < 0.05$. Notably, the medians and quartiles exhibit differences between Ukraine and Poland. In Ukraine, the median is 105 (“Strongly Agree”), whereas in Poland, it is 104, corresponding to the “Agree” code. The first quartile for Ukraine is 104 (“Agree”), while for Poland, it is 103, denoted by the “Undecided” code. Similarly, the third quartile for Ukraine is 105 (“Strongly Agree”), whereas for Poland, it is 104, following the “Agree” code.

For “Abilities and inclinations for natural sciences and mathematics,” $p = 0.007 < 0.05$. Examining the data, we find that the medians are similar for both Ukraine and Poland, both at 104 according to the “Agree” code. However, differences arise in the first quartile, where Ukraine is at 104 (“Agree”) and Poland at 103 (“Undecided”). Similarly, in the third quartile, Ukraine registers 105 (“Strongly Agree”), while Poland reports 104, following the “Agree” code.

For individual components of “soft skills’, $p = 0.000 < 0.05$. Examining the medians, we find similarities between Ukraine and Poland, both at 104 according to the “Agree” code. However, variations emerge in the first quartile, where Ukraine is at 104 (“Agree”) and Poland at 103 (“Undecided”). In the third quartile, Ukraine reports 105 (“Strongly Agree”), while Poland records 104, following the “Agree” code.

For “Methodological competencies,” $p = 0.018 < 0.05$. The medians for Poland and Ukraine are similar, both at 104 (“Agree”). Additionally, the quartiles are equal, with Poland’s first quartile at 103 (“Undecided”) and Ukraine’s at 104 (“Agree”). The third quartile for both Poland and Ukraine is 104 (“Agree”), while the third quartile for both Ukraine and Poland is 105 (“Strongly Agree”).

For “Social competences,” p = 0.025<0.05. Observing the medians, we find similarities between Ukraine and Poland. However, distinctions emerge in the first quartile, where Ukraine is at 104 (“Agree”) and Poland at 103 (“Undecided”). Meanwhile, the third quartile for both Ukraine and Poland is similar and equal, standing at 105 (“Strongly Agree”).

For “Civic competences,” p = 0.000<0.05. Examining the medians, we observe similarities between Ukraine and Poland. However, differences arise in the first quartile, where Ukraine is at 104 (“Agree”), while Poland is at 103 (“Undecided”). In the third quartile, Ukraine reports 105 (“Strongly Agree”), while Poland records 104, according to the “Agree” code.

For “Entrepreneurship,” **p = 0.091>0.05**. Examining the medians, we observe similarities; both Ukraine and Poland have a median of 104 (“Agree”). However, differences emerge in the first quartile, where Ukraine is at 104 (“Agree”), while Poland is at 103 (“Undecided”). In contrast, the third quartile for both Ukraine and Poland is similar and equals 105 (“Strongly Agree”).

The Mann-Whitney U test (continuity corrected) was conducted for the STEAM (Poland and Ukraine) variable: country. Marked results are considered significant with p<0.05. For **RQ3** and its sub-questions 3.4.1, 3.4.2, 3.4.3, 3.4.4, 3.4.5, 3.4.6 3.4.7, 3.4.8, p<0.05, **H3 (1–8)** has been **refuted**. For **RQ3** and sub-question 3.4.9, **H3** has been **confirmed**.

The study examined nine sub-questions, and eight of them showed significant differences. For instance, the study found a significant difference between Poland and Ukraine regarding knowledge in the field of STEAM disciplines, IT (digital) competences, research competences, abilities and inclinations for natural sciences and mathematics, individual components of soft skills, methodological competencies, social competences, and civic competences.

Tables 9–11 and Figure 4 show a correlation of the chosen variables with the descriptive statistics and comparative analysis concerning RQ4 and H4.

Table 9. Descriptive statistics

Variable	Aggregate Results Descriptive Statistics (STEAM Pol Ukraine)						
	Country	**N valid.**	**Median**	**Minimum**	**Maximum**	**First Quartile**	**Third Quartile**
3.7. Do you think STEAM education is the foundation of 21st century education?	Poland	102	104	101	105	103	105
	Ukraine	78	104	101	105	104	105

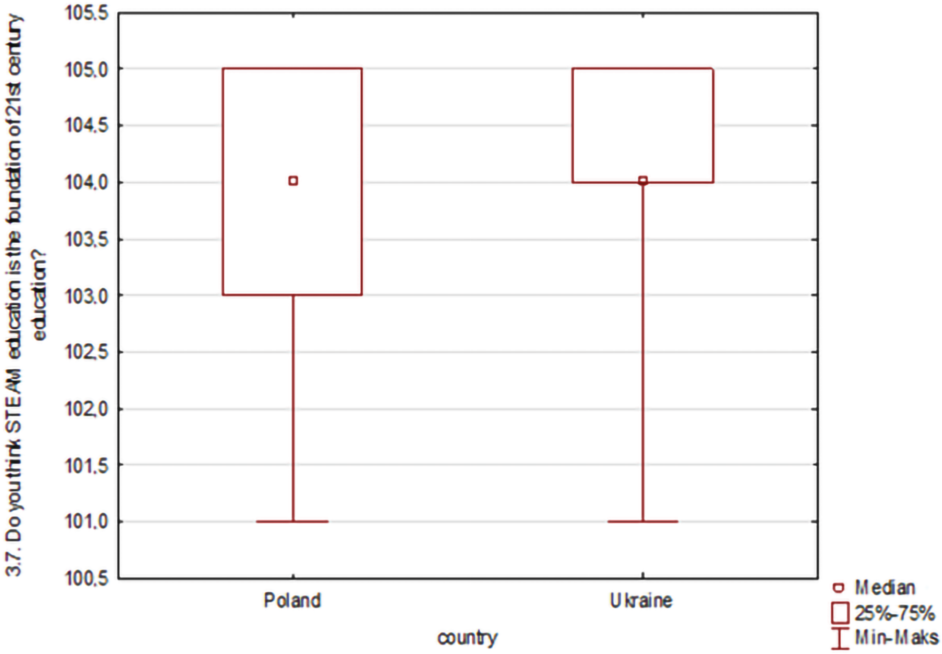
Table 10. Descriptive statistics

	Do you think STEAM education is the foundation of 21st century education?					
Country	**N**	**Median**	**Minimum**	**Maximum**	**First quartile**	**Third quartile**
PL	102	104	101	105	103	105
UA	78	104	101	105	104	105

Table 11. Comparative analysis

Variable	Mann-Whitney U test (continuity corrected) (STEAM Pol Ukraine) Variable: country Marked results are significant with p <.05000		
	p	**N valid. Poland**	**N valid. Ukraine**
3.7. Do you think STEAM education is the foundation of 21st century education?	0.154	102	78

Figure 4. Comparison of the responses obtained for question "Do you think STEAM education is the foundation of 21st century education?



The Mann-Whitney test found a **significant difference** in the parameter: "*Do you think STEAM education is the foundation of 21st century education*", with **p = 0.154 > 0.05.** Upon examining the medians, they appear similar. However, the First Quartile for Ukraine is 104 ("Agree"), while in Poland, it is 103 ("Undecided"). This discrepancy led to the **confirmation** of **Hypothesis H4**.

4. DISCUSSION

The results from the analysis of RQ1 and its corresponding hypothesis indicate a need for significant investment in teacher training and resources to develop STEAM competences in Ukraine and Poland. Despite the increasing attention towards STEAM education, it faces notable obstacles such as insufficient funding and resources, inadequate teacher preparation, and a general unawareness among stakeholders regarding its significance. Piekarska and Piekarski (2020 Bybe) support the findings of RQ1 (as referenced in Table 2 and Table 3), revealing that both pre-service and in-service teachers in Poland acknowledge the value of STEAM education and consider STEAM competencies crucial for teaching effectiveness (p. 84). This paper examines the prospects and challenges of STEAM education and teacher development in Ukraine. The study, conducted through a qualitative approach, involved interviews with 30 teachers, policymakers, and experts in the field of education. (p. 141)

This study examines the prospects and challenges for STEAM education and teacher development in Ukraine (Table 4 and Table 5). The findings indicate an increasing enthusiasm for STEAM education within Ukraine, yet highlight substantial barriers to its adoption. These obstacles encompass insufficient funding and resources, inadequate training for teachers, and a widespread lack of understanding among stakeholders regarding the critical value of STEAM education.

Research has shown (Table 6 and Table 7) that the development of STEAM competences can differ depending on the educational level of the teacher. In a study conducted by Bozkurt and Erişti (2019 among Turkish pre-service teachers, the researchers found that the development of STEAM competences differed between primary and secondary school teacher education. The researchers reported that primary school teacher education programmes focused more on the integration of Arts and Mathematics, while secondary school teacher education programmes focused more on Science and Technology.

The results of Research Question 3 (RQ3) suggest that there are some differences in the process of developing STEAM competences between primary and secondary school teacher education programs in Poland and Ukraine. Both groups recognized the importance of STEAM education and the role of STEAM competences in teaching, but there were some differences in the approaches to developing these competences, such as differences in medians and quartiles. In Ukraine, responses leaned more towards “Strongly Agree,” while in Poland, they tended to be less affirmative, more akin to “Agree”.

Overall, the evidence from Tables 8 and 9 suggest that curriculum design, pedagogy, teacher professional development, and collaboration among teachers are essential components for shaping teachers’ STEAM competences. However, the degree of importance of these components may vary among teachers from different countries due to differences in educational systems and teaching cultures.

The results (Tables 10 and 11) will explore the opinions of students and teachers regarding whether STEAM education is the foundation of 21st century education and whether the opinions of Polish and Ukrainian respondents are similar (RQ4, H4).

Analyzing the results from Poland and Ukraine, we observe that both countries exhibit similar outcomes in terms of STEAM competencies. However, they differ from the results observed in countries such as China, Korea, and the United States. In studies conducted in China (Li et al., 2020), it was demonstrated that primary school students significantly improved their computational thinking skills through the use of educational robots. These results contrast with those from Poland, where a 2015 study found that the use of constructivist approaches with didactic aids produced positive effects, but not to the same degree as in China.

In Korea (Park & Jang, 2020), students participating in STEAM activities showed substantial progress in problem-solving and critical thinking skills, which differs from the results in Ukraine, where a focus on methodological competencies did not yield equally remarkable outcomes. In the United States (Abedi, 2023), research on the use of mobile applications with augmented reality technology revealed significant improvements in understanding spatial relationships, indicating the advantage of immersive technologies, the implementation of which remains limited in Poland and Ukraine. These comparisons suggest that the educational systems in Poland and Ukraine, despite certain similarities, still require greater investment in technological tools and methodologies to match the achievements of countries like China and the United States.

To effectively implement STEAM competencies in daily teaching practice, educators should focus on integrating interdisciplinary projects that encourage critical thinking and problem-solving. For example, designing lessons that connect scientific concepts with real-world applications, such as environmental challenges or technological innovations, can foster deeper student engagement. Teachers should also utilize digital tools and resources, such as simulation software or educational apps, to create immersive learning experiences. Moreover, collaborative group work, where students take on different roles to solve complex tasks, can enhance both social and methodological competencies. Lastly, ongoing professional development focused on specific STEAM tools and methods will empower teachers to continuously adapt their strategies to the evolving needs of their students.

5. CONCLUSIONS

Regarding the perspectives of Polish and Ukrainian participants, research is scarce. Nonetheless, Elkordy's (2016) investigation among Ukrainian pre-service teachers highlighted that content and pedagogical knowledge are paramount in developing teachers' STEAM competencies. Additionally, the study discovered that self-efficacy and attitudes towards STEAM education hold moderate significance (Deng, 2022).

The significance of various components in developing teachers' STEAM competencies can differ based on the context and the individual. Content knowledge and pedagogical knowledge are universally recognized as crucial elements, yet the relevance of self-efficacy and attitudes towards STEAM education may fluctuate. Future studies could delve deeper into these components' roles and how they interact to influence teachers' STEAM competencies.

Overall, the opinions of both students and teachers suggest that STEAM education is essential for the development of 21st-century skills and can provide numerous benefits for students. However, the implementation of STEAM education can be challenging due to a lack of resources, training, and support. To fully realize the benefits of STEAM education, it is crucial to address these challenges and provide teachers with the necessary resources and support to effectively implement STEAM education in the classroom.

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