STEAM+H: A model for integrating humanities and sustainable development in the STEAM educational paradigm

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Abstract

The paper is devoted to the substantiation and development of the STEAM+H model. It involves the integration of humanities and natural sciences based on the modern STEM concept. While researching approaches to STEM education, the authors performed a bibliometric analysis of scientific research in this area. As a result of applying this method, they identified the main clusters of STEM research, such as the implementation of the concept of sustainable development, the introduction of an interdisciplinary approach, the justification of technological approaches, and the achievement of humanistic learning goals. On this basis, the components of the author's model "Horizon of Opportunities: STEAM+H for a sustainable future" were identified. It combines STEAM components with the humanities concept. The principles of sustainable development are the core of this model. The authors have performed a comparative analysis with other models of STEAM education. They identified the advantages and ways of implementing the model. The authors have conducted a study of potential barriers that may hinder the implementation of their model. Using a survey of educators, they identified academic, administrative, conceptual, and psychological barriers.

Keywords

model, STEAM, STEAM+H, sustainable development, global challenges, teaching methods, the 21st century skills, humanities, art component

1. Introduction

STEM education today is one of the key areas in forming a modern education system focused on developing critical thinking, creativity, and the ability to solve complex problems. These competencies become the foundation for the successful integration of students into a dynamic socio-economic space where innovations determine the development of society. However, traditional approaches to implementing STEM models do not always meet the needs of the modern world, which requires updating and adaptation.

This study aims to analyse current research in STEM education, identify their directions, and develop a model that considers current challenges and prospects. The article critically reviews approaches to integrating interdisciplinary learning, including participation of humanitarian and artistic components, inclusion, and a focus on sustainable development.

A "STEM education model" is a structured approach that combines science, technology, engineering, and mathematics into a single learning process. The literature review focuses on the latest scientific achievements, highlighting interdisciplinary issues, technology integration, and other aspects. The research objectives include the following:

- identifying gaps in the current theory and practice of STEM education;

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- studying the characteristics and identifying the components of the author's STEAM+H model focused on global challenges;
- analysing the role of innovative technologies in the development of 21st century skills.

The proposed systematic approach is intended to lay the foundations for the further development of STEM education, promoting the integration of theoretical and practical components into the educational process.

1.1. Research methods

The following methods were used in the research process:

- bibliometric analysis of primary sources;
- designing the STEAM+H model with a focus on sustainable development;
- questionaire and descriptive statistics to determine the barriers to implementing the authors' model in the educational process.

This study used a comprehensive approach that combines qualitative and quantitative analysis. In particular, bibliometric analysis was applied to systematize scientific sources, identify current trends in STEM education, and evaluate existing models using VOSviewer v. 1.6.20 (https://www.vosviewer.com/). We used bibliometric analysis methodology described in detail by I. Mintii and S. Semerikov [1].

1.2. Stages of the study

1. Data collection. We collected scientific publications from international databases (Scopus, Web of Science) for the analysis. The key criteria for selecting sources were:
    - Publications on STEM education, STEAM, technology integration and interdisciplinarity.
    - Articles covering aspects of the humanitarian component and sustainable development.
    - Publications from the last 10 years to ensure the relevance of the analysis.
2. Data processing and bibliographic analysis. All selected publications were exported to csv-format for further analysis. The VOSviewer software was used to visualize the scientific landscape by building maps of author collaboration, citations, and the joint appearance of keywords.
3. Development of the STEAM+H model and study of its characteristics.

1.3. Analysis of bibliographic data

Data from two leading scientific databases, Scopus and Web of Science (WoS), were used to analyse current STEM research areas, guaranteeing high quality and completeness of the information required for bibliometric analysis. The bibliometric analysis of primary sources based on Scopus and WoS provides valuable information for assessing scientific activity, identifying current trends, and effectively planning further research.

Search in Scopus on 4 January 2025 by query

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TITLE-ABS-KEY ( ( steam OR stem ) AND ( education OR learning ) )
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and setting further filters to identify primary sources that relate only to the education sector and meet the specifics and purpose of this study, allowed us to obtain a list of 6633 primary sources.

The graph of the distribution of the number of publications by year (figure 1) shows that researchers' interest in this topic is constantly growing.

The diagram of the number of publications by country (figure 2) clearly shows a group of American and UK authors working on integrating STEM into different levels of education. At the same time, isolated groups of authors from Europe and Asia are working on implementing sustainable development.

A search in WoS on 4 January 2025 for the query

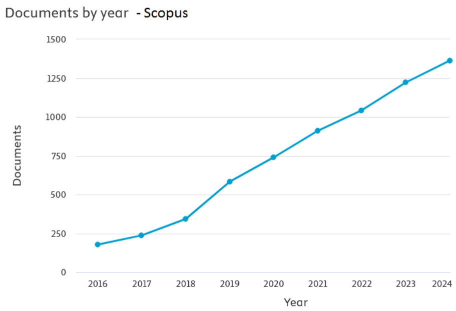

Figure 1: Graph of the distribution of the number of publications by years related to STEM education and current trends in its development, taken from the Scopus scientific database.

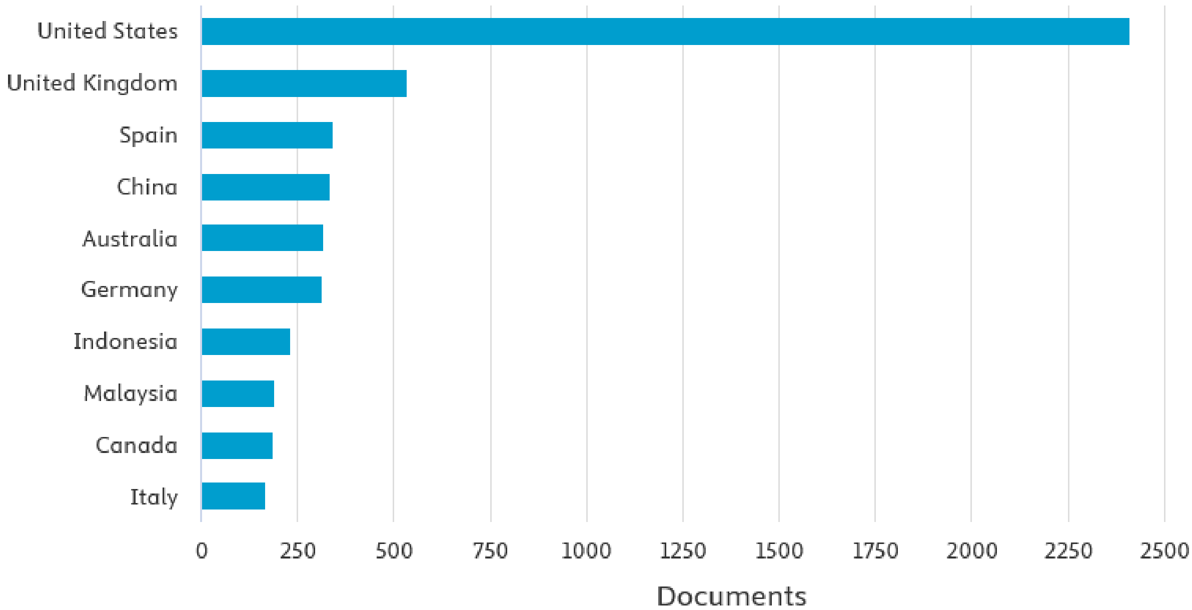

Figure 2: Diagram of the distribution of the number of publications by country related to STEM education and current trends in its development, taken from the Scopus scientific database.

AK=((steam OR stem) AND (education OR learning))

and setting similar filters, we get a list of 1684 publications.

Combining the two lists with the removal of 499 duplicate records allowed us to obtain a csv file with 7818 different primary sources (URL: https://drive.google.com/file/d/1fWWhZONs334lXqtPRs4vvnT9Pzlpb-97).

Further analysis of the obtained bibliographic data was carried out using the VOSviewer tool.

1.4. Keyword map

The type of analysis we chose in VOSviewer is Co-occurrence, and the unit of analysis is all inclusive words (All keywords are author's words and are indexed by Scopus and WoS themselves).

The selection limit (the minimum number of occurrences) was set at 50, which allowed us to select 75 keywords out of 26738.

The VOSviewer application allowed us to obtain a keyword network (see figure 3) and build 4 clusters that reflect the main areas of research (the division of a set of keywords into clusters was obtained using algorithms built into VOSviewer):

- *Cluster 1.* Innovative pedagogical strategies and technologies in STEM/STEAM education. This cluster contains 25 keywords (red): active learning, assessment, augmented reality, collaborative

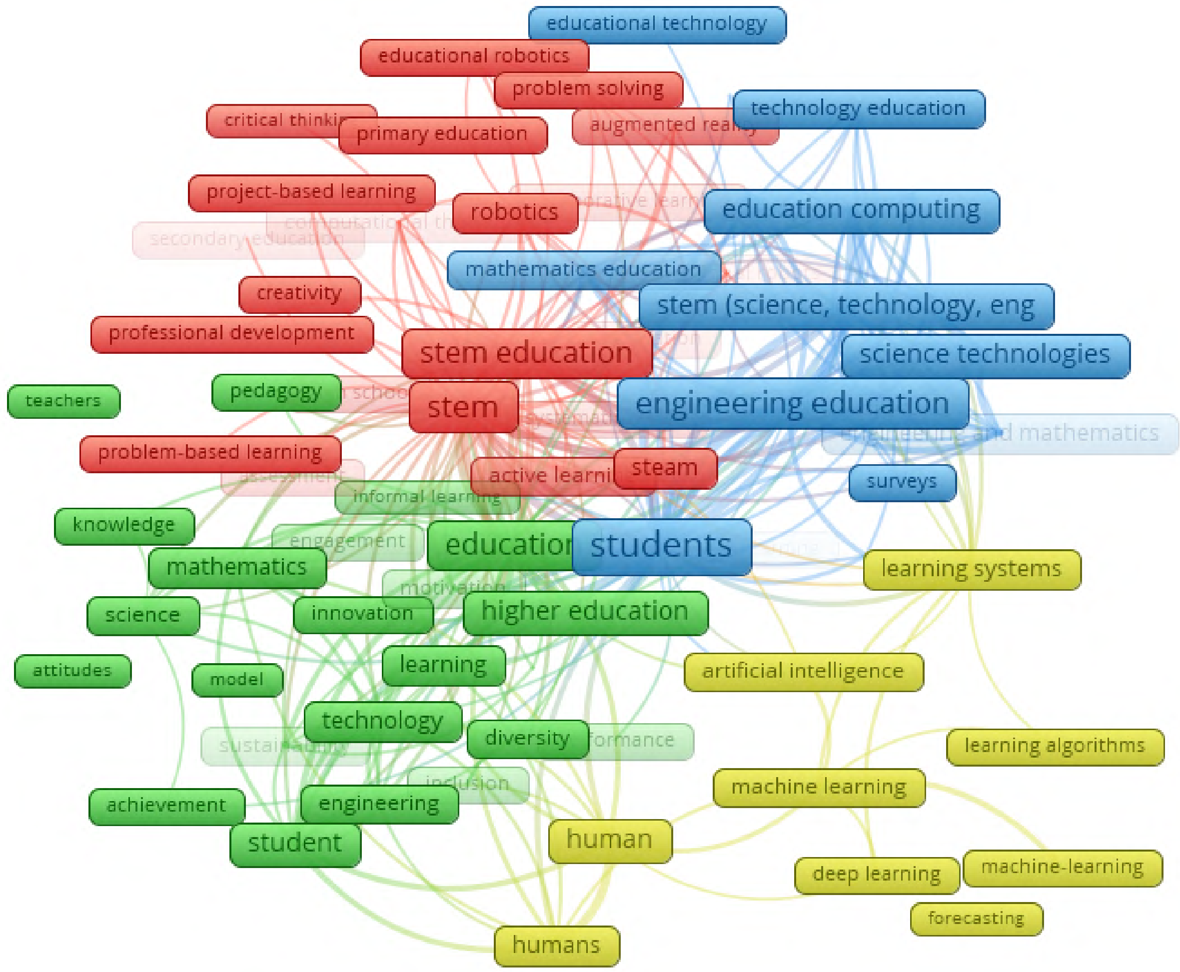

Figure 3: A network of links of keywords of primary sources related to STEM education and current trends in its development, taken from the Scopus and WoS scientific databases.

learning, computational thinking, creativity, critical thinking, educational robotics, educational robots, gamification, high school, primary education, problem solving, problem-based learning, professional development, project-based learning, robotics, secondary education, steam, steam education, stem education, systematic review, teacher education, teacher training.

- *Cluster 2.* Educational approaches, inclusion and innovation for sustainable development. This cluster includes 23 keywords (green): achievement, attitudes, diversity, education, engagement, engineering, higher education, inclusion, informal learning, innovation, knowledge, learning, mathematics, model, motivation, pedagogy, performance, science, student, sustainability, sustainable development, teachers, technology.
- *Cluster 3.* Technological innovations and digital technologies in STEM education. This cluster contains 18 keywords (blue): computer aided instruction, computer science education, curricula, e-learning, education computing, educational technology, engineering and mathematics, engineering education, mathematics education, online learning, professional aspects, science technologies, "stem (science, technology, engineering and mathematics)", student engagement, students, surveys, technology education, virtual reality.
- *Cluster 4.* Artificial intelligence, machine learning and humanistic orientation in STEM education. This cluster contains 9 keywords (olive color): artificial intelligence, deep learning, forecasting, human, humans, learning algorithms, learning systems, machine learning, machine-learning.

Here is the author's understanding of the resulting grouping of keywords into clusters.

Cluster 1 emphasises that modern education requires the integration of the latest methodologies, technologies and teacher training for effective STEM/STEAM learning. The main thematic areas of this cluster:

1. *Methods of active learning*: active learning, collaborative learning, problem-based learning, project-based learning, critical thinking, creativity.
2. *Innovative technologies in education*: augmented reality, educational robotics, gamification, computational thinking, robotics.
3. *STEM/STEAM education*: steam, steam education, stem education.
4. *Educational levels*: high school, primary education, secondary education.
5. *Teacher training and professional development*: teacher education, teacher training, professional development.
6. *Analysis and evaluation of the educational process*: assessment, systematic review.

Cluster 2 brings together concepts related to educational processes, student engagement, inclusion, innovation, sustainable development and the role of teachers. The main thematic areas of this cluster:

1. *Engagement and achievement in education*: achievement, engagement, motivation, performance, student.
2. *Inclusion and diversity*: diversity, inclusion, informal learning.
3. *Innovations and teaching methodologies*: innovation, pedagogy, model, knowledge, learning, teachers.
4. *Interdisciplinary STEM focus*: engineering, mathematics, science, technology.
5. *Sustainable development and education*: sustainability, sustainable development, education, higher education.

Cluster 3 contains concepts related to the scientific justification of technological approaches in STEM education based on feedback from the target audience. The main thematic areas of this cluster:

1. *Digital technologies in education*: computer aided instruction, e-learning, educational technology, online learning, virtual reality.
2. *STEM-oriented education*: computer science education, engineering and mathematics, engineering education, mathematics education, "STEM (science, technology, engineering and mathematics)".
3. *Curricula and approaches*: curricula, education computing, technology education, science technologies.
4. *Student engagement and assessment*: student engagement, students, surveys, professional aspects.

This cluster emphasises the importance of digital technologies in the development of STEM education and the role of interactive learning to improve the effectiveness of education.

Cluster 4 combines concepts related to artificial intelligence, machine learning and their interaction with humans and educational processes. The main thematic areas of this cluster:

1. *Artificial intelligence and its applications*: artificial intelligence, deep learning, machine learning, machine-learning, learning algorithms, learning systems.
2. *Analysis and forecasting*: forecasting.
3. *Focus on technologies for realising humanistic goals in STEM education*: human, humans.

This cluster emphasises the importance of artificial intelligence and machine learning in forecasting, data analysis, and human interaction, particularly in the educational context.

The data obtained from VOSviewer about the strength of keyword relationships is saved in a file with the following URL: https://drive.google.com/file/d/1lxIlE_dXRoRLFePchDec0O-RhCUmLc4Y. Based on the Links and Total link strength indicators, you can draw conclusions about general trends in the links between keywords and identify groups of keywords that have the greatest interaction and influence in the studied topic.

The following keywords have the highest level of links and connectivity:

- "education" (Links = 75, Total link strength = 1424, Occurrences = 597) is the most central term, which confirms its integrating role in the research. – "stem education" (Links = 73, Total link strength = 1286, Occurrences = 966) is a critical concept for education research that has strong links to other categories.
- "engineering education" (Links = 74, Total link strength = 1606, Occurrences = 485) – confirms the importance of engineering education in research.
- "curriculum" (Links = 63, Total link strength = 352, Occurrences = 141) – reflects the connection of curricula with other concepts.
- "e-learning" (Links = 65, Total link strength = 666, Occurrences = 225) – an important aspect of modern education.

STEAM/STEM-education is closely related to the keywords "mathematics" (Links = 60, Total link strength = 437, Occurrences = 171), "engineering" (Links = 54, Total link strength = 343, Occurrences = 120), "science education" (Links = 69, Total link strength = 559, Occurrences = 238), which is a sign of interdisciplinary links.

The integration of "arts" (in STEAM) is less pronounced, but the relationship with "creativity" (Links = 49, Total link strength = 157, Occurrences = 72) and "innovation" (Links = 42, Total link strength = 132, Occurrences = 56) confirms its importance.

Technological aspects of education are reflected in the keywords "artificial intelligence", "augmented reality" and "educational technology". "Artificial intelligence" (Links = 50, Total link strength = 253, Occurrences = 136) has strong links with "deep learning" (Links = 37, Total link strength = 166, Occurrences = 169) and "machine learning" (Links = 54, Total link strength = 357, Occurrences = 295), which indicates the integration of AI into the educational process.

"Augmented reality" (Links = 50, Total link strength = 207, Occurrences = 93), "virtual reality" (Links = 46, Total link strength = 215, Occurrences = 83) are the latest technologies with high potential.

"Educational technology" (Links = 42, Total link strength = 147, Occurrences = 50) is an important category, but inferior to "e-learning" in connectivity. Analysing the methodological aspects of STEM education, we can say that "active learning" (Links = 54, Total link strength = 201, Occurrences = 125) is a central term that has links to "collaborative learning" (Links = 42, Total link strength = 98, Occurrences = 56) and "problem-based learning" (Links = 43, Total link strength = 145, Occurrences = 62).

The concept of "computational thinking" (Links = 60, Total link strength = 299, Occurrences = 147) plays an important role in the development of logical thinking, and the terms "critical thinking" (Links = 40, Total link strength = 96, Occurrences = 51) and "creativity" (Links = 49, Total link strength = 157, Occurrences = 72) are interrelated with learning methods.

The indicator Avg. pub. year is a measure of new and growing trends in recent research: "machine-learning" (2022.92), "learning algorithms" (2021.75) – indicates the relevance of AI in education; "science technologies" (2022.39), "engineering and mathematics" (2022.32) – confirms the development of technological education; "systematic review" (2022.40, Avg. norm. citations = 3.50) – also indicates the need for review studies.

Thus, STEAM/STEM education has strong interdisciplinary links with technology, engineering and mathematics, but the integration of art remains less pronounced. Artificial intelligence, deep learning, and virtual reality are demonstrating a growing influence on educational methods. Topics related to the key concepts of "diversity" and "inclusion" are a response to global educational challenges. They are actively developing and interacting with STEM.

The analysis conducted allows us to offer the following recommendations:

- Strengthen the connection between humanities and STEM disciplines for more effective implementation of the STEAM approach.
- Expand research on the relationship between AI and educational technologies, given the rapid development of machine learning.
- Focus on the integration of new learning methods using VR/AR and other digital solutions.

The Overlay Visualisation tab in VOSviewer shows how research topics have evolved over time (figure 4).

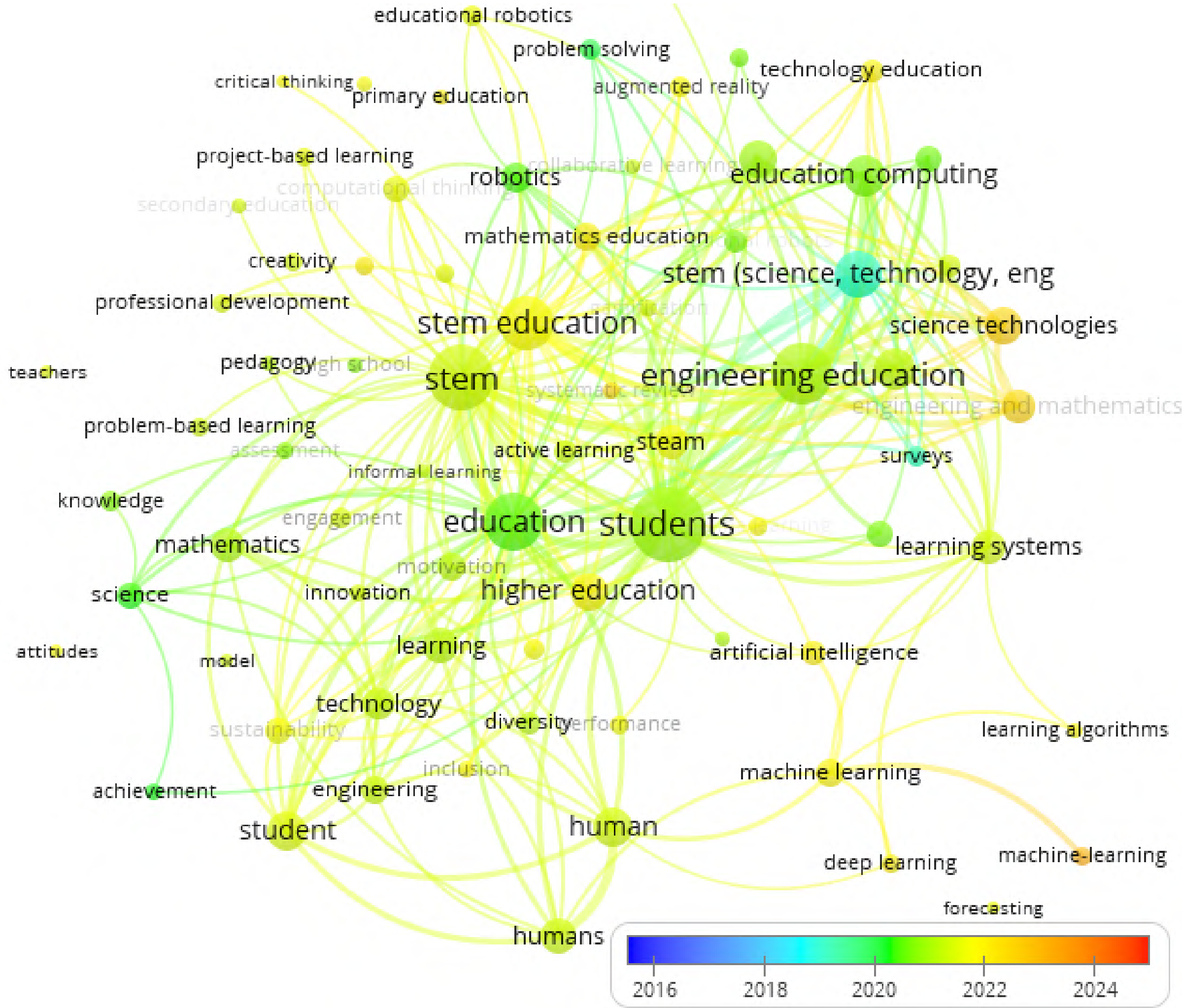

Figure 4: A network of dynamic changes in researchers' interest in STEM education and current trends in its development.

In figure 4, the time chart by year is based on the indicator Avg. pub. year - the average year of publication of documents in which a keyword or term is found. The bulk of the publications were published in 2019-2023. The size of an element depends on the Total link strength attribute, which indicates the total strength of the links between an individual element and other elements.

General trends in the growth of interest in STEM education are as follows:

- Early period of research (before 2021): Research focused on the fundamental issues of STEM education, in particular:
  - "education" (2020.52) – the general concept of education.
  - "stem (science, technology, engineering and mathematics)" (2019.23) - formation of an interdisciplinary approach.
  - "engineering education" (2020.97), "science education" (2021.29) - key areas of STEM.
- Transition to digital technologies in education (2021-2022):
  - "e-learning" (2021.08), "online learning" (2021.66) – growth due to the COVID-19 pandemic.
  - "educational robotics" (2021.45) – expanding the use of robotics in the educational process.
  - "computational thinking" (2021.45) – emphasis on algorithmic thinking.

- Recent trends (2022-2023) - focus on innovative technologies:
  - “artificial intelligence” (2021.91), “machine learning” (2021.78) - integration of AI into STEM education.
  - “science technologies” (2022.39), “engineering and mathematics” (2022.32) - growing interest in technology.
  - “systematic review” (2022.40) – more attention to meta-analysis of research.

Earlier publications focused on fundamental aspects, while more recently, the focus has shifted to modern technological trends and the implementation of the concept of sustainable development and inclusion. This reflects the dynamics of change in research and the integration of innovative approaches and technologies.

1.5. Research on the impact of sources

To continue the bibliometric analysis of the selected sources, we used the Bibliometrix package of the R language. It provides Biblioshiny, a web-based application. We added the “References” field to the metadata export fields to analyse the impact of articles. However, this field has a different format in Scopus and WoS. As a result, combining datasets from these two databases is a difficult task. Therefore, we performed further bibliographic analysis based on Scopus metadata. Analysis of authors’ local impact showed the most cited scientists within the selected dataset (see figure 5).

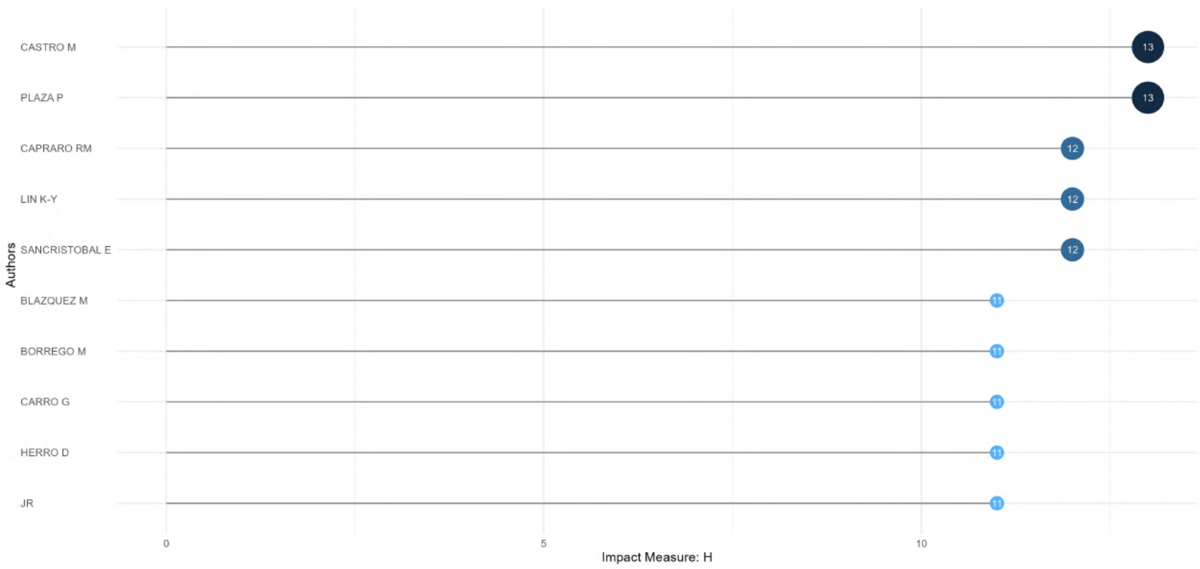

Figure 5: Authors‘ local impact.

Two co-authors, Manuel Castro and Pedro Plaza, have the highest H-index. Their research focuses on inclusive and gender-equal access to STEM education [2], collaborative tools for learning robotics [3]. The third most impactful author in our sample is Robert M. Capraro. His most cited papers relate to the development of computational thinking [4] and methodologies for project-based learning in STEM disciplines [5], [6].

Identifying the most cited papers in the Scopus dataset is also advisable. The three most cited papers (see figure 6).

1. “Defining Computational Thinking for Mathematics and Science” by David Weintrop and his co-authors [7]. They have developed a taxonomy that articulates a definition of “computational thinking in mathematics and science” and contributes a language around which standards, curricula, and assessments can develop.

2. "STEAM in practice and research: An integrative literature review" by Elaine Perignat and Jen Katz-Buonincontro [8]. The authors state a lack of knowledge about the deep history and diversity of the arts, as well as the potential for using them side by side with STEM disciplines. Art making and the creative process were overshadowed by an emphasis on the result, or end product.
3. "Advancing Elementary and Middle School STEM Education" by Lyn D. English [9]. She highlights several issues in STEM education such as discipline integrity and equity in STEM agendas, the protecting of core disciplines by educators, the relationship between mathematics and other STEM fields, realising the research nature of STEM education in programming, and finally, the challenges and unwillingness of teachers to implement STEAM programs that integrate two or more disciplines are extremely important.

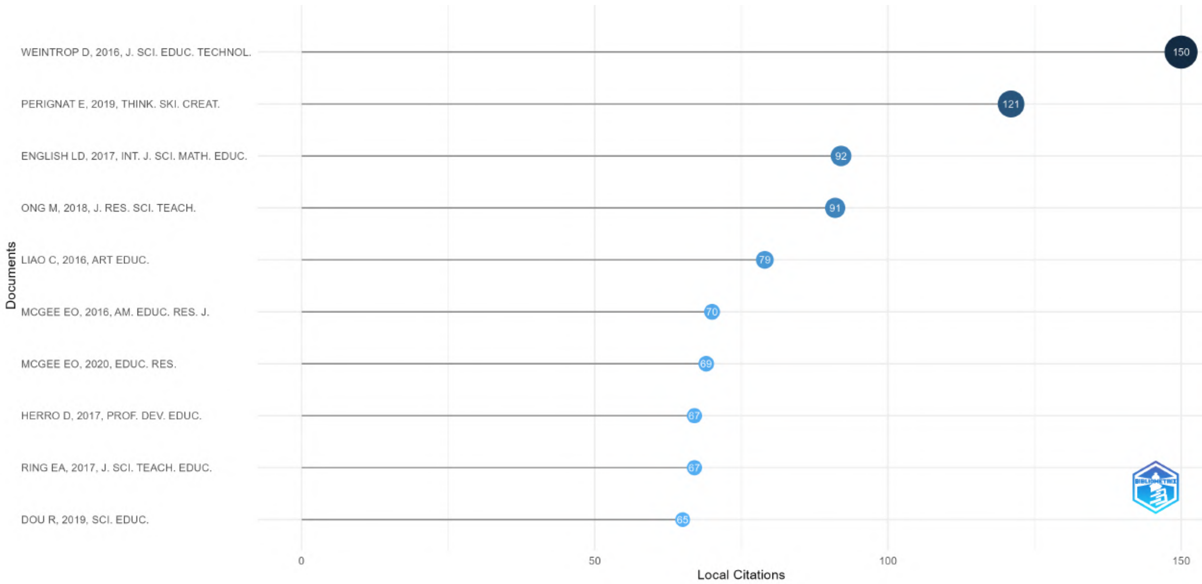

Figure 6: The most local cited documents

2. Review of primary sources

Various scientific sources highlight the multidimensionality of STEM education, offering variations in definitions and models.

- STEM as a holistic approach. This approach combines science, technology, engineering and mathematics to develop critical thinking, problem-solving and innovation [10].
- STEM for 21st century skills. This concept emphasizes the importance of creativity, collaboration and digital literacy in the modern world [11], [12]. The study focused on developing 21st century digital skills through educational platforms during COVID-19 [13].
- STEM for inclusion and equality. Particular attention is paid to attracting representatives of underrepresented groups to STEM disciplines, promoting equity and accessibility [14]. The concept of social justice as a component of STEM education involves the integration of the principles of equity, inclusion and justice into teaching and research related to science, technology, engineering and mathematics. The main idea is to make STEM education more accessible and meaningful to a wide range of students, especially those from underrepresented groups. For example, Colleen M. Lewis and her coauthors' work [15] describes an approach that promotes a well-rounded education for students by combining technical skills with a discussion of social justice.

- STEM as an interdisciplinary framework. This approach focuses on integrating knowledge and its application in real-world contexts, promoting systems thinking [16], [17]. The work [18] demonstrates how modern technologies can be integrated into the curriculum for younger students, contributing to developing their skills and interest in STEM disciplines. An analysis of interdisciplinary approaches to teaching is carried out in the article [19]. This article emphasises the need to integrate the humanities with traditional STEM disciplines and shows how combining technical knowledge with humanitarian perspectives contributes to the formation of ethical thinking, enhancing creativity and developing social responsibility.
- STEM for career readiness. Models in this group aim to develop the skills needed to work in science and technology-related fields [20]. The article [21] discusses a model of education transformation for implementing the STEM approach at a pedagogical university aimed at training a new generation of teachers. The article [22] is devoted to the study of STEM education as an important area of educational reform in the 21st century, implemented through the integration of formal and non-formal education. The authors analyse the ecosystem of STEM education, highlight its key characteristics, and develop a model of the functioning of a STEM educational centre. The model's effectiveness is evaluated through an expert survey and an experiment, which confirmed the success of combining formal and non-formal approaches to develop students' STEM competencies.
- Project-based learning in STEM education. Project-based learning is an essential approach to STEM education, as it promotes the development of skills necessary to solve real-world problems and integrate knowledge from different disciplines [23]. In the article "Redefining the creative digital project for 8th grade in Estonian schools", the authors M. Lust and M. Laanpere study the implementation of project-based learning in Estonian schools for 8th grade students [24]. They propose a new approach to creative digital projects to develop 21st century skills such as critical thinking, collaboration, and digital literacy. The authors of the study [25] show how team design strategies affect the development of metacognitive abilities.
- Integration of artificial intelligence (AI) into STEM education. AI opens up significant opportunities for improving STEM education by facilitating personalized learning, automating routine processes, and introducing innovative approaches. It is worth noting that the central concept of Bita Akram's work is to develop an interdisciplinary curriculum for middle school students that integrates AI concepts into various subjects [26]. The article [27] investigates the factors influencing the intentions of humanities and social sciences students to use AI applications for educational purposes.

In addition, the author of the book [28] notes that technology, science and mathematics acquire a "human face" when they are integrated with the humanities. This book complements traditional STEM education by expanding it with a humanities perspective and contributes to a more comprehensive and responsible innovation space.

The above characteristics highlight the potential of STEM education to prepare students for the challenges of the modern world. At the same time, the analysis also revealed significant differences between models due to the specific context of their implementation.

The literature analysis shows that STEM education has a wide range of goals and forms of implementation, allowing it to be adapted to different social and educational contexts.

3. Designing the STEAM+H model

STEM education models are [6, 9, 11, 12, 14, 29, 21**?** , 30] integrated approaches to learning that combine science, technology, engineering, and mathematics. The main goal is to prepare students to solve real-life challenges by developing analytical, creative and technical thinking. An important feature of such models is an interdisciplinary approach that allows combining knowledge from different fields to solve complex problems. The development of STEM education models involves the practical application of integrated knowledge, which helps students to use it effectively in real-life situations. In view of this, our literature analysis has revealed a variety of modern approaches to the development of STEM education:

1. *An integrated and interdisciplinary approach* to STEM education encourages the development of systems thinking, allowing students to recognise the interconnections between different scientific disciplines. This is manifested, for example, in the need to integrate knowledge of physics, chemistry, mathematics and engineering design when solving problems such as designing solar panels. Models based on an interdisciplinary approach emphasise the synergy of academic knowledge and its practical application.
2. *Project-based learning* is a dominant trend in modern STEM models, which involves students solving real-world problems. This approach promotes not only the practical application of theoretical knowledge (for example, when creating prototypes or studying natural phenomena), but also the development of soft skills: time management, teamwork and responsibility.
3. *The integration of innovative technologies* is an important component of STEM education, including the use of virtual and augmented reality (VR/AR), 3D modelling, cloud computing and sensor systems. Their application allows for simulations, virtual experiments and project testing directly in the learning environment [31], and also contributes to increasing the level of digital literacy of students [32].
4. *Adaptability and local context* characterise modern STEM models, which take into account the age and cultural characteristics of students, as well as the resources of educational institutions. For example, in primary school, the emphasis is on interactivity and game-based learning, while for high school students, more complex projects and vocationally oriented research are a priority.
5. *Formation of future skills* is the strategic goal of STEM education, aimed at developing competencies in demand in the modern labour market: critical thinking, analytical skills, creativity and technological awareness. The implementation of STEM models contributes to the development of the so-called "21st century skills", including leadership, communication skills and the ability to collaborate effectively, which are key factors for success in any professional field.

The study found that the most effective models are those that: focus on real-world problems that motivate students; integrate modern technologies, engaging students in active interaction with innovations; and ensure inclusiveness, taking into account the needs of different social groups.

At the same time, implementing these models depends on many factors, including teacher qualifications, availability of resources, and the educational context.

3.1. STEAM+H model with a focus on sustainable development

The modern world is facing numerous challenges (from climate change and social inequality to rapid technological progress) that require interdisciplinary solutions. While traditional STEM education has its merits, it often underestimates the human dimension that gives science, technology, engineering and mathematics a human face. The STEAM+H model extends STEM by integrating the humanities, arts, and ethical principles, which stimulates critical thinking, creativity, and social responsibility. This approach not only deepens the understanding of technological innovations, but also ensures their ethical and socially responsible implementation, contributing to a sustainable and inclusive future.

To overcome such challenges, we propose the STEAM+H model, which expands traditional STEM by adding such components:

- Arts to develop creative thinking.
- Humanities to develop ethical consciousness and social responsibility.
- Sustainability concepts to consider environmental, social and economic aspects.

It should be noted that the concept of STEAM education has been proposed and developed by many researchers [16], [33], [30], [34]. The proposed model has the following advantages:

- *Comprehensive development*, which involves a combination of different disciplines and contributes to the formation of students' systemic thinking.
- *The relevance* of the model is that it meets the needs of the modern world for specialists who are able to work in interdisciplinary teams, have ethical principles and understand the social context.
- *Support for sustainable development*, which helps prepare students to address global issues such as biodiversity conservation, rational use of natural resources and the introduction of environmentally friendly technologies.

The article [35] analyses 44 scientific articles published between 2019 and 2023 and focuses on the importance of combining STEM education with sustainable development strategies to prepare students for modern global challenges.

The model we propose is the result of a bibliometric analysis and a generalisation of the issues raised and considered by a large number of other researchers in the field of STEM education.

We developed the STEAM+H model in the following stages.

1. Needs analysis. We identified the key challenges of modern education, including the need to integrate creative and socially-oriented components.
2. Identification of components. The structural basis of the model is developed, which, in addition to the components established in the STEM model, additionally includes:
   - Artistic component. For example, creating a design for a technology project.
   - Humanitarian component. Analysis of ethical aspects of technology.
   - Sustainable development. Implementation of projects that take into account environmental, social, and economic aspects.

As you can see in figure 7, the model combines STEAM (science, technology, engineering, art, math) components with the humanities (H), creating a more comprehensive approach to education. It reflects an interdisciplinary approach, which allows global challenges to be viewed through the lens of different fields of knowledge.

The central element, the core of the model, is a set of principles of sustainable development, which are considered to be the fundamental basis of the educational process. These principles are structured around three integrated dimensions: environmental, social and economic. The implementation of these principles in curricula and teaching methods ensures the practical orientation of the educational process and helps to develop a responsible attitude towards the future of the planet and readiness to solve global problems. The core of the model is surrounded by a dynamic environment representing the following key characteristics: knowledge base dynamics, innovative openness, adaptive potential, and the concept of lifelong learning.

In addition, the model also contains the following three orbits:

1. The inner orbit ("Global Challenges" – climate change, poverty, inequality, lack of resources) reflects the key real-world issues that students apply their knowledge to solve.
2. The middle orbit ("teaching methods" – project-based learning, experimental learning, game-based learning, design thinking, etc.) reflects modern approaches to organising the learning process that promote active student engagement.
3. The outer orbit ("21st century skills") covers the key competencies for the modern world: critical thinking, creativity, communication, collaboration, and media literacy.

We believe that the strong point of the model is its comprehensiveness. It includes the humanities, which makes it more balanced than standard STEAM models. As a result, students not only learn technology and science, but also develop ethical thinking and an understanding of the social implications of scientific achievements.

The model also focuses on the practical application of knowledge. It focuses on sustainable development and global challenges, helping students connect learning to real-world problems. This contributes to the development of responsibility for the environment and social well-being.

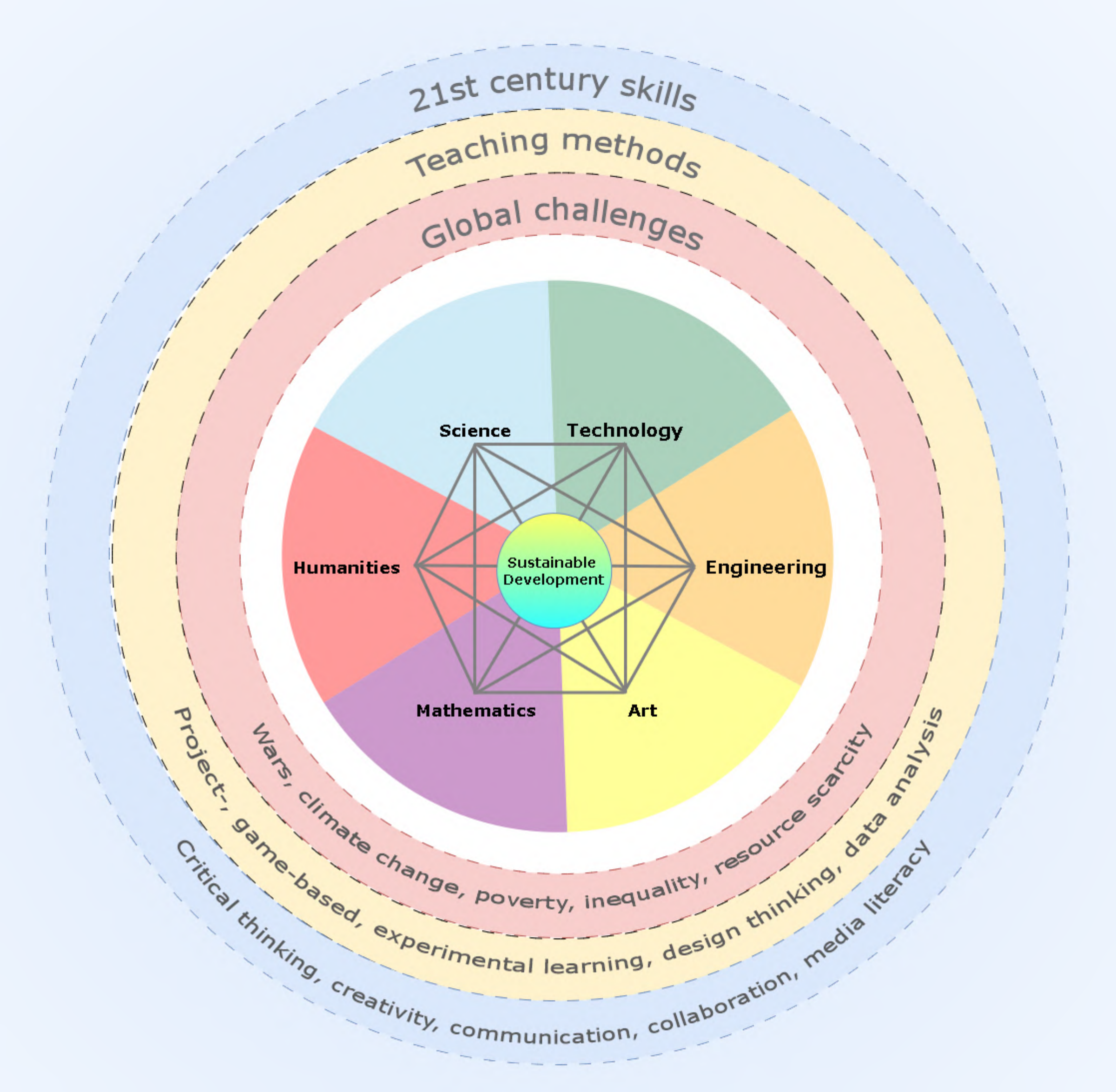

Figure 7: Horizon of Opportunities: STEAM+H for a sustainable future.

Another important feature of this model is its flexibility. Thanks to modern teaching methods and the possibility of adaptation, the model can be adjusted to meet the different needs of students and the specifics of the local context.

Let us highlight the difficulties that may arise when implementing the STEAM+H model. Combining humanities and technical disciplines can be difficult because they differ in content. Also, the successful implementation of the model requires qualified teachers who are able to use interdisciplinary approaches. In addition, appropriate resources are needed, such as access to modern laboratories and technology.

Given the experience of the STEM Centre at Ternopil Volodymyr Hnatiuk National Pedagogical University, we see the following ways to implement the STEAM+H model:

- STEAM centers and clubs that engage students in project activities.
- Interdisciplinary lessons, where one topic is considered from the perspective of different sciences.
- Extracurricular activities and interaction with professional communities.
- Project-based learning aimed at solving local environmental or social problems.

The model "Horizon of Opportunities: STEAM+H for a Sustainable Future" is an innovative educational framework that integrates interdisciplinarity, modern pedagogical methods and sustainable development principles. Its effective implementation requires professional development of teachers and adaptation to the local context, but it has significant potential for transforming the educational environment.

3.2. Comparative analysis of the STEAM+H model with well-known models of STEM education

Four existing models of STEM education [36], [16], [37], [38] and the proposed STEAM+H model are used for comparison. The evaluation criteria were chosen according to the degree of implementation of each model. They include interdisciplinarity, integration of technologies, development of 21st century skills, emphasis on sustainable development, humanitarian component, artistic component, creativity, social responsibility, and flexibility in implementation. The evaluation scale includes 4 indicators: no implementation (missing), limited, average and high. Table 1 shows the author's assessment of these models.

Table 1
Comparison of STEM-education frameworks.

Criterion/ Framework	**Moore et al.** [36]	**Kelley and Knowles** [16]	**Banks and Barlex** [37]	**LSF** [38]	**STEAM+H**
Interdisciplinarity	High	Average	Low	High	High
Technology integration	High	Average	Low	High	Average
21st Century Skills	High	Average	High	Average	High
Sustainability	Limited	Missing	Missing	Limited	High
Humanitarian component	Missing	Missing	Missing	Missing	High
Art component	Missing	Low	Missing	Average	High
Creativity	Average	Average	Low	Low	High
Social responsibility	Low	Low	Low	Low	High
Implementation flexibility	Average	High	Low	Average	Average

4. Discussion

The results of the review of current STEM education models demonstrate significant progress in the use of interdisciplinary approaches, the integration of innovative technologies, and the focus on developing skills of the 21st century. However, some aspects remain insufficiently researched, while others are controversial. The following is a concise analysis of the aspects mentioned above.

Integration of artistic and humanitarian components. Despite the growing popularity of STEAM, most current models are still limited to technical disciplines, neglecting the potential of the arts and humanities to foster creative thinking, cultural awareness and ethical responsibility. Implementing the humanities component contributes to a deeper understanding of the social and cultural implications of scientific achievements, but requires empirical evidence of effectiveness in school education.

Sustainable development. Models that integrate sustainable development ideas remain rare, even though today's global challenges, such as climate change and social inequality, require urgent attention. Sustainability is a central element of the STEAM+H. It aims to create socially responsible citizens. However, successful implementation requires adaptation to local educational contexts, which remains an open question.

Technology and innovation. Recent studies have highlighted the significant impact of technology on STEM education, including VR/AR, 3D modeling and robotics. However, using these tools requires significant resources, which can create barriers for less well-off educational institutions. In the STEAM+H model, the emphasis on technology is complemented by a humanities component that helps students critically evaluate the impact of technology on society.

Equality and inclusivity. While STEM is often seen as a tool to address social inequalities, evidence suggests that many models still fail to engage students from all social groups sufficiently. The STEAM+H model has the potential to overcome this problem by providing a variety of approaches and topics that can appeal to a broader audience.

Problem-based learning. The review results confirm the effectiveness of PBL in STEM education, but emphasize the importance of precise structured tasks to ensure interdisciplinary. PBL is the basis of the STEAM+H model. It allows combining knowledge from different disciplines to solve complex real-world problems.

4.1. Limitations and challenges

The implementation of STEAM+H, like any other model in real life, can face some challenges. To outline them, we have described the STEAM+H model and interviewed practicing science and humanities teachers. The study was conducted in two stages, from September 2024 to November 2024. The task of the first stage was to identify categories of barriers. 378 teachers of the Ternopil region (Ukraine) participated in this stage. We provided respondents with a description and graphical representation of the STEAM+H model. We also asked teachers to answer an open-ended question such as "Please name and describe the 5 most important barriers to implementing this model." The data were processed according to the methodology of Shadle et al [39], [40]. After analysing the data, we rejected 12 incomplete questionnaires and identified 21 barriers. In the second stage of the experimental study, we asked teachers to rate each of these barriers according to the five-point scale choices: 1 – no barrier, 2 – minor barrier, 3 – medium barrier, 4 – significant barrier, 5 – very strong barrier. This time, 298 teachers were involved in the survey. The data obtained in this survey is available at the following https://docs.google.com/spreadsheets/d/1lJGkThBgjlnA1jO2WpQwcO-cehvigmG2/edit?usp=sharing&ouid=104522410325639968746&rtpof=true&sd=true link. After the survey, we verified the internal consistency of the questions. We computed Cronbach's alpha for all 21 items. The alpha coefficient for all barriers is 0,707 and is considered "acceptable". We used the method of L.Y. Muilenburg and Z.L. Berge [41] to estimate the significance of the barriers and the categories they form. We calculated the average values of indicators for each barrier, which were obtained by summing the responses of all respondents. The following scale was used to assess the degree of manifestation of any barrier to model implementation complexity:

$$1 \leq \ no\, difficulty\ \leq 1.8;$$

$$1.8 < \ minor\, difficulty\ \leq 2.6$$

$$2.6 < \ medium\, difficulty\ \leq 3.4$$

$$3.4 < \ significant\, difficulty\ \leq 4.2$$

$$4.2 < \ very\, high\, difficulty\ \leq 5$$

Each of them calculated the average values (see the table 2).

The highest mean values were found for the following barriers: limited professional development opportunities for interdisciplinary teaching (B10), the feeling of autonomy loss (B20), teacher's overload (B3), the need for additional training on integration of different disciplines (B1), lack of motivation among teachers (B18), resistance to innovations (B15) and institutional inertia of educational institutions (B6). These barriers are highlighted in red in the figure 8.

These barriers can be grouped into 4 categories such as,

- academics (AC) covers B1 – B5 barriers;
- administrative (AD) covers B6 – B11 barriers;
- conceptual (C) covers B12 – B16 barriers;
- psychological (PS) covers B17 – B21 barriers.

Table 2
Investigated barriers.

Code	Issues	Mean	Description
B1	The necessity for additional training of teachers for the integration of different disciplines	4.06	significant difficulty
B2	Problems of evaluating interdisciplinary learning	3.08	medium difficulty
B3	Teacher's overload	4.09	significant difficulty
B4	Lack of engagement with stakeholders	2.34	minor difficulty
B5	Lack of systematic and sustained collaboration and communication between teachers from different disciplines	3.12	medium difficulty
B6	Institutional inertia of educational institutions	3.92	significant difficulty
B7	The need for redesign of educational programs	3.18	medium difficulty
B8	Lack of regulatory requirements for assessment	2.10	minor difficulty
B9	Lack of support at school, local and national levels	2.99	medium difficulty
B10	Limited Professional Development Opportunities for Teachers for Interdisciplinary Teaching	4.32	significant difficulty
B11	Lack of investment in specialized laboratories, equipment and technological resources	3.06	medium difficulty
B12	Complexity of integrating disciplines within the STEAM model	2.65	minor difficulty
B13	Complexity of integrating disciplines within the STEAM+H model	2.96	medium difficulty
B14	Greater time requirements for the implementation of interdisciplinary methodologies	3.19	medium difficulty
B15	Resistance to innovations by teachers, parents or even students	4.04	significant difficulty
B16	Problems of involvement of local communities	2.97	medium difficulty
B17	Negative stereotypes of teachers about certain disciplines	3.07	medium difficulty
B18	Lack of motivation among teachers to implement the ideas of the STEAM+H model in their activities	4.06	significant difficulty
B19	Feeling of competition with other subject teachers	3.36	medium difficulty
B20	Feeling of loss of autonomy in teachers	4.12	significant difficulty
B21	Teachers' discomfort in subjects beyond their competence	3.76	significant difficulty

Table 2 and figure 8 show that in the category Academics (AC), the main problems are teacher overload (AC3: 4.09 is a significant difficulty) and the need for additional teacher training (AC1: 4.06 is a significant difficulty). The least critical is the lack of interaction with stakeholders (AC4: 2.34 is a minor difficulty). In the Administrative (AD) category, the most problematic are limited opportunities for professional development of teachers (AD5: 4.32 is a significant difficulty) and institutional inertia of educational institutions (AD1: 3.92 is a significant difficulty). The lack of normative requirements for assessment (AD3: 2.10 is a minor difficulty) is perceived by teachers as a minor problem.

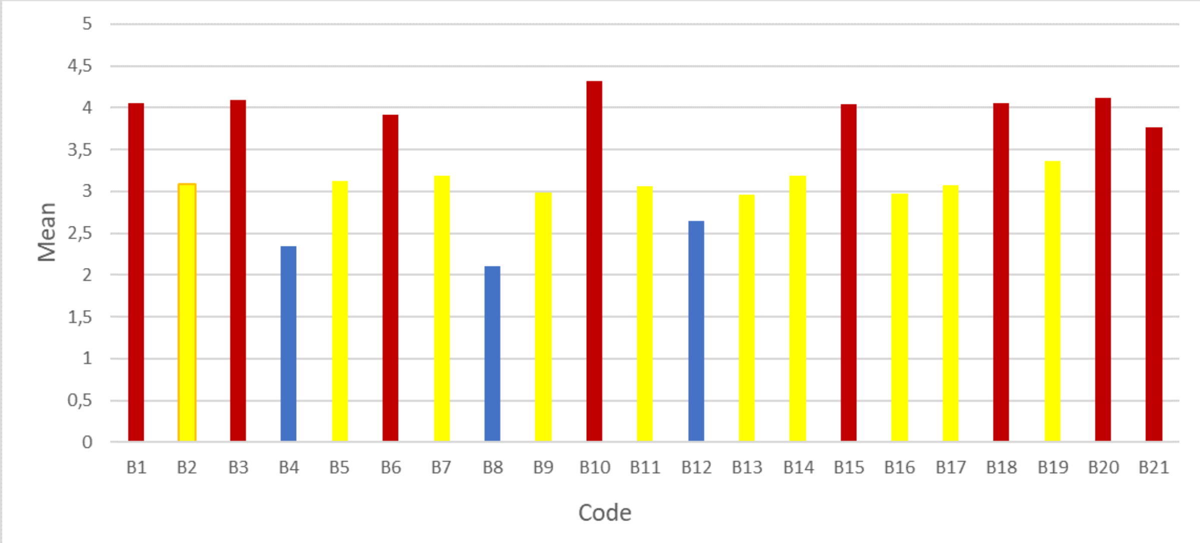

Figure 8: Barriers to implementing the STEAM+H model identified in the survey.

Among the conceptual barriers (C), the most critical is resistance to innovation from teachers, parents, or students (C4: 4.04 is significant difficulty), and the least critical problem is the integration of disciplines within the model (C1: 2.65 is medium difficulty). Psychological barriers (PS) have the highest overall average score: 3.81 is a significant difficulty), indicating significant difficulties associated with the implementation of STEAM+H due to teachers' internal resistance, a sense of loss of autonomy, and discomfort with the interdisciplinary nature of the model. The main problems are the feeling of loss of autonomy (PS4: 4.12 is a significant difficulty), lack of motivation among teachers (PS2: 4.06 is a significant difficulty) and teachers' discomfort with subjects outside their competence (PS5: 3.76 is a significant difficulty). The least critical are negative stereotypes of teachers about certain disciplines (PS1: 3.07 is medium difficulty). Administrative problems (AD) and conceptual barriers (C) have similar mean scores (3.30 and 3.29 respectively). In the administrative area, the most critical is the lack of resources and professional support for teachers. In conceptual terms, the main problem is resistance to innovation. Academic barriers (AC) have a medium level of complexity (3.34), but some problems, such as teacher overload and the need for additional training, have a high level of complexity (4.09 and 4.06, respectively). Only one problem (AD5) was found to be very high in complexity, indicating a critical need for investment in teacher professional development. Many problems are of medium complexity (2.6–3.4), which indicates the need for a systematic approach to their solution. Some administrative and academic problems, which require fewer resources to overcome, are of low complexity (1.8–2.6) in terms of potential solutions.

Thus, psychological barriers require priority attention, as teachers' negative attitudes toward change, fear of losing autonomy, and discomfort with interdisciplinary subjects can significantly hinder the implementation of the model. Institutional support is critical. Therefore, it is necessary to develop professional development programs, improve cooperation between teachers of different disciplines, and attract resources to create educational infrastructure. Conceptual barriers can be overcome through educational trainings and community involvement in supporting STEAM+H education. The overload of teachers and the need for additional training indicate the need to redistribute responsibilities and improve methodological support.

The analysis shows the complex nature of the problems of STEAM+H implementation, which require an interdisciplinary approach, resource mobilization, and the creation of favorable conditions for teachers.

Despite the possible challenges (the complexity of integrating disciplines, the need for teacher training, and limited resources), the feasibility of implementing the STEAM+H model is due to the need to focus on the following areas of activity such as

A response to the challenges of the modern world. Traditional models of education do not always meet the needs of a rapidly changing technological and social environment. STEAM+H offers tools to adapt to these changes. Preparing to work in interdisciplinary teams. Many professional fields require a combination of technical, creative, and humanitarian knowledge, which stimulates the need to develop these skills at school. *Reducing the gap between theory and practice.* Using the STEAM+H model allows students to apply theoretical knowledge to solve real-world problems, increasing the value of education. Supporting creativity and innovation. The addition of humanitarian and artistic components contributes to the formation of creative thinking, which is key to innovative development. *Fostering environmental and social responsibility.* Integration of sustainable development into the educational process encourages students to be aware of their actions and impact on the environment and society.

5. Conclusions

The article provides a bibliographic review of modern models of STEM education, analyses them and substantiates the feasibility of expanding the traditional concept to the STEAM+H model. STEM education ensures the development of critical thinking, analytical skills and technological literacy, but has limitations in terms of integrating the humanities, creativity and sustainable development.

The analysis of the bibliography confirmed the importance of interdisciplinarity, social responsibility, and innovative technologies for modern education. The identified shortcomings of modern STEM education models motivate the introduction of STEAM+H, which integrates the components of art, humanities, and sustainable development while maintaining the fundamental principles of STEM. STEAM+H is a universal model that prepares students not only for scientific and technical activities, but also for social and environmental challenges, forming critical thinkers, creatives, and responsible citizens. The proposed model is a promising area of education modernization. Still, its practical implementation requires additional research, development of teaching materials, adaptation to different educational environments, and training of teaching staff. The implementation of the STEAM+H model is not only potentially possible, but also necessary for modern education. This model allows to create an integrated system of knowledge that meets the needs of students and the challenges of the 21st century. However, its successful implementation requires support at the state, institutional, and local levels, teacher training, resources, and systematic work to overcome administrative and psychological barriers. Further research should focus on:

- An empirical analysis of the impact of the STEAM+H model on students' academic performance and motivation.
- Development of methodological materials to support teachers.
- Adaptation of the model to the conditions of under-resourced schools.

Author Contributions

Conceptualization – Nadiia R. Balyk; methodology – Vasyl P. Oleksiuk; formulation of tasks analysis – Yaroslav P. Vasylenko and Vasyl P. Oleksiuk; software – Yaroslav P. Vasylenko and Vasyl P. Oleksiuk; writing – original draft – Yaroslav P. Vasylenko and Galyna P. Shmyger; analysis of results – Vasyl P. Oleksiuk and Yaroslav P. Vasylenko; visualization – Nadiia R. Balyk and Anatolii V. Balyk; reviewing and editing – Yaroslav P. Vasylenko and Vasyl P. Oleksiuk. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

New bibliometric and experimental data have been created and shared via Google Drive. Relevant links are provided in the text of this paper.

Conflicts of Interest

The authors declare no conflict of interest.

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Declaration on Generative AI

During the preparation of this work, the authors used X-GPT-4 to assist with writer's block, Grammarly for spelling checks and Claude Sonnet to improve the clarity of sentences.

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