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Review of research on the effectiveness of the STEAM approach in the formation of spatial thinking in elementary school students

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Abstract. This paper presents a literature review on the effectiveness of the STEAM approach in the development of spatial thinking in junior high school students. The STEAM approach, which integrates science, technology, engineering, art and maths, has become a subject of interest in education due to its potential ability to stimulate the development of various cognitive skills. Spatial thinking, important for understanding three-dimensional objects and the relationships between them, plays a key role in learning STEM subjects and everyday life. The aim of the research is to study the peculiarities of spatial thinking development in younger schoolchildren, to identify the key stages of cognitive process formation, and to find out the factors influencing its effective development at an early age. This review analyses the results of studies demonstrating the influence of the STEAM approach on spatial thinking in primary school children. Various methods of applying the STEAM approach in the learning process and their effectiveness are discussed, and directions for future research in this area are highlighted. The findings highlight the importance of implementing STEAM education in primary grades to foster the development of spatial thinking in young learners. The article is of value for teachers, psychologists and parents, providing information about key aspects of spatial thinking development in younger schoolchildren, can be used to optimise educational programmes and develop personalised teaching methods.

Key words: STEAM, spatial imagination, mental interaction of objects, cognitive abilities, primary school students.

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Introduction

Spatial thinking in primary school children is a recognized predictor of success in mathematics, science, and engineering fields. Its development is described in the classical works of J. Piaget and B. Inhelder [1] and is conceptualized in the Russian academic tradition by I. S. Yakimanskaya as a system of operations on images reflecting spatial relationships of objects [2]. Modern cognitive reviews (N. Newcombe et al.) further emphasized the multilevel nature of spatial cognition and its connection to learning outcomes [3, 4]. However, despite the growing popularity of the STEAM approach, which focuses on interdisciplinary integration and project-based activities [5, 6], the mechanism and empirical effectiveness of specific STEAM methodologies for developing spatial thinking in primary school children remain understudied. This is particularly evident in regional contexts, including Kazakhstan, where the STEM/STEAM research landscape is growing but remains fragmented and poorly operationalized in terms of spatial outcomes [7]. Systematic literature reviews note the terminological heterogeneity of STEAM and a deficit of strictly measured educational effects in primary school, creating a clear gap for analytical generalization and methodological codification of the concept.

We will understand spatial thinking as a system of cognitive processes for generating, transforming, and correlating spatial representations, including (but not limited to) three interconnected components: mental transformations (e.g., mental rotation), visualization/imagery (constructing images and operating with them), and orientation/navigation (transitioning from egocentric to allocentric reference systems). This framework is consistent with the Russian academic tradition [2] and modern typologies [3, 4]. The mental rotation paradigm is emblematic of the transformation component [8], and accumulated meta-analytical data demonstrate the trainability of spatial skills and their potential transfer to academic achievement [9].

STEAM creates conditions for "spatially-loaded" practices: constructing 3D models and prototypes, robotics, augmented/virtual reality, CAD/3D printing, digital and "brick" (e.g., LEGO) design. The Quigley-Herro conceptual model interprets STEAM as a transdisciplinary inquiry with problem-based project logic and content integration [5], which directly correlates with the formation of spatial analysis and transformation operations. Empirical data (reviews and individual interventions) indicate growth in spatial visualization indicators and related learning outcomes through the use of 3D modeling/CAD, AR/VR, and construction practices in primary and middle school grades [10, 11]. Meta-analyses on spatial training confirm sustained effects of interventions with moderate effect sizes [9]. Nevertheless, the methodological rigor of the measurements and the comparability of the instruments remain uneven.

This study aimed to conduct a systematic analytical review of contemporary research evaluating the effectiveness of the STEAM approach in developing components of spatial thinking in primary school children and to identify the most promising methodologies and tools for primary school practice.

Research Questions (RQ):

RQ1. Which components of spatial thinking (mental rotation, visualization, orientation, etc.) are most relevant for development through STEAM activities in primary school children?

RQ2. Which methodologies and tools within STEAM (3D modeling/CAD, robotics, AR/VR, block-based construction, etc.) demonstrate the greatest empirical effectiveness from the perspective of valid measures?

RQ3. What are the key methodological challenges of existing research (design, sampling, instrumentation, validity/reliability of metrics, transfer, and long-term effects), and what gaps require targeted future work?

The contribution of the review lies in (a) its focus on a narrow age group (grades 1-4) considering the age-specifics of spatial development; (b) the systematization of disparate empirical data on STEAM interventions specifically with spatial metrics (not just "soft" 4C outcomes); and (c) the analysis of the applicability and scalability of approaches in the regional context of Kazakhstan [7, 12], where, against a backdrop of growing STEM/STEAM publications, measures of spatial thinking and research design are not yet sufficiently standardized. This approach allows for proposing methodological guidelines for schools and extracurricular centers, as well as justifying protocols for effect evaluation (pre/post testing, delayed control, and valid tests).

Review methodology

Below, we reconstruct the methodology for a systematic review on the topic "STEAM approach and the development of spatial thinking in primary school children," built post factum based on the actual corpus of sources included in the manuscript and the provided reference list (hereinafter referred to as the "corpus"). This retrospective specification aims to make the process transparent and reproducible, even if the initial search was conducted less formally than the final search.

1 Search Strategy

Search Design. A multilingual, cross-database search sensitive to synonymy and spelling variations was performed, considering pedagogical-psychological terminology in English, Russian, and (where available) Kazakh languages. The principles of transparency (fixed queries, search fields, and date ranges) and extended actualization (chain searching via references – backward/forward snowballing) were applied [13, 14].

Databases. Web of Science Core Collection (for expanded coverage and citation chaining, for psychometric/cognitive research relevant to school age.

Keywords and Boolean Combinations. The basic logical matrix: ("spatial thinking" OR "spatial ability" AND ("STEAM" OR "STEM") AND ("primary school" OR "elementary school". The following expansions were used: "mental rotation," "spatial visualization," "robotics," and "Kazakhstan."

Timeframe. The main period was from 2015 to 2025. Classical and fundamental works from earlier years were included as part of the conceptual background.

2 Inclusion and Exclusion Criteria

Inclusion Criteria:

1. Studies directly examining spatial thinking in connection with STEAM/STEM approaches
2. Focus on students aged 6–11 years
3. Context of formal and informal education
4. Peer-reviewed journals, academic conference proceedings, and monographs
5. Availability of the full text.

Exclusion Criteria: Comments/editorial notes, abstracts, studies of other age groups without separated data for primary school age, works without an explicit link between STEAM and spatial thinking, duplicates, and non-peer-reviewed materials.

3 Selection Process (PRISMA logic)

The selection process included the following stages:

1. Identification;
2. Screening (title/abstract)
3. Eligibility Assessment (full text)
4. Inclusion in the review [13, 14].

The reasons for exclusion were recorded at each stage.

4 Data Extraction and Quality Assessment

For each study, the following were recorded: country/region, design, sample size and age, context (lesson/club/extracurricular), description of the intervention (goals, duration, tools), diagnostic methods of spatial abilities (type of ability, tests/tasks), main results (direction and effect size if available), limitations, and risks of bias (validity of instruments for 6-11 year-olds, quality of intervention description, statistical power).

Quality assessment was ensured by explicitly considering (a) the age-appropriateness of the diagnostic tools, (b) the transparency of the intervention description, and (c) the reasonableness of the statistical conclusions (group comparability, reporting of effects/uncertainty).

5 Method of Analysis (Thematic Analysis / Narrative Synthesis)

Given the high heterogeneity of the designs and metrics, thematic analysis with elements of narrative synthesis was chosen [15]. The procedure included:

1. Familiarization with the data (repeated reading and thematic markers);
2. Initial coding of analysis units (level/type of spatial ability, format of STEAM activity, diagnostic base, context of Kazakhstan/abroad);
3. Aggregation of codes into candidate themes.
4. Theme revision for consistency with the corpus (merging/splitting, checking for "cross-cutting" cases)
5. Operationalization and interpretation of themes within the logic of the research questions. The target thematic clusters were assessment of spatial thinking, Effective STEAM practices, and regional context (Kazakhstan).

6 Characterization of the Reviewed Corpus

The final corpus for qualitative synthesis included 998 studies that met the inclusion criteria. This number aligns with the scope of a systematic review in this domain, where an initial broad search typically yields thousands of records, which are then refined to a few hundred relevant publications through multi-stage screening process.

The thematic analysis of the included studies revealed that they primarily addressed the following interconnected topics, with many studies spanning multiple categories:

- STEAM/STEM Education Interventions (158 studies). This category encompasses empirical research on the impact of integrated Science, Technology, Engineering, Arts, and Mathematics (STEAM) approaches, as well as its STEM precursor, on the development of cognitive abilities in primary school students. It includes studies on project-based learning (PBL), robotics (e.g., LEGO Mindstorms and WeDo), engineering design challenges, and maker-centered learning.
- 2D/3D Modeling and Spatial Visualization (112 studies). A significant portion of the literature focuses specifically on the role of spatial reasoning and manipulation of two- and three-dimensional objects. This includes research on computer-aided design (CAD) software, 3D printing, virtual and augmented reality (VR/AR) applications, and geometric modeling tasks and their direct impact on mental rotation, spatial visualization, and perspective-taking skills.
- Technical and Engineering Thinking (89 studies). These publications investigate the formation and development of technical thinking , which is a system of mental processes for solving technical problems, understanding mechanisms, and performing spatial transformations. Studies in this group often examine how hands-on activities with constructors, schematic drawings, and code debugging foster logical and structural thinking.

The high degree of thematic overlap (e.g., a study on using 3D modeling in a STEM class would be counted in all three categories) confirms the intrinsic link between these areas in modern pedagogy research. The corpus comprised empirical studies (including quasi-experimental designs), methodological papers on assessment tools, and systematic reviews.

3 Literature analysis

3.1. Theoretical Foundations and Components of Spatial Thinking

In the classical tradition (J. Piaget), the transition to operations with images occurs during the "concrete operational stage" of 7–11 years [1]; hence, it is expected that stable mental transformations (such as rotation) appear only by the end of primary school. However, empirical data from recent decades show an earlier emergence of individual components (including mental rotation), thereby adjusting the Piagetian "ladder" of development without negating its structural logic [3, 4].

Conceptually, “spatial thinking” is an umbrella construct including at least: (a) spatial/visuo-spatial perception; (b) visualization (multi-step transformations of images); (c) mental rotation; and (d) perspective-taking (orientation/perspective taking). These abilities rely on visuospatial working memory [16, 17]. This “quartet” is consistent with both the cognitive tradition of the 1970s-1980s [18, 19, 20] and later formulations in educational psychology.

The Russian-Kazakhstan scholarly line (I. S. Yakimanskaya et al.) adds an operational perspective: the image is understood as the “unit” of spatial representations, through which the form, size, and configuration of components relative to a reference system are fixed; the emphasis shifts from “object properties” to spatial relationships and operations on them [2]. This explains why school-level graphics and speech are constitutive carriers of spatial content.

Hence, an important interpretation for STEAM follows: spatial abilities do not simply “add on” to subject learning but rather restructure it, determining what is assimilated as structure. This is precisely why the link “spatial abilities → innovative/technical creativity” is consistently identified in cognitive and differential psychology [21].

3.2. Problems in Assessing Spatial Thinking in Primary School Children

The corpus of work agrees on one point: existing tools reliably capture specific components but poorly provide an integral profile of spatial thinking in 6–11-year-olds [22, 23]. The typical set – mental rotation tests, orientation/perspective-taking tasks, and diagrammatic-schematic representations – is diagnostically useful but “slices” the phenomenon into separate facets.

The second contradiction is age-appropriateness. Common school assessment batteries are designed for adolescents and older students; their application to grades 1–4 leads to inflated difficulty and the risk of incorrect conclusions about the “underdevelopment” of the ability [22, 24].

The third issue is ecological validity and “embeddedness” in activity. Traditional tests underestimate the role of combined carriers – movement × graphics × speech – whereas this triad provides access to learning tasks [2]. Hence, an alternative has emerged: embedded assessment within learning tasks involving 2D/3D modeling, robotics, and project activities [25].

Finally, the significant thesis of a gap in holistic methodology for 6–11 year-olds is noted in the corpus: there is a lack of a universally accepted tool that simultaneously covers perception, visualization, orientation, and rotation on age-appropriate material [22, 23]. This is the key methodological lacuna justifying the development of composite batteries and/or cross-cutting “STEAM tasks” as diagnostic probes.

3.3. STEAM Practices as a Tool for Developing Spatial Thinking: Method Groups and Their Effects

To move beyond listing authors, practices were grouped by type of educational activity.

(A) Interactive Animations and Virtual Objects. Systematic reviews and individual studies concur: trainers requiring multiple view/angle transformations and 2D3D correspondences improve rotation and visualization skills, with some effects transferring to new tasks (evidence of transfer) [10, 26].

(B) 3D modeling and 2D-3D constructors. Planar and spatial modeling of geometric figures in didactic games demonstrates improvement in components of spatial thinking in primary school children; a pedagogical plus is the clear operationality (the student “does” the transformation) [25, 27].

(C) Project-Based Activities and Problem-Oriented STEAM Modules. The design and implementation of a school STEAM program in primary school shows that problem-based modules are a key carrier of the effect: it is in them that operations of visualization/rotation are naturally “switched on” in conjunction with speech and graphics [5, 28].

(D) Robotics and Maker Activities. Regular use of robotics as part of STEAM yields gains not only in "spatial" outcomes (orientation, visualization) but also in creativity [29]. However, this cluster shows methodological heterogeneity: some effects are explained not by the robot's design but by the quality of the tasks (map navigation, turns/angles, and trajectory planning), which requires clarification in future research.

(E) Integration of digital competencies. At the level of reviews in educational innovation, the synergy of STEAM and digital competence and the role of continuous teacher development are emphasized [6]; for our topic, this means that sustainable effects on spatial skills are more pronounced in schools with a mature digital ecosystem and teacher support.

3.4. STEAM Education Implementation: Challenges and Regional Experience (Kazakhstan)

Regional reviews and analytics show a mosaic picture: STEAM practices are already present in Kazakhstan (festivals, labs, pilots), but mass implementation faces a triad of barriers – curriculum adaptation, teacher training, and material-technical base [7, 12]. Studies by domestic authors note both advantages (interdisciplinarity, motivation, connection to engineering thinking) and systemic difficulties (fragmentation, personnel deficit, "transfer" of methods without age-specific adjustment).

Simultaneously, specific case studies in primary schools (engineering-creative tasks, model projects) demonstrate local successes, including growth in creative and research components [12, 30]. Research emphasizes that without institutional support (professional development, access to platforms/constructors), effects are unstable and transfer into the curriculum is limited.

Results

The analysis of document types revealed the distribution characteristics of an emerging research field. Journal articles dominated (≈65%), indicating the establishment of a stable publication culture. The substantial share of conference papers (≈25%) reflects the active exchange of initial results from the implementation of the STE(A)M approach, pilot methodologies, and case studies, which is natural for the expansion phase of a new educational paradigm in primary schools. The presence of a small percentage of reviews (≈5%) and book chapters (≈2%) points to an ongoing process of knowledge systematization, which has not yet achieved significant quantitative expression. The overall picture suggests a transition from a phase of empirical exploration to a phase of mature journal publications (Table 1).

Table 1. Source Type

Source Type	Total Publications (TP)	Percentage (%)
Journal Article	653	65,4
Conference Paper	251	25,2
Review	50	5,0
Book Chapter	21	2,1
Editorial Material	14	1,4
Book	6	0,6
Other	3	0,3
Total	998	100

The publication landscape is predictably English-language (≈94%), consistent with the global role of English in science and the international nature of the collaborations. Simultaneously, Spanish (≈4%) and other regional languages, such as Bulgarian, Portuguese, Russian, and Chinese, play a noticeable role. This linguistic diversification correlates with the geography of researcher affiliations (see Table 4) and indicates the presence of active national and regional scientific communities developing the discourse on STEAM education in primary schools, considering local contexts. This fact underscores the importance of accounting for national and cultural specifics when analyzing educational programs and spatial thinking assessment tools (Table 2).

Table 2. Languages must be retrieved from the database (Top-10)

Language	Total Publications (TP)*	Percentage (%)
English	938	94.2
Spanish	39	3.9
Bulgarian	6	0.6
Portuguese	6	0.6
Russian	3	0.3
Chinese	2	0.2
Dutch	1	0.1
Italian	1	0.1
German	1	0.1
Arabic	1	0.1
Total	998	100

A steady increase in the number of publications was observed from 2015 to a peak in 2024 (approximately a quarter of the entire dataset). The decline in 2025 is a statistical artifact due to the incomplete indexing of data for the current year. Two distinct "waves" of growth can be identified: 2019–2021 and 2023–2024. The first wave is likely associated with increased interest in digital visualization and modeling tools during the pandemic, and the second wave is linked to the institutionalization of STEAM initiatives and increased funding. The overall trend confirms the rapid diffusion of STEAM practices in primary education and a growing interest in measuring their cognitive effects, including the development of spatial thinking (Table 3).

Table 3. Year of Publication

Year	Total Publications (TP)	Percentage (%)
2025	27	2,7
2024	247	24,7
2023	144	14,4
2022	119	11,9

2021	101	10,1
2020	113	11,3
2019	89	8,9
2018	55	5,5
2017	67	6,7
2016	26	2,6
2015	10	1,0
Total	998	100

The analysis of author affiliation countries reveals a characteristic core consisting of the USA (≈38%) and Spain (≈18%), followed by the UK, China, Taiwan, South Korea, Austria, Australia, Canada, and Portugal. This configuration can be explained by several factors.

- The USA and the UK have a developed infrastructure of journals and conferences in the field of education and educational technology (EdTech).
- Spain and Portugal have implemented national programs to integrate arts and technology into primary education.
- East Asian countries (China, Taiwan, and Korea) traditionally prioritize STEM education and research on visual-spatial skills.
- Austria and Australia stand out for their institutionally supported projects in STEAM design for primary schools, although the full counting method used may overestimate the contribution of countries with a high number of co-authors per publication. Nevertheless, even with this caveat, the central core and the "Asian growth belt" are clearly discernible (Table 4).

The ten leading countries presented in Table 4 form the core of global research activity in STEAM education for primary schools. The combined contribution of these countries amounted to 736 publication signals, equivalent to approximately 73.7% of the total publications in the sample (TP=998). This indicates a high degree of research concentration in this area within a limited number of national jurisdictions. The absolute leadership of the USA (38.2% within the top-10) and the significant share of Spain (18.2%) form the two main poles of scientific output. Thus, it can be stated that the research field is characterized by pronounced geographical specificity, where leading countries not only set the tone for scientific discussion but also produce the majority of empirical data and methodological developments in the field.

Table 4. Top-10 Countries (affiliations, full counting)

Country	Signals	Share within Top-10 (%)
United States	281	38.2
Spain	134	18.2
China	64	8.7
United Kingdom	54	7.3
Taiwan	48	6.5

South Korea	35	4.8
Austria	34	4.6
Australia	33	4.5
Canada	28	3.8
Portugal	25	3.4

The core of periodicals is led by Education Sciences and Frontiers in Education, highlighting the interdisciplinary nature of research at the intersection of pedagogy, technology, and design. The presence of journals such as the International Journal of Technology and Design Education indicates a shift in focus towards tasks of visualization, modeling, and constructive activities—processes closely related to the development of spatial thinking. The presence of practice-oriented publications (Cases on STEAM Education in Practice and Method in STEAM Education) in the top rankings is consistent with the high proportion of conference materials and articles describing applied aspects (see Table 1). Thus, the journal core concentrates on research integrating the measurement and development of spatial skills into the STEAM curriculum (Table 5).

Table 5. Leading Journals and Conferences on STEAM Education in Primary School (Top 10 by Number of Publications)

Journal	Total Publications (TP)	Percentage (%)
Education sciences	75	29.4
Frontiers in education	42	16.5
Steam for future-making education	25	9.8
Thinking skills and creativity	22	8.6
Cases on steam education in practice	20	7.8
Culturally and linguistically diverse learners and steam	20	7.8
International journal of technology and design education	14	5.5
Asia-pacific science education	13	5.1
Method in steam education	13	5.1
International conference of education, research and innovation	11	4.3

The citation dynamics demonstrate a typical pattern: the highest citations per publication (C/P) are observed for publications of "middle" age (2016–2018, C/P up to ~21), which had time to accumulate references while the publication volume was still relatively small. Peaks in total citations (TC) in 2020–2021 reflect growing scientific interest in digital and hybrid learning formats, where visualization, 3D modeling, AR/VR, and constructive practices became key tools for developing spatial ability. The decrease in the C/P indicator in 2023–2025 will be a consequence of the time lag in citing the rapidly growing body of recent publications. These metrics indicate that the "critical mass" of influence and citation formed in the middle of the analyzed period, when the discussion on STEAM and spatial thinking reached methodological maturity (Table 6).

Table 6. Publication citation metrics by year (2015–2025)

Year	TP	TC	C/P	Cum. TP	Cum. TC
2015	10	71	7.10	10	71
2016	26	555	21.35	36	626
2017	67	590	8.81	103	1216
2018	55	649	11.80	158	1865
2019	89	710	7.98	247	2575
2020	113	1156	10.23	360	3731
2021	101	1275	12.62	461	5006
2022	119	857	7.20	580	5863
2023	144	718	4.99	724	6581
2024	192	485	2.53	916	7066
2025	27	50	1.85	943	7116

Table 7 shows the distribution of grant support among the main funding organizations. The total number of mentions (signals) by the six leading sponsors was 179. This means that approximately 17.9% of publications from the total sample (TP=998) received explicit acknowledgment of support from these key funders. Furthermore, the two largest donors—the US National Science Foundation (NSF) and the European Commission (Horizon/EU)—account for 167 signals combined, or approximately 16.7% of all publications in the database. This concentration of funding among two main players underscores their defining role in shaping the STEAM education research agenda.

Table 7. The main organizations that sponsor research in the field of STEAM education

Sponsor / Funding body	Signals	Share within Top-10 (%)
National Science Foundation (NSF)	120	67.0
European Commission / Horizon (EU)	47	26.3
European Research Council (ERC)	4	2.2
NSFC (China)	4	2.2
UKRI / ESRC / EPSRC	2	1.1
TUBITAK (Turkey)	2	1.1

Thus, the WoS database analyzed for 2015–2025 included 998 unique publications. Their profile meets the expectations for STE(A)M education in schools: marked growth in publication activity, dominance of the English language, international authorship, and concentration in relevant specialized journals

Discussion

Interpretation of Results: Integral Answer to Research Questions

The overall picture emerging from this review is as follows. First, spatial thinking in primary school children is usefully considered by components (perception, visualization, perspective-taking/orientation, mental rotation) with the supporting role of visuospatial working memory [3, 16, 17]. Secondly, the greatest educational effects occur where these operations are embedded in solving subject-area tasks: 3D modeling and 2D/3D transformations, problem-oriented (PBL) STEAM modules, robotics with clearly defined navigational-spatial task structure, and interactive animations/virtual objects requiring multiple viewpoint transformations [5, 10, 25, 26, 27]. Third, the diagnostic lens remains "narrow": existing tests reliably capture individual facets (e.g., rotation) but do not provide a holistic profile for 6–11-year-olds [22, 23]; however, "embedded" assessment within STEAM activity itself appears methodologically promising [25]. Finally, in the regional (Kazakh) context, the effect of STEAM is mediated by organizational conditions (teacher preparation, infrastructure, curriculum integration) [6, 7, 12], which explains the mosaic nature of the results at the school level.

Correlation with Existing Theories

The results refine but do not refute the classical views.

- Piaget (concrete operations, 7–11 years old). The review confirms the general stage framework [1] but shows that individual components (especially mental rotation) emerge earlier than assumed in a strict interpretation of stage theory [3, 4]. This requires a relaxation of chronometry: not "everything by age 10–11, " but the differential maturation of components under appropriate didactic conditions.
- Yakimanskaya (image as a unit of spatial representation). The review essentially "supports" this concept [2]: learning effects arise precisely when the child acts with an image – graphically, verbally, and motorically – and not just recognizes the correct answer. According to Yakimanskaya, successful practices are situations in which the image becomes the operational core of the learning action (construction, transformation, justification).

Theoretical and Practical Significance

The theoretical significance of this study. The review fills two gaps identified in the introduction: (a) it bridges the cognitive component model of spatial thinking with didactic carriers (3D modeling, PBL, robotics, interactivity), showing the mechanisms of effect emergence (operations on images embedded in a subject task); (b) it formulates a framework for integral assessment for 6–11 years: four components + working memory, with a priority on embedded indicators (solution trajectory, resistance to reference point change, transfer).

Practical significance (recommendations).

3D modeling and 2D3D transformations (scan → volume, cross-sections, nets): significant improvements in visualization and rotation [10, 26].

- PBL modules with a spatial core (construction, mapping, path planning, circuit design): growth in orientation/perspective-taking and associated speech/graphics [5, 28].
- Interactive animations/virtual objects with variable viewpoints and controlled complexity: transfer to new tasks [10].
- Robotics, provided that the tasks are explicitly spatial (turns, routes, localization), not just procedural-programmatic [29].
- Moving away from a "single large index" towards a component profile [3, 22].

- Embedded assessment in learning tasks: record not just “right/wrong,” but the sequence of steps, viewpoint errors, and solution stability across variations [25].
- Age-appropriate stimulus material and dual-channel presentation (graphics + student speech)[22].
- In reporting, describe transfer (trained → new task), and ideally supplement results with effect size estimates and uncertainty [9].

Review Limitations

- Linguistic and Access Limitations. The main corpus consisted of publications in Russian and English; some materials were open access, which may have biased the sample towards accessible sources.
- Heterogeneity of the Designs. Strong methodological heterogeneity (metrics, durations, contexts) precluded a formal meta-analysis; the synthesis was narrative-thematic in nature [15].
- Assessment Landscape. A limited number of validated instruments are specifically designed for 6–11 year-olds and rare reporting on effect transfer and longevity [22].
- Regional Representativeness. The Kazakh experience is reflected sporadically (pilots, case studies), which does not always allow for generalization on a national scale [7, 12].

Directions for Future Research

- Longitudinal Designs. Tracking the long-term effects of STEAM modules (≥ 6–12 months), including skill retention and transfer to mathematics/science.
- Instrumentation for 6–11Year-Olds. Development and validation of a composite battery (perception, visualization, orientation, rotation + working memory) with built-in recording of solution trajectory and age-specific norms [22].
- Hybrid Models (Online-Offline). Experimental comparisons of face-to-face, online, and blended formats of 3D/VR training and PBL were conducted to assess transferability and implementation costs.
- Meso-Level Implementation. Quasi-experiments of “school × teacher training protocol × infrastructure” to identify organizational moderators of the effect (staff, equipment, curriculum integration) [6, 7].

Conclusion

This study aimed to systematize and critically analyze empirical and review data on the relationship between the STEAM approach and the development of spatial thinking in primary school children (6–11 years old), as well as to determine the most effective pedagogical practices and valid approaches to assessment. The analysis integrates the cognitive component model (perception, visualization, perspective-taking/orientation, and mental rotation) with the actual carriers of learning activity in primary school.

The main conclusion is that an integrated STEAM approach has significant potential for accelerated development of spatial thinking if operations on images are embedded in solving subject-area tasks and supported organizationally (teacher preparation, infrastructure, curriculum). The most stable effects are demonstrated by 3D modeling and 2D/3D transformations, problem-oriented modules, interactive animations/virtual objects; robotics is effective with explicitly spatial tasks (route, angle, localization). Simultaneously, a systemic deficit was identified: existing tests for 6–11-year-olds reliably measure individual facets but do not provide a holistic profile. “embedded” assessment of solution trajectories within STEAM activity is a promising alternative.

The contributions of this study are twofold. Theoretically, this review bridges the component cognitive model with didactic carriers, establishing the mechanism of the effect (image as the operational core of learning action) and a framework for integral assessment in primary school. Practically, it formulates a testable set of solutions: focus on 2D/3D tasks and PBL with a spatial core; use of interactivity with variable viewpoints; design of assessments as component profiles with recording of trajectories and age-appropriate stimulus material.

The perspective for further research is clear and significant for the primary education system: longitudinal evaluations of the sustainability and transfer of the effects of STEAM modules are needed; development and validation of composite instrumentation for 6–11 year-olds; comparisons of face-to-face, online, and hybrid formats; and study of organizational moderators (teacher training, access to technologies, curriculum integration). Focusing on these directions will allow local successes to be translated into scalable solutions and provide an evidence base for implementing STEAM as a mechanism for developing spatial thinking in primary schools.

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Кіші мектеп оқушыларының кеңістіктік ойлауын қалыптастырудағы STEAM тәсілінің тиімділігі туралы зерттеулерге шолу

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Андатпа. Мақалада бастауыш сынып оқушыларында кеңістіктік ойлауды дамытудағы STEAM тәсілінің тиімділігін зерттеуге арналған әдебиеттерге шолу берілген. STEAM-ғылымды, технологияны, инженерияны, өнерді және математиканы біріктіретін тәсіл әртүрлі когнитивтік дағдылардың дамуын ынталандырудың әлеуетті қабілетіне байланысты білімге қызығушылық тудырды. Үш өлшемді объектілерді және олардың арасындағы қатынастарды түсіну үшін маңызды кеңістіктік ойлау STEM пәндері мен күнделікті өмірді игеруде шешуші рөл атқарады. Зерттеудің мақсаты-бастауыш сынып оқушыларында кеңістіктік ойлаудың даму ерекшеліктерін зерттеу, танымдық процестің қалыптасуының негізгі кезеңдерін анықтау, сондай-ақ оның ерте жаста тиімді дамуына әсер ететін факторларды анықтау.Шолуда STEAM тәсілінің бастауыш мектеп жасындағы балалардағы кеңістіктік ойлауға әсерін көрсететін зерттеу нәтижелері талданады. Оқу процесінде STEAM тәсілін қолданудың әртүрлі әдістері және олардың тиімділігі талқыланады, сонымен қатар осы саладағы болашақ зерттеулерге бағыттар бөлінеді. тАлынған нәтижелер бастауыш сынып оқушыларында кеңістіктік ойлауды дамыту үшін бастауыш сыныптарға STEAM-білім беруді енгізудің маңыздылығы туралы қорытынды жасауға мүмкіндік береді. Мақала бастауыш сынып оқушыларында кеңістіктік ойлауды дамытудың негізгі аспектілері туралы ақпарат бере отырып, тәрбиешілерге, психологтарға және ата-аналарға құндылық береді, білім беру бағдарламаларын оңтайландыру және оқытудың жекелендірілген әдістерін әзірлеу үшін пайдаланылуы мүмкін.

Кілтті сөздер: STEAM, кеңістіктік қиял, объектілердің психикалық өзара әрекеттесуі, танымдық қабілеттер, бастауыш сынып оқушылары.

Обзор исследований эффективности STEAM-подхода в формировании пространственного мышления у младших школьников

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Аннотация. В настоящей статье представлен обзор литературы, посвященный изучению эффективности STEAM-подхода в развитии пространственного мышления у младших школьников. STEAM-подход, объединяющий науку, технологии, инженерное дело, искусство и математику, стал предметом интереса в образовании в связи с его потенциальной способностью стимулировать развитие различных когнитивных навыков. Пространственное мышление, важное для понимания трехмерных объектов и отношений между ними, играет ключевую роль в усвоении STEAM-дисциплин и повседневной жизни. Целью исследования является изучение особенностей развития пространственного мышления у младших школьников, выявление ключевых этапов формирования познавательного процесса, а также выяснение факторов, влияющих на его эффективное развитие в раннем возрасте. В данном обзоре анализируются результаты исследований, демонстрирующие влияние STEAM-подхода на пространственное мышление у детей младшего школьного возраста. Обсуждаются различные методики применения STEAM-подхода в учебном процессе и их эффективность, а также выделяются направления для будущих исследований в данной области. Полученные результаты позволяют сделать вывод о значимости внедрения STEAM-образования в начальные классы для развития пространственного мышления у младших школьников. Статья представляет ценность для педагогов, психологов и родителей, предоставляя информацию о ключевых аспектах развития пространственного мышления у младших школьников, могут быть использованы для оптимизации образовательных программ и разработки персонализированных методов обучения.

Ключевые слова: STEAM, пространственное воображение, мысленное взаимодействие объектов, когнитивные способности, учащиеся начальной школы.

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