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The Impact of STEAM Education on 21st - Century Skills Development among Cycle One Students: A Mixed-Methods Investigation in South Lebanon

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Abstract

This study investigates the relationship between Science, Technology, Engineering, Arts, and Mathematics (STEAM) education and the development of four critical 21st- century skills - creativity, critical thinking, collaboration, and communication - among Cycle One students (Grades 1-3) in South Lebanon. A concurrent triangulation mixed-methods design was employed, combining quantitative and qualitative approaches. The study involved 100 Cycle One students (ages 6-9) and 30 mathematics and science teachers from eight private schools in South Lebanon that integrated STEAM Education into their curriculum. Data collection utilized validated questionnaires for both student and teacher participants, complemented by structured observation checklists. Reliability analysis confirmed strong internal consistency (Cronbach's $\alpha = 0.891$ for teachers' questionnaire). Regression analysis was conducted to examine relationships between STEAM education integration and each of the four target skills. Results revealed significant positive relationships between STEAM education and three of the four skills: creativity ($R^2 = 0.435$, $p < 0.001$), collaboration ($R^2 = 0.176$, $p = 0.033$), and communication ($R^2 = 0.772$, $p < 0.001$). However, no statistically significant relationship was found between STEAM education and critical thinking ($R^2 = 0.114$, $p = 0.092$). Communication skills showed the strongest correlation, with STEAM education explaining 77.2% of the variance. These findings provide empirical evidence for the effectiveness of STEAM education in developing specific 21st- century competencies. The results inform educational stakeholders about the differential impact of STEAM approaches and highlight the need for targeted pedagogical strategies to maximize critical thinking development. The study contributes to the growing body of literature on STEAM education effectiveness and offers practical guidance for educators in elementary education settings.

***Keywords*:** STEAM education, collaboration skills, communication skills, creativity skills, critical thinking skills

الملخّص

تبحث هذه الدّراسة في العلاقة بين تعليم العلوم والتّكنولوجيا والهندسة والفنون والرّياضيات(STEAM) ، وفي تنمية أربع مهارات أساسيّة من مهارات القرن الحادي والعشرين، ألا وهي: الإبداع، والتّفكير النّاقد، والتّعاون، والتّواصل، لدى متعلّمي الحلقة الأولى (الصّفوف 1–3) في جنوب لبنان. اعتمدت الدّراسة تصميمًا مختلطًا باستخدام أسلوب التّثليث المتزامن الّذي يجمع بين النّهجين الكمّيّ والنّوعيّ. شملت العيّنة 100 متعلّم من الحلقة الأولى (تتراوح أعمارهم ما بين 6 إلى 9 سنوات)، و30 معلّمًا لمادّتي الرّياضيات والعلوم في عدد من المدارس الخاصّة في جنوب لبنان. جُمِعَت البيانات باستخدام استبيانات مُقنّنة لكلّ من المتعلّمين والمعلّمين، مدعومة بقوائم ملاحظة منظّمة. وأكّد تحليل الصّدق والثّبات قوّة الاتّساق الدّاخليّ لاستمارة المعلّمين (كرونباخ $\alpha = 0.891$). كما أُجرِي تحليل انحدار لدراسة العلاقة بين دمج تعليم STEAM وكلّ مهارة من المهارات الأربع

المستهدفة. أظهرت النّتائج وجود علاقات إيجابيّة ذات دلالة إحصائيّة بين تعليم STEAM وثلاث من المهارات الأربع: الإبداع ($R^2 = 0.435, p < 0.001$)، التّعاون ($R^2 = 0.176, p = 0.033$) ، والتّواصل ($R^2 = 0.772, p < 0.001$) . في المقابل، لم يُسجّل ارتباط ذو دلالة إحصائيّة بين تعليم STEAM والتّفكير النّاقد ($R^2 = 0.114, p = 0.092$) . وقد برزت مهارات التّواصل بوصفها الأقوى ارتباطًا، إذ فسّر تعليم STEAM ما نسبته 77.2% من التّباين. توفّر هذه النّتائج دليلًا تجريبيًّا على الفعاليّة الانتقائيّة لتعليم STEAM في تنمية بعض كفاءات القرن الحادي والعشرين. كما تُفيد صنّاع القرار التّربويّ بشأن الأثر التّفاضليّ لمقاربات STEAM ، وتبرز الحاجة إلى استراتيجيات بيداغوجيّة موجَّهة لتعزيز تطوير التّفكير النّاقد. وتُسهم الدّراسة في إثراء الأدبيّات المتنامية حول فاعليّة تعليم STEAM ، وتقدّم توجيهات عمليّة للمعلّمين في بيئات التّعليم الأساسيّ.

Introduction

In the context of rapid global transformation, education systems are increasingly challenged to evolve in ways that prepare learners for the complexities of the twenty-first century. The integration of Science, Technology, Engineering, Arts, and Mathematics (STEAM) education has emerged as a promising pedagogical approach to meet these demands. STEAM education is designed to foster interdisciplinary learning, creativity, and problem-solving by merging traditionally disconnected subjects into cohesive, experiential learning environments (Bassachs et al., 2020). Originating from the STEM initiative launched by the National Science Foundation in the 1990s, STEAM gained momentum with the inclusion of the arts, championed by Dr. Georgette Yakman, who argued that artistic expression enhances critical thinking and communication (Yakman, 2008). This educational model aims to equip students with the skills necessary to thrive in a dynamic, technology-driven world, including the core competencies known as the 4Cs: creativity, collaboration, communication, and critical thinking (White, 2014).

In Lebanon, the urgency to reform educational practices is underscored by ongoing economic and political instability, which has significantly impacted the quality and relevance of schooling (Afach & Kebbi, 2022). As global trends emphasize digital literacy, sustainability, and innovation, Lebanese schools face mounting pressure to align with international standards and prepare students for future challenges. The integration of STEAM education offers a pathway to bridge the gap between local educational conditions and global expectations. However, despite its growing prominence worldwide, STEAM remains underexplored and inconsistently implemented in Lebanese classrooms, particularly at the primary level. This gap is especially pronounced in Cycle One classrooms, which include first, second, and third graders - an age group critical for foundational skill development.

The integration of STEAM education in Lebanese Cycle One classrooms presents a complex challenge shaped by inconsistent practices and limited systemic support. Despite the global recognition of STEAM's potential to cultivate essential twenty-first-century skills - such as creativity, collaboration, communication, and critical thinking - its application within Lebanon remains fragmented and uneven (El-Sayegh, 2018; Chaya, 2023).

Schools often adopt isolated elements of the approach without a cohesive framework, and many educators lack the necessary training to implement interdisciplinary, inquiry-based strategies effectively. This fragmented implementation restricts students' exposure to the kind of experiential learning that characterizes successful STEAM education and may hinder the development of skills needed to navigate an increasingly complex and competitive world.

Moreover, regional disparities in educational resources and pedagogical innovation further complicate the situation. While main cities like Beirut may have greater access to STEAM-related initiatives, peripheral areas such as South Lebanon are often underrepresented in both practice and research. This uneven distribution of educational opportunities raises concerns about equity and the capacity of the national education system to prepare all learners for future challenges. Without a

structured and well-supported integration of STEAM principles, students may miss out on critical learning experiences that foster higher-order thinking, problem-solving, and collaborative engagement - skills that are increasingly vital in today's global landscape (White, 2014; Bassachs et al., 2020).

Given these challenges, the purpose of this study is to explore the relationship between STEAM education and the development of twenty-first century skills among Cycle One students in South Lebanon. Specifically, the research focuses on the four core competencies - creativity, collaboration, communication, and critical thinking - that are widely recognized as essential for success in the modern world (Vivekanandan & Pierre-Louis, 2020). By examining how STEAM-based activities influence these skills, the study aims to provide empirical evidence that can inform curriculum development, teacher training, and educational policy. The research adopts a mixed-methods approach, combining quantitative data from student and teacher questionnaires with qualitative insights from classroom observations. This triangulated design enhances the validity of the findings and offers a comprehensive understanding of how STEAM practices are enacted and experienced in real educational settings.

The study is guided by four central research questions that reflect its core objectives. The first question is: What is the relationship between STEAM education and Cycle One students' creativity? Creativity, defined as the ability to generate original ideas and make unconventional connections, is a key outcome of interdisciplinary learning and hands-on exploration (Brandt & Christopher, 2021). The second question is: What is the relationship between STEAM education and the development of Cycle One students' critical thinking? Critical thinking involves analyzing information, evaluating arguments, and making reasoned decisions (Evans, 2020b). The third question is: What is the relationship between STEAM education and Cycle One students' collaboration skills? Collaboration is understood as the capacity to work effectively with others toward shared goals (Evans, 2020a). The last question is: What is the relationship between STEAM education and Cycle One students' communication? Communication skills encompass both verbal and non-verbal expression and the ability to engage in meaningful dialogue (Thompson, 2020).

These questions are particularly relevant in the Lebanese educational context, where traditional teaching methods often prioritize rote memorization over experiential learning. By focusing on Cycle One students, the study addresses a critical developmental stage where foundational skills are formed and where innovative pedagogies can have lasting impact. The findings are expected to contribute to both local and international literature on STEAM education, offering insights into how interdisciplinary approaches can be adapted to diverse cultural and institutional settings.

Literature Review

STEAM Education: Historical Development

The development of STEAM education is rooted in the broader STEM movement initiated by the National Science Foundation (NSF) in the early 1990s, which was a strategic response to global industrial and technological competition. STEM originally focused on strengthening education in science, technology, engineering, and mathematics to meet workforce demands and national innovation goals (White, 2014). In the late 2000s, Dr. Georgette Yakman introduced the STEAM framework by incorporating the arts into STEM, arguing that this integration enhances learners' critical thinking, creativity, and communication skills - key competencies for navigating complex, real-world challenges (Yakman, 2008). The significance of STEAM was further elevated in 2011 when the President of the United States announced a national initiative to prepare 100,000 new teachers in STEAM disciplines. This effort aimed to equip students with the cognitive and creative skills necessary

to become innovative problem solvers and competitive contributors to the evolving global workforce (White, 2014).

Pedagogical Approaches

STEAM education is grounded in student-centered pedagogical approaches that actively engage learners in constructing knowledge through experiential and interdisciplinary methods. Among the most prominent strategies are project-based learning, which immerses students in extended tasks that require them to investigate complex questions and synthesize solutions across multiple disciplines (Martinez & Stager, 2019); inquiry-based learning, which fosters curiosity and critical thinking by encouraging students to formulate hypotheses, conduct research, and draw evidence-based conclusions (Malecha, 2020); and hands-on activities, where learners manipulate materials and interact directly with phenomena to bridge concrete experiences with abstract concepts (Bassachs et al., 2020). Additionally, technology-enhanced learning plays a vital role by integrating digital tools and platforms that expand access to authentic data, simulations, and collaborative environments (Chaya, 2023). These approaches reflect the principles of constructivist and socio-constructivist theories, particularly those of Dewey and Vygotsky, emphasizing experiential, reflective, and socially mediated learning (Lind, 2023; Newman & Latifi, 2020). By embedding these strategies into instructional practices, STEAM education cultivates essential twenty-first century skills such as creativity, collaboration, communication, and critical thinking, preparing learners to navigate real-world challenges in dynamic and inclusive learning environments.

STEAM Education

STEAM - an acronym for Science, Technology, Engineering, Arts, and Mathematics - is defined as an interdisciplinary teaching approach that removes barriers between subjects to promote holistic learning (Liu et al., 2021). Sanders (2009) described STEAM as the integration of two or more disciplines in authentic contexts, while Kelley and Knowles (2016) emphasized its connection to real-world problems. Despite the lack of a unified definition, STEAM is widely recognized for its capacity to engage students in meaningful, cross-disciplinary learning.

In Lebanon, however, STEAM implementation remains inconsistent. While many teachers associate STEAM with hands-on activities and student-centered learning, few incorporate project-based learning, engineering design, or technological literacy in a structured way (Chaya, 2023). Barriers include lack of vision, curricular constraints, limited resources, and insufficient teacher training (El-Sayegh, 2018). Teachers in Abu Dhabi, for example, reported time constraints, lack of planning time, and pressure from multiple responsibilities as obstacles to STEAM integration (Thibaut et al., 2018). Creating a supportive school environment for STEAM is costly and time-consuming, and professional development is essential to equip teachers with the necessary skills (DeJarnette, 2018).

21st-Century Skills Framework

Conceptual Development

Twenty-first-century skills have emerged as a holistic goal for educational systems and policies worldwide. These skills are defined as abilities that can be taught or learned to enhance one's capacity to succeed in life and work in the contemporary global environment. The concept encompasses a broad range of competencies beyond traditional academic subjects, reflecting the complex demands of modern society.

Various classification systems have been proposed for organizing 21st-century skills. Chalkiadaki (2018) categorized these skills under four domains: personal skills, social skills, information and knowledge, and digital literacy. The National Research Council (2012) organized 21st-century skills into three competency domains: cognitive, interpersonal, and intrapersonal, recognizing their interconnected and overlapping nature.

The Four C's Framework

This study centers on the "Four C's" framework - communication, collaboration, creativity, and critical thinking - which are widely recognized as foundational competencies for learners navigating the demands of the twenty-first century. Communication is understood not merely as the exchange of information but as a dynamic process shaped by beliefs, emotions, cultural norms, and social structures. It involves both verbal and non-verbal expression, active listening, and the ability to tailor messages to diverse audiences and contexts (Thompson, 2020). Collaboration, meanwhile, is a form of interdependent engagement where individuals work together to solve problems, accomplish shared goals, and construct collective understanding. It requires teamwork, conflict resolution, leadership, and the capacity to integrate varied perspectives (Evans, 2020a). Creativity is defined as a cognitive habit that blends divergent and convergent thinking, enabling learners to generate original ideas, forge unconventional connections, and devise innovative solutions to complex challenges (Brandt & Christopher, 2021). Finally, critical thinking encompasses the ability to systematically analyze problems, ask insightful questions, evaluate evidence, and interpret outcomes. It involves logical reasoning and the discernment of assumptions and biases within arguments and information (Evans, 2020). These four competencies are not only interrelated but also essential for learners to thrive in increasingly complex, interdisciplinary, and technology-driven environments, making their development a central focus of STEAM education and this research.

Previous Research on STEAM Education

Research on STEAM education has expanded significantly over the past decade, with studies examining various aspects of implementation and effectiveness. International research has demonstrated positive outcomes associated with STEAM approaches, particularly in terms of student engagement, motivation, and academic achievement. A meta-analysis by Becker and Park (2011) found that integrated STEM approaches led to improved student outcomes in mathematics and science achievement. However, most studies have focused on secondary education levels, with limited research examining elementary implementation and its impact on specific skill development. European studies have highlighted the importance of teacher preparation and professional development in successful STEAM implementation. Research by Honey et al. (2014) emphasized that effective STEAM education requires significant changes in teaching practices, curriculum design, and assessment approaches.

In the Middle Eastern educational context, research on STEAM education remains limited. In Jordan, Eitah and Abueita (2023) investigated the effectiveness of a STEAM-based learning approach by teaching educational robotics to Grade Eight students. Their experimental study ($n = 33$ in the STEAM group vs. $n = 31$ in the control group) used pre- and post-testing with Torrance's Creative Thinking assessment and applied MANCOVA analysis, revealing that students exposed to STEAM-based instruction demonstrated significantly higher creative-thinking skills compared to peers taught by traditional methods.

In the Lebanese context, educational research has traditionally focused on language education and traditional subject areas, with limited investigation of innovative pedagogical approaches. For instance, Chaya (2025) conducted a large-scale investigation in Lebanon using a systems-thinking framework to examine how STEAM curriculum design - emphasizing innovation, quality, and viability - affects students' problem-solving and interpersonal skills. The study surveyed 700 high school students and applied structural equation modeling to reveal that engagement mediates the relationship between curriculum design and skill development, with teaching practices and digital literacy acting as important moderators.

Although STEAM education has garnered increasing global attention, several notable gaps persist within the existing body of research specifically in Lebanon. Much of the literature has focused predominantly on secondary and post-secondary education, leaving elementary-level implementation and outcomes underexplored (Boice et al., 2021). Additionally, many studies tend to treat twenty-first century skills as a singular construct, without investigating how STEAM education may differentially influence specific competencies such as creativity, collaboration, communication, and critical thinking (Evans, 2020a; Evans, 2020b; Brandt & Christopher, 2021; Thompson, 2020). Another limitation lies in the cultural scope of current research, which is largely situated in Western educational contexts and may not translate effectively to Middle Eastern settings like Lebanon, where educational structures and sociocultural dynamics differ significantly (Afach & Kebbi, 2022; Chaya, 2023). In response to these gaps, the present study offers a targeted investigation into the impact of STEAM education on the Four C's among elementary students in South Lebanon, employing a mixed-methods framework to yield both statistical and contextual understanding.

Methodology

Research Design

This study employed a concurrent triangulation mixed-methods design, a comprehensive approach that involves collecting both qualitative and quantitative data simultaneously, analyzing them separately, and then comparing or integrating the results to provide a more complete understanding of the research phenomenon. The concurrent triangulation design was particularly appropriate for this study because it allowed for the examination of STEAM education's impact from multiple perspectives, providing both statistical evidence of relationships and rich qualitative insights into the mechanisms underlying these relationships. The quantitative component enabled the measurement of relationships between variables and the testing of hypotheses, while the qualitative component provided contextual understanding and explanatory insights.

Participants and Sampling

The study was conducted in eight private schools located in the Southern governorate of Lebanon. These schools were selected purposively as they integrate STEAM education into their curriculum. The student sample in this study consisted of 100 Cycle One learners, encompassing first, second, and third graders aged between 6 and 9 years. To ensure generalizability within the target population, homogeneous convenience sampling was employed, allowing for a consistent sociodemographic profile across participants. The age distribution revealed that 26% of the students were between 6 and 7 years old, 29% fell within the 7 to 8-year range, and the largest group of students (45%) were aged 8 to 9 years. Gender representation was relatively balanced, with 42% male and 58% female students. All participants were enrolled in the same eight private schools and shared similar socioeconomic backgrounds, which contributed to the sample's homogeneity and minimized potential confounding variables related to social or economic disparities.

The teacher sample included 30 teachers specializing in mathematics and science, selected through purposeful sampling. This approach ensured that participants met specific criteria relevant to the study, including subject area expertise and a demonstrated willingness to engage in the research process. Gender distribution among teachers showed that 40% were males and 60% were females. In terms of professional experience, 23.33% of the teachers had less than two years of teaching experience, 46.67% had between two and five years of experience, and 30% had more than five years of experience. This range of experience levels provided a rich spectrum of insights into STEAM education practices, reflecting varying degrees of pedagogical maturity and familiarity with interdisciplinary instructional strategies. The diversity within the teacher sample was instrumental in

capturing detailed perspectives on the implementation of STEAM education across different stages of professional development.

Data Collection Instruments

To assess students' acquisition of 21st-century skills through STEAM learning experiences, a self-completed questionnaire was developed and distributed using Google Forms. The instrument was carefully designed to be age-appropriate, incorporating visual elements to support comprehension among young learners. It focused on four key domains aligned with the Four C's framework: creativity, critical thinking, collaboration, and communication. Each domain included tailored items to evaluate students' competencies in these areas, ensuring a comprehensive understanding of their skill development.

To explore teachers' instructional strategies aligned with STEAM learning and their perceptions of student skill development, a comprehensive questionnaire was administered using Google Forms. This digital format allowed for efficient distribution and data collection, while also enabling structured responses across multiple domains. The questionnaire was designed to capture a wide range of insights from teachers, focusing on their teaching practices.

The content of the questionnaire was divided into several key sections. It began with demographic information and professional background to contextualize the responses. Subsequent sections delved into teachers' educational approaches and pedagogical practices, particularly those that emphasize the integration of STEAM principles. Teachers were asked to reflect on how frequently they fostered student skills through STEAM activities and to share their perceptions of how these experiences influenced student development.

To assess the depth of STEAM integration, the questionnaire included items targeting four essential skill areas: scientific inquiry practices, engineering design processes, mathematical thinking development, and technology literacy integration. These domains were chosen to reflect the interdisciplinary nature of STEAM education and to evaluate how effectively teachers incorporate these elements into their instruction. The responses provided a good understanding of both the strengths and gaps in current teaching practices, offering valuable data for enhancing STEAM implementation in educational settings.

To gather qualitative data on students' demonstration of 21st-century skills during STEAM-based activities, a structured observation checklist was developed using the Partnership for 21st Century Skills (2009) framework. This tool was specifically designed to assess students' engagement with the Four C's - communication, collaboration, creativity, and critical thinking - within authentic classroom contexts. The checklist served as a systematic guide for observers to identify and record specific behaviors that reflected these core competencies.

Observations were carried out over a six-week period in five randomly selected Cycle One classes. Each class was observed twice per week, resulting in a total of 12 observation sessions. This extended timeframe allowed for the identification of consistent behavioral patterns and provided a more reliable picture of how students applied these skills across different STEAM activities. The repeated observations also helped mitigate the influence of isolated incidents or atypical classroom dynamics.

The checklist included detailed behavioral indicators for each of the Four C's. Creativity was assessed through signs of divergent thinking, the generation of novel solutions, creative expression, and the use of innovative approaches. Critical thinking was observed through students' ability to analyze problems, employ questioning strategies, evaluate evidence, and justify their reasoning. Collaboration was measured by students' capacity to work cooperatively, share responsibilities, resolve conflicts, and participate inclusively. Communication was evaluated through active listening, clarity of expression, both verbal and non-verbal communication, and the ability to adapt messages to different

audiences. These indicators provided a comprehensive framework for capturing the depth and breadth of student skill development in a STEAM learning environment.

Data Analysis Procedures

Quantitative Analysis

To analyze the data collected from both student and teacher participants, a comprehensive descriptive statistical analysis was conducted. This initial step was essential for characterizing the sample demographics and establishing baseline information regarding participant attributes and response patterns. The descriptive statistics provided a clear overview of the distribution of age, gender, professional experience, and other relevant variables, setting the foundation for subsequent inferential analyses.

To ensure the reliability of the measurement instruments, Cronbach's alpha was calculated for both the student and teacher questionnaires. The teacher questionnaire achieved a Cronbach's alpha of 0.891, which indicates excellent internal consistency. Similarly, the student questionnaire demonstrated strong reliability across all four assessed skill domains - creativity, critical thinking, collaboration, and communication - affirming the robustness of the instrument in capturing students' 21st-century skill development.

Further analysis was conducted using multiple regression techniques to explore the relationships between STEAM education integration and the development of each of the four 21st-century skills. In this model, STEAM integration served as the independent variable, while creativity, critical thinking, collaboration, and communication were treated as separate dependent variables. Individual regression models were constructed for each skill domain to allow for a more detailed examination of the unique impact of STEAM practices on specific competencies.

Statistical significance for all analyses was set at $p < 0.05$, adhering to standard conventions in educational research. Effect sizes were interpreted according to Cohen's guidelines, providing additional insight into the practical significance of the findings. This rigorous analytical approach ensured that the study's conclusions were both statistically sound and educationally meaningful.

Qualitative Analysis

To gain deeper insights into the impact of STEAM-based learning, qualitative data from structured observation checklists were analyzed using thematic analysis. This method allowed researchers to identify recurring patterns in student behavior and skill demonstration, particularly in relation to the Four C's. Observations captured during classroom activities revealed how students engaged with STEAM tasks, highlighting both individual and group dynamics that contributed to skill development.

In parallel, teacher responses to open-ended questionnaire items were subject to content analysis. This approach facilitated the extraction of key themes related to the implementation of STEAM education, including instructional successes, and observed student outcomes. Teachers shared valuable reflections on their experiences, offering detailed perspectives on the practical realities of integrating STEAM into their pedagogical practices.

To ensure a comprehensive understanding of the research phenomenon, triangulation was employed by comparing and integrating findings from both qualitative and quantitative data sources. This methodological strategy enhanced the validity of the study's conclusions by corroborating evidence across different data types. The convergence of observational insights, teacher narratives, and statistical analyses provided a multidimensional view of how STEAM education influences the development of essential 21st-century skills among young learners.

Validity and Reliability

To ensure the rigor and credibility of the study, several measures were taken to enhance internal validity. Homogeneous sampling was employed to minimize confounding variables related to

socioeconomic and cultural differences, thereby strengthening the consistency of the findings. The use of multiple data sources - such as questionnaires, observations, and open-ended responses - enabled triangulation, which reduced the risk of single-source bias and provided a more holistic understanding of the research phenomenon. Standardized instruments were used across all data collection procedures, ensuring uniformity and reliability in how information was gathered. Additionally, the extended observation period, spanning six weeks, allowed the researcher to capture stable behavioral patterns rather than isolated or atypical incidents, further reinforcing the internal validity of the study.

External validity was also carefully considered to support the generalizability of the findings. The sampling strategy ensured that participants were representative of the target population of Cycle One students, enhancing the relevance of the results to similar educational contexts. Observations and data collection took place in authentic classroom environments, preserving ecological validity and reflecting real-world learning conditions.

The study demonstrated strong psychometric properties for both measurement instruments. The teachers' questionnaire achieved a Cronbach's alpha of 0.891, indicating excellent internal consistency and reliability. Similarly, the students' questionnaire showed strong reliability across all four dimensions of 21st-century skills (Cronbach's alpha of 0.89), validating the measurement approach and ensuring the trustworthiness of the collected data.

These high reliability coefficients provide confidence in the consistency and stability of the measurement instruments, supporting the validity of subsequent statistical analyses and interpretations.

Findings

Student Demographics and Characteristics

The student sample (N = 100) demonstrated diversity in age distribution while maintaining gender balance. The age distribution showed an upward trend, with the largest group comprising students aged 8-9 years (45 students), followed by those aged 7-8 years (29 students), and 6-7 years (26 students). This distribution reflects typical enrollment patterns in Cycle One education and provides adequate representation across the target age range.

Gender distribution showed a slight predominance of female participants (58%) compared to males (42%), representing a moderate gender imbalance that was considered in the interpretation of results. All participants shared similar sociodemographic characteristics, belonging to the same eight private school environment, which enhanced sample homogeneity and reduced potential confounding variables.

Teacher Demographics and Experience

The teacher sample (N = 30) represented diverse professional experience levels, with the majority (46.67%) having 2-5 years of teaching experience, indicating that most participants were beyond the novice stage but still developing their professional expertise. Teachers with more than 5 years of experience comprised 30% of the sample, while those with less than 2 years represented 23.33%.

Gender distribution among teachers showed 60% female and 40% male participants, reflecting typical gender patterns in elementary education. The diversity in professional experience provided valuable perspectives on STEAM implementation across different levels of pedagogical development.

Observational Findings

Creativity Indicators

Observational data collected during STEAM activities revealed a high level of creativity engagement among students, with all four creativity indicators consistently demonstrated throughout

the observation period. Students exhibited strong divergent thinking as they explored multiple solutions to the problems presented. Their approaches reflected a notable flexibility and openness to alternative perspectives, suggesting a capacity for adaptive and imaginative reasoning.

In terms of novel solution generation, participants regularly moved beyond conventional responses, offering original ideas and inventive strategies that showcased their personal insight and creativity. These contributions were not only unique but also contextually relevant, indicating a deep engagement with the tasks at hand.

Creative expression was evident across a range of modalities. Students articulated their ideas through artistic representations, verbal explanations, and physical demonstrations, each reflecting their individual styles and interpretations. This multimodal engagement enriched the learning environment and allowed for diverse forms of self-expression.

Finally, students demonstrated a clear comfort with creative risk-taking through their use of innovative approaches. They willingly experimented with unconventional methods, showing curiosity and resilience in the face of uncertainty. This behavior underscored their readiness to explore new possibilities and embrace the exploratory nature of STEAM learning. Overall, the observational data highlighted a dynamic and sustained engagement with creativity, affirming the effectiveness of STEAM activities in fostering essential 21st-century skills.

Critical Thinking Observations

The assessment of students' critical thinking during STEAM activities revealed a multifaceted picture, with clear strengths in foundational skills and notable gaps in more advanced cognitive processes. Observational data indicated that students consistently excelled in problem analysis, demonstrating the ability to deconstruct complex challenges into manageable components and identify key elements that required attention. This analytical approach was complemented by frequent instances of critical questioning, where students posed thoughtful and probing inquiries that reflected curiosity and a desire to understand underlying concepts and relationships more deeply.

Additionally, students showed competence in reasoning justification. They were able to articulate their thought processes and provide logical explanations for their conclusions and decisions, suggesting a solid grasp of reflective thinking and argumentation. These observed behaviors highlight a strong engagement with the core elements of critical thinking and suggest that students are developing essential skills for navigating complex problems.

However, the data also revealed areas where critical thinking was less consistently demonstrated. Students showed limited ability to evaluate different viewpoints systematically, indicating a need for further development in considering alternative perspectives and competing explanations. Similarly, interpreting results posed a challenge for many participants, as they struggled to draw comprehensive conclusions from data and connect their findings to broader concepts or contexts.

This mixed pattern suggests that while students are actively engaging in foundational aspects of critical thinking, higher-order skills - such as synthesis, evaluation, and abstraction - require more targeted instructional support. These findings underscore the importance of scaffolding critical thinking development within STEAM education to ensure that students not only analyze and question effectively but also interpret, evaluate, and integrate knowledge in more sophisticated ways.

Collaboration Skills Assessment

The collaboration assessment revealed consistently positive outcomes across all measured indicators, highlighting students' strong interpersonal and teamwork skills during STEAM-based activities. One of the most prominent findings was the students' ability to engage in cooperative work. They regularly collaborated with peers in a productive manner, sharing tasks and responsibilities

efficiently to achieve common goals. This cooperative spirit fostered a sense of unity and mutual support within the classroom environment.

Students also demonstrated competence in managing shared responsibilities. They distributed tasks fairly among group members and ensured that everyone contributed meaningfully to the collective effort. This equitable approach to teamwork reflected a mature understanding of group dynamics and reinforced the value of each participant's role.

When conflicts arose, students employed constructive strategies to resolve disagreements. Their ability to find mutually acceptable solutions and maintain a respectful tone during discussions indicated a high level of emotional intelligence and problem-solving capacity. This skill was particularly important in maintaining group cohesion and ensuring that collaborative efforts remained focused and effective.

Inclusive participation was another key strength observed. Students made deliberate efforts to involve all group members, including those who were quieter or less confident. This inclusive behavior not only enhanced the overall quality of collaboration but also created a supportive environment where every student felt valued and empowered to contribute.

Finally, adherence to group norms was consistently evident. Students showed a clear understanding of established expectations and collaborative protocols, demonstrating respect for rules and procedures that guided their interactions. This compliance helped maintain order and facilitated smooth group functioning throughout the STEAM activities. Overall, the collaboration assessment underscored the students' ability to work harmoniously and effectively in team settings, a critical component of 21st-century skill development.

Communication Skills Evaluation

The assessment of students' communication skills during STEAM activities revealed a high level of competence across all measured dimensions, indicating that learners were actively engaging in meaningful and effective interpersonal exchanges. One of the most consistently observed behaviors was active listening. Students demonstrated attentiveness through appropriate eye contact, responsive body language, and thoughtful follow-up questions, all of which contributed to a respectful and engaged classroom environment.

Clear expression was another area of strength. Participants were able to articulate their ideas using age-appropriate vocabulary and logical organization, ensuring that their messages were easily understood by both peers and teachers. This clarity in communication supported collaborative learning and allowed students to contribute confidently to group discussions and problem-solving tasks.

In terms of verbal communication, students exhibited strong oral skills, maintaining appropriate volume, pace, and clarity during spoken interactions. These competencies enabled them to express their thoughts effectively and participate in classroom dialogue with confidence and precision.

Non-verbal communication also played a significant role in students' interactions. Observers noted that students were aware of and skillfully used gestures, facial expressions, and body positioning to reinforce their verbal messages and convey emotions or emphasis. This multimodal communication enriched their overall expressiveness and helped foster deeper connections with their peers.

Finally, audience adaptation emerged as a developing skill among students. While some participants demonstrated the ability to adjust their communication style based on the audience and context-such as simplifying explanations for younger peers or using more formal language with teachers-this skill varied across individuals. Nonetheless, the presence of emerging audience awareness suggests a promising trajectory in students' communicative development. Overall, the findings

highlight a strong foundation in communication skills, essential for success in both academic and collaborative settings.

Regression Analysis Results

STEAM Education and Creativity

The relationship between STEAM education and creativity demonstrated the strongest positive correlation among the measured skills. Statistical analysis revealed compelling evidence for this association:

Table 1: Model Summary - STEAM Education and Creativity

Model	R	R Square	Adjusted R Square	Std. Error of Estimate
1	0.659	0.435	0.421	0.524

The correlation coefficient (R = 0.659) indicated a moderately strong positive relationship between STEAM education integration and creativity development. The R-squared value (0.435) demonstrated that approximately 43.5% of the variance in students' creativity scores could be explained by STEAM education integration, a substantial proportion in educational research that suggests meaningful practical significance.

Coefficients Analysis

- Unstandardized coefficient (B) = 0.592
- Standard error = 0.132
- t-value = 4.471
- Significance (p) < 0.001

The coefficients analysis provided additional support for the relationship, with the unstandardized coefficient indicating that each one-unit increase in STEAM education integration corresponds to a 0.592-unit increase in creativity scores. The high t-value (4.471) and significance level well below 0.001 provided strong statistical evidence for rejecting the null hypothesis (H_{01}) and accepting the alternative hypothesis (H_{11}) that there is a significant positive relationship between STEAM education and creativity development.

STEAM Education and Critical Thinking

The analysis of STEAM education's impact on critical thinking revealed contrasting results compared to other skills:

Table 2: Model Summary - STEAM Education and Critical Thinking

Model	R	R Square	Adjusted R Square	Std. Error of Estimate
1	0.338	0.114	0.096	0.673

The correlation coefficient (R = 0.338) indicated only a weak positive relationship between STEAM education and critical thinking development. The R-squared value (0.114) demonstrated that merely 11.4% of the variance in critical thinking skills could be attributed to STEAM education, suggesting that other factors play more significant roles in critical thinking development.

Coefficients Analysis

- Unstandardized coefficient (B) = 0.303
- Standard error = 0.172
- t-value = 1.757
- Significance (p) = 0.092

Despite the positive direction indicated by the regression coefficient, the relationship failed to achieve statistical significance ($p = 0.092 > 0.05$). The t-value of 1.757, while positive, was insufficient to meet the conventional threshold for statistical significance. Based on these results, the null hypothesis (H_{02}) was accepted, and the alternative hypothesis (H_{12}) was rejected, indicating no statistically significant relationship between STEAM education and critical thinking development in this sample.

STEAM Education and Collaboration Skills

The relationship between STEAM education and collaboration skills demonstrated moderate positive correlation with statistical significance:

Table 3: Model Summary - STEAM Education and Collaboration

Model	R	R Square	Adjusted R Square	Std. Error of Estimate
1	0.419	0.176	0.159	0.721

The correlation coefficient ($R = 0.419$) suggested a moderate positive relationship between STEAM education and collaboration skills development. The R-squared value (0.176) indicated that 17.6% of the variance in collaboration skills could be explained by STEAM education integration, representing a meaningful though modest contribution to skill development.

Coefficients Analysis

- Unstandardized coefficient (B) = 0.834
- Standard error = 0.369
- t-value = 2.262
- Significance (p) = 0.033

The coefficients analysis revealed an unstandardized coefficient of 0.834, indicating that each one-unit increase in STEAM education integration corresponds to a 0.834-unit increase in collaboration skills. The t-value of 2.262 and significance level of 0.033 (< 0.05) provided statistical evidence for a significant positive relationship. These results supported the rejection of the null hypothesis (H_{03}) and acceptance of the alternative hypothesis (H_{13}) that there is a significant positive relationship between STEAM education and collaboration skills development.

STEAM Education and Communication Skills

The analysis of STEAM education's impact on communication skills revealed the most compelling findings of the study:

Table 4: Model Summary - STEAM Education and Communication

Model	R	R Square	Adjusted R Square	Std. Error of Estimate
1	0.879	0.772	0.767	0.394

The correlation coefficient ($R = 0.879$) indicated a very strong positive relationship between STEAM education and communication skills development. The R-squared value (0.772) demonstrated that an impressive 77.2% of the variance in communication skills could be explained by STEAM education integration, representing the strongest relationship observed in the study.

Coefficients Analysis

- Unstandardized coefficient (B) = 0.872
- Standard error = 0.097
- t-value = 9.017
- Significance (p) < 0.001

The coefficients analysis strongly supported this relationship, with an unstandardized coefficient of 0.872 indicating that each one-unit increase in STEAM education integration corresponds to a 0.872-unit increase in communication skills. The exceptionally high t-value (9.017) and significance level well below 0.001 provided strong statistical evidence for the relationship. These results supported the strong rejection of the null hypothesis (H_{04}) and acceptance of the alternative hypothesis (H_{14}) that there is a highly significant positive relationship between STEAM education and communication skills development.

Summary of Hypothesis Testing

Table 5: Summary of Hypothesis Testing Results

Skill Area	Null Hypothesis	Alternative Hypothesis	R^2	p-value	Decision
Creativity	H_{01}: No relationship	H_{11}: Significant relationship	0.435	<0.001	Reject H_{01}
Critical Thinking	H_{02}: No relationship	H_{12}: Significant relationship	0.114	0.092	Accept H_{02}
Collaboration	H_{03}: No relationship	H_{13}: Significant relationship	0.176	0.033	Reject H_{03}
Communication	H_{04}: No relationship	H_{14}: Significant relationship	0.772	<0.001	Reject H_{04}

The hypothesis testing results reveal a differentiated pattern of STEAM education's impact on the four 21st-century skills, with significant positive relationships established for creativity, collaboration, and communication, while no significant relationship was found for critical thinking.

Discussion

The findings of this study provide important insights into the differential effectiveness of STEAM education in developing specific 21st-century skills, revealing a complex pattern that both supports and challenges existing literature on interdisciplinary education approaches.

STEAM Education and Communication Skills

The strongest relationship observed in this study was between STEAM education and communication skills development, with STEAM explaining 77.2% of the variance in communication competencies. This finding strongly aligns with existing literature on interdisciplinary education and supports theoretical predictions about STEAM's communicative demands.

The relationship between STEAM and communication can be understood through several theoretical lenses. First, STEAM activities inherently require students to articulate complex ideas across multiple disciplines, necessitating the development of sophisticated communication skills. Students must explain scientific concepts, describe engineering processes, present mathematical reasoning, and express creative ideas, all of which demand diverse communication competencies. Second, the collaborative nature of STEAM projects requires extensive peer interaction, providing authentic contexts for communication skill development. Students must negotiate ideas, share responsibilities, present findings, and engage in constructive discourse - all activities that directly exercise and strengthen communication abilities.

The practical implications of this finding are significant for educators and curriculum developers. The strong relationship suggests that STEAM education can serve as an effective vehicle for

communication skill development, potentially addressing concerns about declining communication competencies among young learners in digital age contexts.

STEAM Education and Creativity Development

The significant positive relationship between STEAM education and creativity ($R^2 = 0.435$) aligns with much of the existing literature on interdisciplinary education approaches. This finding validates arguments made by proponents of STEAM education who have long contended that the integration of arts into STEM disciplines would enhance creative thinking and innovation.

The theoretical foundation for this relationship is well-established in creativity research. STEAM education's emphasis on divergent thinking, problem-solving, and interdisciplinary connections provides multiple pathways for creative expression and development. The hands-on, project-based nature of STEAM activities offers students opportunities to experiment, take creative risks, and develop novel solutions to authentic problems.

The moderate strength of this relationship (43.5% variance explained) suggests that while STEAM education makes a substantial contribution to creativity development, other factors also play important roles. This finding is consistent with creativity research that identifies multiple influences on creative development, including individual differences, environmental factors, and instructional approaches.

From a practical perspective, this finding supports educational policies that emphasize STEAM integration as a means of fostering creativity and innovation. However, the moderate effect size also suggests that creativity development may benefit from additional targeted interventions and instructional strategies beyond STEAM implementation alone.

STEAM Education and Collaboration Skills

The moderate positive relationship between STEAM education and collaboration skills ($R^2 = 0.176$) provides evidence for STEAM's effectiveness in developing teamwork competencies, though the relationship is weaker than might be expected given the collaborative nature of most STEAM activities.

STEAM projects typically require students to work in teams, share responsibilities, and coordinate diverse expertise-activities that should theoretically strengthen collaboration skills. The significant relationship observed in this study supports this theoretical expectation.

However, the relatively modest effect size (17.6% variance explained) suggests that collaboration skill development may depend on factors beyond simple exposure to collaborative STEAM activities. Research conducted by Johnson & Johnson (1999) on collaborative learning indicates that effective collaboration requires explicit instruction in teamwork skills, structured interaction protocols, and ongoing support for group process development.

The observational data from this study support this interpretation, showing that while students demonstrated collaborative behaviors during STEAM activities, the quality and sophistication of their collaboration varied considerably. This suggests that STEAM education provides opportunities for collaboration skill development but may require additional scaffolding and explicit instruction to maximize its effectiveness.

STEAM Education and Critical Thinking

Perhaps the most surprising and significant finding of this study was the absence of a statistically significant relationship between STEAM education and critical thinking development ($R^2 = 0.114$, $p = 0.092$). This finding challenges common assumptions about STEAM education's effectiveness and raises important questions about implementation practices and theoretical expectations.

Several factors may contribute to this unexpected result. First, the observational data revealed that while students engaged in some critical thinking behaviors (problem analysis, questioning, reasoning justification), they showed limited ability to evaluate different viewpoints and interpret results

comprehensively. This pattern suggests that the STEAM activities observed may not have consistently challenged students to engage in higher-order critical thinking processes.

Second, critical thinking development may require more explicit instructional support than is typically provided in STEAM implementations. While STEAM activities present complex problems and require analytical thinking, students may need structured guidance to develop sophisticated critical thinking skills such as evidence evaluation, assumption identification, and logical reasoning.

Third, the developmental appropriateness of critical thinking expectations for Cycle One students (ages 6-9) may be a contributing factor. While young children can engage in concrete reasoning and basic analysis, the abstract thinking skills required for advanced critical thinking may still be developing at this age level.

This finding has important implications for STEAM education implementation. It suggests that educators should not assume that STEAM activities automatically develop critical thinking skills but should instead incorporate explicit critical thinking instruction and scaffolding into their STEAM implementations.

Limitations of the Study

This study provides valuable insights into the impact of STEAM education on 21st-century skills development but acknowledges several limitations affecting the generalizability and depth of its findings. Conducted in eight private schools in South Lebanon with Cycle One students (ages 6–9) and a relatively small sample of 100 students and 30 teachers, the results may not represent other regions, public schools, or older age groups. The reliance on self-reported questionnaires, parental assistance for younger students, and brief six-week observations may have introduced response bias and limited the scope of observed behaviors. The study's cross-sectional design prevents causal inferences, while its focus on mathematics and science restricted the broader interdisciplinary nature of STEAM, particularly the integration of arts. Additionally, only four 21st-century skills were examined, omitting other important competencies such as digital literacy and adaptability. Despite these constraints, the study offers foundational evidence for the role of STEAM education in skill development and underscores the need for longitudinal, comprehensive, and contextually diverse research.

Conclusion

This mixed-methods investigation examined the relationship between STEAM education and the development of four critical 21st-century skills - creativity, critical thinking, collaboration, and communication - among Cycle One students in South Lebanon. The study's findings provide empirical evidence for the selective effectiveness of STEAM education in developing specific competencies while highlighting important considerations for educational implementation and future research.

The research revealed a differentiated pattern of STEAM education's impact across the four examined skills. Most notably, STEAM education demonstrated a very strong positive relationship with communication skills development, explaining 77.2% of the variance in communication competencies. This finding suggests that STEAM approaches are particularly effective for developing students' ability to articulate ideas, engage in meaningful discourse, and communicate effectively across diverse contexts.

A moderately strong positive relationship was observed between STEAM education and creativity development, with 43.5% of creativity variance explained by STEAM integration. This finding supports theoretical expectations about STEAM's capacity to foster innovative thinking and creative problem-solving through interdisciplinary, hands-on learning experiences.

STEAM education also showed a significant but more modest positive relationship with collaboration skills, explaining 17.6% of the variance in collaborative competencies. While this

relationship was statistically significant, the moderate effect size suggests that collaboration skill development may require additional targeted interventions beyond STEAM implementation alone.

Perhaps most significantly, the study found no statistically significant relationship between STEAM education and critical thinking development. This unexpected finding challenges common assumptions about STEAM's effectiveness and highlights the need for more targeted approaches to critical thinking instruction within interdisciplinary educational frameworks.

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