INVESTIGATING THE IMPACT OF STEAM EDUCATION ON STUDENTS' DESIGN THINKING AND PROBLEM-SOLVING SKILLS IN A PRIVATE SCHOOL IN DUBAI, UAE

By

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ABSTRACT

In an era defined by rapid technological advancements and complex global challenges, education systems are increasingly turning to (Science, Technology, Engineering, Arts, and Mathematics) STEAM education to cultivate essential 21st-century skills. This study investigates the impact of STEAM education on students' design thinking and problem-solving abilities in a school in Dubai. While global interest in STEAM integration has grown, limited research exists on its practical outcomes in the Middle Eastern educational landscape, particularly in the UAE. This research adopted a qualitative approach to explore how students and educators experience STEAM education in real classroom settings. Data was collected through semi-structured interviews with the Head of STEAM and subject teachers, focus group discussions with students, and classroom observations across Grades 3, 7, and 10. These methods provided rich, contextual insights into how students engage with the design thinking process —ideation, prototyping, and testing—in interdisciplinary, hands-on learning environments. Findings revealed that students exhibited design-thinking and problem-solving behaviors at varying levels throughout the ideation, prototyping, and testing stages. The STEAM program helps students develop age-appropriate design thinking and critical problem-solving skills, fostering innovation and creativity skills that are needed for the future. However, challenges such as time constraints, varying teacher readiness, and limited access to resources were also identified. The study concludes that STEAM education can serve as a powerful framework for enhancing design thinking and problem-solving skills in school settings. It highlights the need for sustained professional development and institutional support to maximize the potential of STEAM approaches in diverse educational contexts such as Dubai. These insights can inform policymakers, educators, and curriculum designers aiming to foster innovation-driven learning environments across the region.

Keywords: STEAM education; design thinking, problem-solving, technology, professional development, 21st century skills, interdisciplinary learning.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Full Term
STEAM	Science, Technology, Engineering, Arts, Math
UAE	United Arab Emirates
AI	Artificial Intelligence
VR	Virtual Reality
TTCT	The Torrance Tests of Creative Thinking
DTS	Design Thinking Scale
HPSA	Holistic Problem-Solving Assessment
OECD	Organization for Economic Co-operation and Development
PBL	Problem-based Learning
CTSI	Creative Thinking Skills Inventory
SDG	Sustainable Development Goals

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Statement of the Problem/Context

With the dilemmas that the world is entangled in becoming increasingly complicated, there is an imperative need to equip learners with such critical 21st-century skills as creativity, critical thinking, communication, and collaboration (Almazroa & Alotaibi, 2023). Even though interdisciplinary learning models like the integration of Science, Technology, Engineering, Arts, and Mathematics (STEAM) are meant to develop these skills, it is still hard to understand how they affect design thinking and problem-solving (Thornhill-Miller et al. 2023). STEAM education combines in a unique way both analytical rigor and creative processes, thus becoming an important method by which students can prepare for future workforce needs (Henriksen, 2014). On the other hand, comprehensive research into its effectiveness, especially within various educational contexts, remains scant (Kang 2019).

The adoption of the STEAM approach is equipping students with such 21st-century competencies as critical thinking, problem-solving, and interdisciplinary collaboration, which is gaining recognition across the world as an effective strategy (Maas and Hughes, 2020). On the other hand, its practice faces challenges, such as a lack of studies with regard to its effectiveness across diverse educational contexts (BouJaoude, 2020).

There are a variety of obstacles that must be overcome in an effective integration of STEAM education. Some of them include a lack of funding, unqualified instructors, and cultural

obstacles such as parental hesitation (Ma et al., 2022). There is a significant deficiency in equipping students for the demands of the 21-st century, primarily due to the insufficient integration of STEAM within educational institutions. This shortcoming persists due to several key barriers, which in turn hinder the effective implementation of interdisciplinary instruction for students (Anisimova et al., 2020; Kijima et al., 2020).

The Middle Eastern nations like Saudi Arabia and the United Arab Emirates are increasingly showing interest in STEAM education as part of broader education reforms aimed at renewing curriculum and better aligning skills and knowledge for an ever-changing workforce (Kayan-Fadlelmula et al., 2022). There have been improvements, but teacher training and new educational technology need to be addressed (Amiruddin et al. 2022). Documentation of efforts to strengthen STEAM in Saudi Arabia has been acquired through programs' implementations that endorse digital instruction and learning derived from a variety of subjects (Al-Ghamdi & Al-Khalifa, 2020). Meanwhile, the United Arab Emirates Vision 2030 aims to infuse STEAM values in private and public schools in an attempt to bridge gaps between traditional studies and the requirements of jobs in modern times (Ministry of Education, UAE, 2023). This interest, however, is faced with many kinds of specific challenges coming from the educational traditions, limitations in the resources, and cultural hostility towards such interdisciplinary education (Amiruddin et al., 2022). Through its multicultural private school system, the UAE is giving significant emphasis to the use of STEAM by introducing more innovative ideas in the classroom through advanced technology such as artificial intelligence and virtual reality (Almazroa & Alotaibi, 2023).

New technologies such as augmented and virtual reality increase the impact of STEAM education with immersive, activity-based learning (Maas and Hughes 2020). Studies have

demonstrated how these emerging technologies can enhance outcomes further (Algerafi et al. 2023). The introduction of such innovative technologies into frameworks of STEAM has not so far been pursued on a systematic level (Ma et al., 2022). Consequently, this represents a notable gap in the literature, as there are only a limited number of studies that have investigated how such technologies may contribute to the development of critical design and research competencies (Mejias et al., 2021).

Despite growing global interest in STEAM, there is limited empirical evidence from K–12 classrooms in the UAE and wider Middle East on how STEAM, enacted through the design-thinking cycle, shapes students' problem-solving across grade bands and what implementation conditions enable or hinder impact. This study addresses that gap by providing classroom-proximal accounts from Grades 3, 7, and 10 in a Dubai school.

This study is delimited to one private school, three grade levels (3, 7, 10), and three qualitative sources (interviews, focus groups, observations). STEAM outcomes are interpreted through a design-thinking lens rather than standardized achievement metrics; generalizability is not claimed.

1.2 Research Aim and Research Questions

Research Aim

The aim of this study is to research the impact of STEAM education on developing design thinking and problem-solving skills among students from diverse grade levels in an American curriculum private school in Dubai, UAE, while identifying the challenges and opportunities related to its implementation within this educational context. The school community includes

administrators, teachers, and students from numerous nationalities. A multicultural educational setting is a valuable opportunity to investigate STEAM teaching, the problems faced by educators, and its influence on students' problem-solving and design thinking skills.

Research Questions

1. How is STEAM education implemented in schools?
2. What is the impact of STEAM education on students' design thinking and problem-solving skills across different grade levels?
3. What challenges do educators face in implementing STEAM education, and how do these challenges vary by grade level?
4. What role does the integration of emerging technologies, such as AI and virtual reality, play in enhancing the impact of STEAM education on students' design thinking and problem-solving?

1.3 Rationale of the Study

Despite the broad acknowledgment of STEAM education's potential, gaps in understanding its impact on different educational settings are overwhelming (Aguilera & Revilla, 2021; Suslenco, 2024). Literature has revealed that STEAM education has enhanced student creativity and engagement, for example, in countries like the United States and South Korea (Becker & Park, 2011; Park et al., 2016). In the Middle East, where educational systems are rapidly modernizing, STEAM education presents a promising solution to reconcile traditional learning methods with the demands of a globalized economy. Yet, resource limitations, untrained teachers, and cultural resistance to the idea of interdisciplinarity hinder its large-scale adoption

(Amiruddin et al., 2022; Kijima et al., 2021). Furthermore, limited research has been performed on STEAM education within the Middle East (BouJaoude, 2020).

Besides, emerging technologies like artificial intelligence and virtual reality continue to reshape approaches to education across the world, creating new potential for improving learning outcomes in STEAM education (Algerafi et al., 2023; Maas & Hughes, 2020). These kinds of technologies could help create more immersive, activity-based learning experiences that would help students get better at design thinking and solving problems (Herro & Quigley, 2016; Mejias et al., 2021). There hasn't been much systematic research on how they can be used in the STEAM framework, especially in the Middle East's social, cultural, and educational settings (Jia et al., 2021).

This study gauges the efficacy of STEAM instruction in developing students' problem-solving and thinking skills in a Dubai, UAE, private school. It engages with students' and teachers' experiences, barriers in its use, and the role of new technology in STEAM integration. Outcomes will shape regional and international discussion regarding STEAM instruction, offering direction for its integration in a range of educational environments. The current study fills in important gaps and opens new opportunities when it comes to implementing and studying STEAM education, including the study area ‘UAE’.

The findings are intended to benefit:

• School leaders and curriculum designers, for decisions on sequencing STEAM content and resourcing.

• Teachers and instructional coaches, for practical patterns of scaffolding/assessment across different grade levels.

• Policy makers and PD providers, for targeted professional-learning priorities and infrastructure support in the UAE/MENA context.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition of STEAM Education

In the academic field, "STEAM" is a model for the integration of scientific, technological, engineering, artistic, and mathematical ideas in one multidisciplinary model for learning. By putting students in a position to apply information derived from a variety of subjects in real-life environments, STEAM helps pupils gain expertise in critical thinking, problem-solving, and creative thinking.

Even though there is a lot of talk about STEAM teaching methods and whether cross-, multi-, and inter-disciplinarity are all the same thing, academics keep saying that integration is important. Bertrand and Namukasa (2020) reiterate STEAM in enhancing learning through the integration of thinking and analysis processes and in preparation for problem-solving in complex situations. In a similar manner, Aguilera and Revilla (2021) cite that a structured STEAM curriculum creates individuals who are ingenious, speedy, and perceptive minds capable of fitting into future challenges for them.

The implementation in schools comes in a variety of instructional methodologies, such as inquiry, design thinking, and project-based instruction frameworks. All of these approaches harmonize with theoretical frameworks such as constructivism, an educational theory postulating that students best learn through hands-on and experiential hands-on experiences. Engaging new technology, such as artificial intelligence and virtual reality, continues to reinforce STEAM's role

in shaping skill development through immersive experiences in a field of study (Wieselmann, Sager, & Price, 2022).

STEAM does not confine itself to discrete subject silos; rather, it connects the analytical robustness of the sciences with the creative processes found in the arts. This integration, according to Bertrand and Namukasa (2020), is more than infusing the artistic disciplines into the sciences but rather a deliberate way to create an awareness of the wholeness of practical and theoretical ideas. This synthesis allows learners to be very effective in applying their skills in a real situation and makes them innovative and adaptable.

STEAM education has proved to be enormously promising in bringing forth the skills of the 21st-century student, such as problem-solving, collaboration, and thinking across disciplines, in countries across the world. Flores-Nicolás (2003) refers to this thriving interdisciplinary approach in her press work, one that effectively readies students for creative real-world problem-solving in collaboration.

The importance of STEAM education rests in the way it prepares students with the fundamental 21st-century competence by relating and interweaving creativity within a tapestry of analytical reason (Bülbül, 2024). Aguilera and Revilla (2021) point to how STEAM learning places students into job circles through the act of critical inquiry and creative expression, in addition to interdisciplinary levels of problem resolution. By adding an aesthetic dimension through art, this process builds knowledge platforms where people can work together to find solutions to problems, combining their creative and analytical skills.

According to Bertrand and Namukasa (2020), the approach used in STEAM encourages interdisciplinary collaboration, communication, and digital literacy for problem-solving among

the students in a rapidly evolving technological world (Bertrand & Namukasa, 2020). The interdisciplinary learning framework prepares the students for their future lives in the field, not only with skills but also by enhancing their capacity to be creative and innovative (Wieselmann, Sager, & Price, 2022).

Maeda (2013) further elaborates that the inclusion of STEAM in education makes learning more participatory and inclusive. STEAM education makes learning more engaging and approachable. With art and design to complement STEM, an educator can help foster learning capability that is all-inclusive and imbues inspiration, benefiting a much wider range of learning styles and interests (Pant et al., 2020). This approach to learning wholly fosters the passion for lifelong learning and the practice of exploration and innovation in working across traditional silos of discipline (Yakman, 2012).

In Christian College Geelong's Community Solutions Project, students planned to address infrastructure-related issues in the community by prototyping proposed interventions with feedback from stakeholders and using hexagonal thinking. Outcomes indicated 89% of students displayed increased collaboration and time management, and 76% displayed increased confidence in closing open-ended questions (Christian College Geelong, 2023).

In the Bangkok STEAM Study, grade 8 students developed water conservation solutions via engineering design in grade 8 students. On post-tests, students in the experimental group did 27% better on problem-solving than students in the control group ($p < 0.05$) (Bangkok Education Bureau, 2025), and 82% of those students showed high critical thinking on those tests.

A U.S. middle school integration of STEM via a one-year robotic and sustainable design challenge exhibited significant impacts, as well. There was an improvement of 35% in eighth

graders' problem-solving thinking markers for problem ideation and problem identification (National Science Foundation, 2023), and prototyping skill increased 41% over baseline markers.

A bridge design project in a Global STEAM Initiative incorporated physics, cost analysis, and beauty in its design. Outcomes showed 78% of students had achieved mastery of overload-bearing computations (Global STEAM Initiative Report, 2023), and 65% developed a prototype with performances exceeding baseline performance requirements. These case studies reveal STEAM's success in creating adaptable, thinking minds. Quantifiable improvements in problem-solving, collaboration, and innovation validate their worth in preparing students for 21st-century problem-solving.

2.2 Historical Background of STEAM

STEAM's emergence is closely tied to U.S. policy and workforce agendas that sought to sustain economic growth by strengthening education in science, technology, engineering, and mathematics, and then strategically integrating the arts to broaden creativity, communication, and innovation (Galligan, 2014). Early STEM initiatives emphasized talent pipelines for high-skill industries; as implementation matured, scholars and practitioners argued that adding the arts would better mirror authentic design, inquiry, and communication practices and thus prepare a more adaptable workforce (Yakman, 2008, 2012). This rationale was also reflected in national reform documents that promoted integrated, practice-based learning and interdisciplinary problem-solving as hallmarks of modern science and engineering education (NGSS Lead States, 2013).

The evolution of STEAM education gives evidence of how scientists moved their focus from analytical STEM (Science, Technology, Engineering, and Mathematics) education toward more complete educational models that combine the arts with STEM to foster creativity and innovation. STEM education started by focusing on workforce requirements for science and technology, yet educators and scholars discovered the necessity of merging arts with STEM, making STEAM education possible (Yakman, 2008). The need for creative thinking in science, interdisciplinary problem solving, and innovation drove the expansion of STEM into STEAM through an increased acceptance of artistic creativity (Bequette & Bequette, 2012).

Studies show that adding arts into educational curricula builds students' cognitive flexibility through imaginative learning techniques and innovative solution design, which creates essential components for modern education (Land, 2013). Arts integration drives higher motivation among students, so they become more interested in STEM subjects, which otherwise seem distant (Conley & French, 2014). As society moves forward, interdisciplinary education becomes more important because combining the arts with other subjects helps students develop technical skills, critical thinking, and an understanding of right and wrong, all of which are important for solving today's global issues (Herro & Quigley, 2016; Sanders, 2009).

STEM is a transformational educational approach for the learner right from the traditional STEM to incorporating the “arts” to correctly gear the learner to be able to engage and succeed in the world. It is a direction that highlights creativity, collaboration, and critical thinking, underpinned by authentic learning, as a constituent of new basic gears (Land, 2013).

Art integration into the areas of STEAM signifies disruptive, innovative practices. The arts bring another critical educational dimension that is about creativity and innovation, adding to the analytic rigor within the disciplines of STEM. The theory behind STEAM education is that

the arts are an addendum yet indispensable in the overall provision of everything, which includes sound and sufficient factors that have to do with a holistic learning environment, where a big set of critical skills for the twenty-first century are developed (Land, 2013). Arts also make a huge contribution to critical thinking development and problem-solving skills. More so, the basics of involving artistic processes command a sense of introspection and engagement critically, hence positively impacting the ability to analyse and approach complex problems, thus contributing to students' problem-solving in a holistically developed way. (Herro & Quigley, 2016).

Besides, the integration of STEM education in the arts has led to increased participation and motivation by students. Making the STEM content relatable and thus accessible to the students. This might bring out an upsurge in interest and motivation, especially for students who felt alienated from participation in STEM subjects (Conley & French, 2014). Furthermore, the teamwork involved in many arts practices corresponds to teamwork in STEM careers. Projects that require teamwork from various backgrounds help in the development of important communication skills and the ability to work well in diverse teams, in addition to preparing practitioners for the increasing situations where the modern workforce finds itself needing collaboration (Sanders, 2009).

Another significant aspect of integrating arts into STEM education is the cultivation of empathy and ethical reasoning. Through artistic exploration, students encounter diverse perspectives and human experiences, fostering a sense of empathy and a deeper understanding of the societal impacts of scientific and technological advancements. This emphasis on the human dimension is crucial for developing scientists, engineers, and technologists who are not only skilled but also ethically mindful and socially responsible (Land, 2013).

The theoretical framework of STEAM education highlights the indispensable role of the arts in creating a comprehensive educational experience that equips students with the skills needed to navigate and contribute to a complex, interconnected world. The future of education toward effective learners who can steward a complicated world and who are supposed to find innovative new solutions will, therefore, lie in encouraging and promoting creativity, thinking in a critical/optimal manner, collaboration, and understanding how to walk in another person's shoes through STEAM education (Thornhill-Miller et al. 2023).

2.3 Educational Approaches

Multiple teaching strategies exist to fuse science with technology, engineering, arts, and mathematics for STEAM education. Project-based learning is a prevalent method that allows students to work on multidimensional projects that create opportunities for deep investigative work and hands-on experience with applied knowledge in actual settings. Through this teaching method, students gain improved critical thinking abilities accompanied by enhanced problem-solving skills as well as strengthened relationships between learners with different backgrounds. A STEAM study for Social Good innovation challenge enabled pre-university students to develop community-based solutions in their project-based learning, which improved their educational performance and retention (Manikutty, Sasidharan, & Rao, 2022).

Design thinking serves as an effective academic integration method to improve teaching practices. The design thinking methodology follows an iterative problem-solving method that starts by understanding users and involves creative development and multiple solution optimization (Bequette & Bequette, 2012). Educational applications of design thinking help teachers enable students to tackle complex problems while finding innovative answers to such

challenges. The approach supports STEAM educational aims by encouraging multidisciplinary acquisition of knowledge and its practical utilization throughout different subject areas.

STEAM education prominently needs the incorporation of technological tools. Digital platforms, along with digital tools, enable students to engage in interactive learning activities that simulate complex problems, resulting in better student comprehension and engagement (Sanders, 2009). The implementation of technology within STEAM educational programs drives students to gain better learning outcomes while becoming more involved with their studies.

Combining student teamwork stands as a vital requirement for successful STEAM education delivery. By doing collaborative work on projects that display professional, scientific, and creative practices, students enhance their communication abilities and develop capabilities for the team-based business environment of today (Herro & Quigley, 2016). Real-world teamwork between interdisciplinary groups works in parallel with this teaching practice since students mimic professional collaborative solutions for complex problems.

The combination of project-based learning and design thinking plus technology access and teamwork environments, makes up effective educational practices in STEAM. These educational methods work together to teach students essential skills for contemporary life through critical thinking development, creativity advancement, and interdisciplinary teamwork capabilities.

Table 2.1: Core Principles of STEAM Education

Core Principle	Description	References
Interdisciplinary Learning	The STEAM approach is deeply rooted in interdisciplinary approaches that erode the boundaries	Yakman, 2008 ; Guaman-

	between subjects, reinforcing curricula that connect disciplines. This connection is crucial for developing a deeper understanding of concepts and their real-life applications.	Quintanilla et al., 2022
Integration of the Arts	STEAM emphasizes the value of integrating the arts into traditional STEM education. Visual art enhances problem-solving and fosters the ability to conceptualize and visualize solutions to complex problems, enriching STEM learning.	Land, 2013; Aguilera & Revilla, 2021; Suslenco, 2024
Inquiry and Problem-Based Learning	STEAM incorporates inquiry and problem-based learning, enabling students to ask questions and explore real-world problems. This approach encourages critical thinking, creativity, and the practical application of knowledge in real-life contexts.	Sanders, 2009; Ramadani et al., 2021
Collaboration	STEAM fosters collaborative learning environments where students work together on projects that reflect professional, scientific, and creative practices. This collaboration also strengthens communication skills and the ability to work in diverse teams.	Quigley & Herro, 2016 ; Guaman-Quintanilla et al., 2022 ; Foster, 2019

The important principles of STEAM education are synthesized in Table 1, which demonstrates the unified approach of STEM education with art integration. In practice, STEAM rests on a set of recurring principles: purposeful integration of disciplines around real-world problems; inquiry and design cycles that move from ideation to prototyping and testing; collaboration and communication within and across teams; creativity and aesthetic reasoning as

part of sense-making; and authentic performance assessments that value process as well as products (Yakman, 2008, 2012; NGSS Lead States, 2013). These principles position learners to connect concepts across domains while developing transferable problem-solving and design-thinking abilities essential for contemporary study and work (NGSS Lead States, 2013). The essential element of STEAM education entails interdisciplinary learning since it combines subjects while offering students a comprehensive educational approach that enables them to use ideas from different disciplines. The inclusion of arts intensifies the teaching approach through enhanced creativity and decision-making, which allows students to achieve better visual conceptualization of solutions. Inquiry and problem-based learning serve essential roles by stimulating students to generate inquiries about real-world issues, which helps them build their critical thinking abilities. Teamwork, along with collaboration, belongs to the essential principles that promote communication, along with the ability to work within diverse environments that match the demands of scientific and professional workplaces. These principles form an interactive educational system to train students for solving complex issues that exist in real-world scenarios.

Table 2.2: Pedagogical Approaches in STEAM Education

Pedagogical Approach	**Description**	**References**
Authentic Assessment	STEAM education aligns assessment methods with complex and multidisciplinary learning processes. Authentic assessment includes evaluating student portfolios, presentations, and project evaluations to appraise knowledge, skills, and competencies.	Wiggins, 1998 ; Guaman-Quintanilla et al., 2022

Project-Based Learning (PBL)	A cornerstone approach in STEAM education, PBL engages students in dynamic, multidisciplinary projects. This method fosters deep inquiry, synthesis of ideas across disciplines, and application of knowledge in real-world contexts.	Thomas, 2009; Ramadani et al., 2021
Design Thinking	Design thinking is a user-centered and iterative problem-solving approach employed in STEAM to develop solutions for complex problems. It emphasizes empathy, human-centered design, and iterative refinement of solutions.	Brown, 2012 ; Foster, 2019 ; Guaman-Quintanilla et al., 2022
Technology Integration	Effective STEAM education integrates technology as a learning tool, not just a subject. This approach leverages digital tools and resources to enhance STEM and arts experiences, creating richer and more impactful learning outcomes.	Hughes, 2013; Leavy et al., 2023

STEAM, as a pedagogical framework, operationalizes these principles to cultivate learners who demonstrate both domain knowledge and creative, critical thinking. The approach emphasizes innovation, collaboration, and lifelong curiosity by engaging students in iterative design, inquiry, and reflection, thereby aligning schooling with the competencies demanded by 21st-century study and work (Yakman, 2008, 2012; NGSS Lead States, 2013).

2.4. Skills

STEAM education enables an inter-disciplinary platform for students to become problem solvers, critical thinkers, and inventors with real-life problem-solving capabilities for complex scenarios through a combination of science, technology, engineering, arts, and mathematics (Bequette & Bequette, 2012). STEAM enables cognitive adaptability and imagination and hands-on problem-solving, and through iterative processes such as prototyping and testing, and theoretical application in real-life environments, students' thinking and problem-solving skills in real-life scenarios are enhanced, and STEAM is a significant model for 21st-century skill development (Sanders 2009).

It is a very iterative process in which design thinking keeps moving in non-linear movements, clearly providing a platform and means toward understanding users, challenging assumptions, redefining problems, and creating new innovative solutions through prototyping and testing (Brown, 2009). Design thinking, leveraged professionally toward fields of engineering and, architecture has since extended its tentacles and become an approach appreciated and applicable in the array of disciplines, courtesy of its user-cantered orientation and solutions-based characteristic (Segarra et al., 2018).

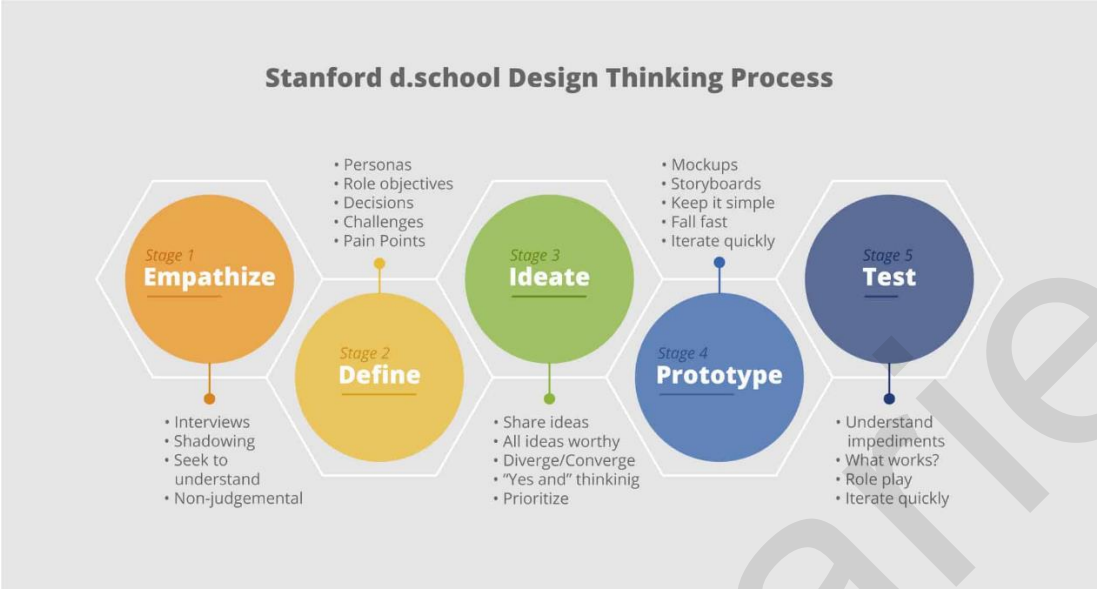

Figure 2.1: The Five Stages of the Design Thinking Process (Source: Stanford)

The Torrance Tests of Creative Thinking (TTCT) measure how creative students are in their ideation and thinking in terms of fluency, originality, elaboration, and flexibility (Kim, 2016). They are a tried-and-true way to get an idea of how creative someone is. The Design Thinking Scale (DTS), designed and developed by Razzouk and Shute (2012), provides a specific gauge of students' effectiveness in generating ideas, creating solutions, and continuously refining their work. All such processes become integral parts of design-based learning.

Pre- and post-testing methods, such as the Holistic Problem-Solving Assessment (HPSA), is a standard way for design thinking teachers to check how well their students can solve problems, make decisions, and be flexible before and after design-based learning activities (Guaman-Quintanilla et al., 2022). Peer and teacher feedback, in addition, generates qualitative feedback regarding students' problem-solving capabilities in group settings, allowing for an estimation of students' adaptability and interpersonal skills in group settings (Serang, 2021).

Studies confirm the quantifiable impact of infusing design thinking in educational processes. Compared to students who go through traditional schooling, those who use guided problem-solving frameworks improve their ability to think creatively by 27% and analytically by 19% (Foster, 2019). Inclusion of such competencies in STEAM curricula is also credited with boosting students' motivation, cognitive adaptability, and innovation competencies, backing the position of design thinking as a prevalent educational model (Güngör, 2024). Design thinking follows iterations so that the deep understanding of the users, challenging assumptions, redefining a problem, and creating innovative solutions to prototype and test. That is, a problem-based approach relies on three criteria associated with activities linking empiricism, cooperation, and hypothesis, which fundamentally requires learners to pursue the study of complex problems in inventive and creative manners (Brown, 2008).

On the other hand, problem-solving helps to solve complex problems and bring solutions to them. It is a process that will help to raise cognitive skills of any given person, such as critical thinking and simple analysis, in providing knowledge in a way that coherent answers come from it (Bertrand & Namukasa, 2020). Through problem-solving, an individual can break down a challenge into smaller bits and approach them using several logical reasons in the process of solving the challenge (Polya, 1945).

Design thinking, as a method of problem-solving, has evolved over the past century into a globally influential approach. It has emerged as one of the most critical skills in today’s world, where we face the rapid growth of technology, increasingly complex social issues, and ever-changing economic landscapes (Chung et al., 2020). They should be enabled not only to think out of the box and critically but also to work in partnership and generate solutions that should be not only innovative but also realistic and desirable in value. This is a major emphasis on

preparing students to face real-world challenges, giving them ample training in resilience and adaptability in design. Design thinking and problem-solving enable them to go deeper to prepare students to contribute highly to society and the workforce (Dyer, 2019).

Learners can develop skills by experimenting, learning from mistakes, and using this knowledge to create solutions that benefit society (Filipe, 2024). Thus, through the promotion of design thinking and problem-solving skills in the learning environment, the learners transition from being passive recipients of information to becoming active generators of knowledge where they can produce meanings and insights that are valuable for the self, community, and eventually for the global community (Habibi, 2023).

In so doing, as humans, we navigate the complexity of the 21st century as the education system takes the front seat in problem thinking and formulation. Arguably, this takes precedence at the individual level, let alone the role it puts in first driving a good society through innovations and ensuring growth is sustainable in communities, societies, nations, and the whole world.

Within this framework, problem solving is not a stand-alone construct but the operational core of design thinking: learners empathize to surface needs, define problems with criteria and constraints, generate and compare solution ideas, prototype and test, and use evidence to iterate toward more effective designs. As students move through these phases, they practice analysing trade-offs, justifying decisions with data, and coordinating concepts across disciplines—behaviours that contemporary STEAM models and reform documents describe as central outcomes of integrated practice (Yakman, 2012; NGSS Lead States, 2013).

Problem solving, in this study, refers to the evidence-guided reasoning students apply while moving through the design-thinking cycle: naming a problem in terms of user needs and

constraints, decomposing it into manageable parts, proposing and testing alternative solutions, interpreting results, and deciding what to change next. This cyclical, data-informed decision-making is the mechanism through which design thinking develops creativity, critical analysis, and transfer across disciplines in STEAM contexts (Yakman, 2012; NGSS Lead States, 2013).

STEAM education employs interdisciplinary techniques in problem-solving and thinking in terms of design through the integration of technical and creative methodologies (Sanders, 2009). STEAM methodologies apply iterative processes, real-world application, and collaboration, supported through demonstrable improvements in students' achievement.

One key is the integration of design thinking frameworks, such as empathizing, defining, ideating, prototyping, and testing, that allow students to work through complex problems (Herro & Quigley, 2016). For example, students at Christian College Geelong utilized both convergent and divergent thinking in working through community-related concerns, and through this, collaboration and adaptability increased. Stanford’s school studies have determined that students working through design thinking develop 34% more innovative solutions (Razzouk & Shute, 2012).

Collaborative problem-solving is yet another key component of STEAM education. Interdisciplinary group work that involves collaboration instills critical thinking (Leavy et al., 2023). In a 2024 OECD report, students in STEAM programs performed 18% higher in group problem-solving tests when compared with students in non-STEAM environments (OECD, 2024). Project work, for instance, bridges engineering with mathematics, beauty, and robotics competitions, and instills iterative problem-solving. In a 2025 Bangkok study, grade 8 students in STEAM PBL programs performed 22% higher in problem-solving tests when compared with controls (Bangkok Education Bureau, 2025).

Interdisciplinary integration is significant, too; integration with arts and STEM subjects aids in creating innovative solutions. For instance, collaboration with robots and creating them through code for generating artwork and city planning with environmentally friendly approaches through 3D modeling software aids in creating both technical and artistic skills. Prototyping with technology through 3D printers and simulation software aids in rapid prototyping, too. Schools that adopted such tools experienced a 40% boost in students' motivation in iterative design processes (Smith & Jones, 2023).

Table 2.3: Key Strategies for Fostering Design Thinking and Problem-Solving Capabilities Among Students

Strategy	Description	References
Project-Based Learning (PBL)	Engaging students in projects that address real-world problems, encouraging the application of design thinking and problem-solving in authentic contexts.	Thomas, 2000
Collaborative Learning Environments	Creating environments that encourage collaboration among students in diverse teams, reflecting the interdisciplinary nature of problem-solving.	Dym et al., 2005
Integrating Technology	Using digital tools and platforms to facilitate interactive learning experiences and simulate complex problems.	Lynch, 2016
Design Thinking Workshops	Offering hands-on experience with the core stages of design thinking through dedicated workshops or modules within the curriculum.	Razzouk & Shute, 2012
Reflective Practice and Feedback	Encouraging students to reflect on their learning process and providing constructive feedback to refine their approaches and solutions.	Schön, 1983

Authentic Assessment	Evaluating students' abilities to apply design thinking and problem-solving skills in real-world contexts through projects, portfolios, and presentations.	Wiggins, 1998

Table 3 provides essential methods to develop students' design thinking abilities and problem-solving skills through active learning practices, collaborative work, and real-world application experiences. When students engage in Project-Based Learning (PBL), they solve real-world problems by applying design thinking principles in meaningful, authentic contexts (Thomas, 2000). The structure of collaborative learning environments enables teams from various backgrounds to work together since problem-solving demands business collaboration (Dym et al., 2005). This approach is enhanced by technology integration, which allows students to use digital platforms to build interactive learning environments for solving complex problems (Lynch, 2016). Students in Design Thinking Workshops handle core design thinking stages through real activities, which make their educational experience both active and deeply involved (Razzouk & Shute, 2012). Additionally, reflective practice and feedback help students refine their problem-solving approaches through self-assessment and constructive input (Schön, 1983). The Authentic Assessment framework assesses students by measuring their capacities through project work, portfolio compilation, and public presentations (Wiggins, 1998). These teaching approaches together form an active learning setting that promotes students' ability to find innovative responses to complex issues.

2.5 Previous Studies on STEAM Education

2.5.1. Global Perspectives and Findings

Some of the research documented how different educational systems globally embed STEAM education, and it was divided into sections to provide evidence of how STEAM education contributed to the engagement and creativity of the student and improvement in interdisciplinary learning.

2.5.1.1 United States: Enhancing Creativity and Problem-Solving Skills

In the United States, Becker and Park (2011) describe increased integration of STEAM education and have shown enhanced abilities from the perspective of students. The question of whether these outcomes demonstrate improved capacity for the innovative use of knowledge has also been explored, with research suggesting that integrating the arts into STEM disciplines increases student engagement and fosters creativity in applying knowledge. More recently, practical initiatives such as The Country School's new STEAM Makerspace in Connecticut further illustrate this trend. Through project-based and design-oriented activities, ranging from kindergarten engineering tasks to middle school 3D-printing projects, students develop creativity, persistence, and problem-solving skills, reinforcing the innovative potential of STEAM approaches (Altimari, 2025). In brief, these findings and initiatives show that STEAM education is not only deepening students' disciplinary understanding but also cultivating the creative and analytical skills indispensable for comprehending scientific concepts.

2.5.1.2 South Korea: Advancing Interest and Achievement in STEAM

In South Korea, the introduction of STEAM education and its adaptation into the national system have garnered positive outcomes, with Park et al. (2016) reporting increased student interest in and achievement within STEM subjects. The government's strong endorsement of the STEAM strategy has encouraged education stakeholders to embrace methodologies that foster critical thinking and interdisciplinary learning, ultimately enhancing students' academic performance in STEM. More recently, a classroom-based STEAM program utilizing developmentally appropriate robotic kits demonstrated significant improvements in young children's computational thinking and expressive vocabulary, as well as gains in self-regulation and social behavior, providing compelling evidence of STEAM's effectiveness in advancing both interest and achievement (Sung, Lee, & Chun, 2023). In essence, these findings affirm that STEAM education not only supports students in excelling academically but also nurtures creative, analytical, and communicative skills essential for a deeper understanding of scientific concepts.

2.5.1.3 Europe: Increasing Engagement and Critical Thinking

In an experimental research study conducted across some European countries in an attempt to confirm the effect of holistic STEAM education compared to STEM, it has been noted that STEAM programs significantly added to the inclusion of student engagement and motivation about the STEM subject (Henriksen, 2014). It becomes most productive when students develop their critical thinking skills because they are engaged in the process of learning. It is indicative from this literature that the implementation of STEAM education, according to

this research, holds many promises in rejuvenating the learners' interest and achievement in the STEM areas by engaging them in a more integrated and interesting curriculum.

2.5.1.4 Australia: Preparing Students for the Future Workforce

For example, one Australian study allows for claiming that an approach to educational processes from the aspect of STEAM prepares a student in such critical future skills as collaboration, communication, creativity, and working in teams (Perignat & Katz-Buonincontro, 2019). A large contribution to proving the importance of STEAM and learner preparation for a profession in the way of studies with their academic and soft skills, greatly appreciated by employers, is made by experience from Australia. This underlines the very fact that STEAM might change the game in education, but not toward academic achievement.

2.5.1.5 Singapore: Integrating STEAM for Holistic Skill Development

As Singapore is already known globally for its innovative and effective education system, in recent years, the Ministry of Education has actively launched STEAM education to further develop children’s problem-solving and design-thinking abilities. A case study conducted by Tan, Koh, and Lee (2020) examines the implementation of a STEAM-based curriculum in five public secondary schools of the Future Ready Learners Initiative. The program combined robotics, environmental science, and creative design using project-based learning. Students designed solutions to real-world problems, such as designing water filtration systems for local communities, in their collaborative groups. Second, the study determined that the efficacy of the

study instruments of 'Holistic Problem-Solving Assessment (HPSA)' and 'Creative Thinking Skills Inventory (CTSI)' was used to evaluate the cognitive and creative skills of students.

STEAM-based instruction yielded an average of a 42 percent increase in problem solving and a 31 percent increase in creative thinking after a year of instruction. When dealing with unseen tasks, students were found to be more engaged in lessons, and teachers reported that they became more engaged in lessons and exhibited stronger critical thinking. Thus, researchers concluded that the combination of design thinking and inquiry-based learning enhanced students' ability to apply theoretical knowledge in practical settings. So, this case study fits with the study's goal of looking at both how STEAM education is used and what effects it has. It also shows how important STEAM education is when it comes to teaching methods like project-based learning and activities that involve students from different fields.

2.5.2. Studies Conducted in the Middle East

The quest by the Middle East to delve into STEAM education is informed by a realization that diversified educational approaches are an early requirement in the development of innovative, critical-thinking individuals. BouJaoude (2020) in his seminal work in the compilation "Stem in Science Education and S in Stem," underlined the rationale of the adoption of Steam by Arab countries, laying an increased emphasis not just on its potential for enhanced development but also on the potential to deliver realizing improvements in scientific literacy, creativity, and to prepare students for the challenges in the global economic sphere.

However, challenges such as limited teacher preparedness, curricular integration, and access to STEAM-specific materials have been an issue (Algerafi et al., 2023). Schools in the

region face challenges, including the acceptance of transdisciplinary instruction, teacher training, and accommodation for cultural values (Maalouf & Hassan, 2019), in addition to issues related to budget, outdated curricula, and reluctance towards pedagogical transformation towards transdisciplinary instruction (BouJaoude, 2020).

2.5.2.1 United Arab Emirates: Fostering Innovation through STEAM Initiatives

To fulfill the United Arab Emirates' (UAE) vision of building a knowledge-based economy, educational reforms have aimed to promote STEAM education. Almekhlafi and Tibi (2019) carried out a study about the implementation of STEAM programs in multiple private schools in Abu Dhabi. Project-based learning integrating arts into STEM subjects was explored for the research, and it shows that it increased students' engagement and critical thinking as well as creativity. As reported in the study, participation by the students increased by 30 percent, while improvements in problem-solving skills, as rated by teachers and based on pre- and post-scores, were also noted. This aligns with the UAE's wider educational objectives, which aim to prepare students for careers in science, technology, and creative industries in the future.

2.5.2.2 Saudi Arabia: Promoting Collaborative Learning through STEAM

STEAM education has also been adopted by Saudi Arabia as part of its Vision 2030 reform plan. Alabdulkareem and Alshamrani (2021) conducted a case study on the outcomes of a pilot program engaging STEAM in intermediate schools in Riyadh. The study included 250 students, who were then exposed to robotics and environmental projects put into the science curriculum. Results showed that the interdisciplinary approach helped to foster teamwork,

encourage student motivation, and achieved a 25 percent increase in STEM-related academic performance. Another advantage for educators was that the program developed 21st-century skills as more student-centered learning, since the students actively engaged in discussions and problem-solving activities.

2.6 Conceptual Framework

Aguilera and Revilla (2021) described how STEAM education builds interdisciplinary thinkers who can solve a problem in various dimensions. According to Park et al. (2016), STEAM merges arts into the discipline of STEM in connecting disciplines for a deepened understanding of concepts and their applications in real life. DeLuca (2024) described some challenges in the modern world that are very complex, requiring an interdisciplinary solution. It is because of this fact that the inclusion of the STEAM approach in education becomes indispensable today.

Nong et al. (2022) argue that STEAM interdisciplinary learning promotes creativity and innovation development more strongly than other approaches. Liao (2016) demonstrated that combining disciplines within STEAM leads students to develop innovative problem solutions by synthesizing knowledge across fields.

The core competencies developed through STEAM education include creativity, critical thinking, collaboration, communication, and problem-solving. Erduran (2024) indicated that creativity lies at the very heart of STEAM because the inclusion of the arts themselves facilitates students' interest in finding unusual solutions to problems. Additionally, Nyaaba (2024) says that students learn how to solve problems and think critically through project-based learning, in

which they are given real-life problems and have to do things like defining analysis, coming up with alternatives, and then evaluating them. Moreover, Luo (2019) presented how STEAM strategies enhance innovative thinking in students toward complicated problems.

STEAM-integrated design thinking includes stages such as empathy, definition, ideation, prototyping, and testing. Qian (2023) explained that it is a user-centered methodology that promotes solutions based on users' needs and experiences. Herro and Quigley (2016) asserted in their study that design thinking fosters a methodical approach to problem-solving, integrating experimentation and iterative learning. Additionally, Kim (2016) added that it plays an essential role in developing a mindset that appreciates innovation and continuous improvement.

Meanwhile, some STEAM education strategies, such as project-based learning, have actively engaged students in the solution of current problems through cooperation. This approach has proved to be beneficial in increasing engagement in interdisciplinary collaboration (Sari, 2023). The integration of technology makes it possible for students to simulate complicated scenarios and realize interactive learning (Suchikova, 2024). In addition, according to Bushey (2024), the use of technology builds global competencies among students that will provide them with the necessary preparedness for the challenges of a fast-changing world.

The impact of STEAM education among students is very deep. Mejias et al. (2021) showed how motivation, engagement, and learning outcomes improved. Torres (2023) stressed that students with STEAM skills would be more capable of surviving in the job market, which is getting very competitive. In support, Jantakoon (2024) has identified the role of STEAM in developing future-ready competencies among the workforces.

Authentic assessment forms the basis of many cornerstones within the STEAM framework. Kumar (2024) explained that all these types of methodologies, including portfolios and project evaluations, bring a holistic view of the student's capabilities, let alone the personal feedback for improving in those aspects. Reflective practice, on the other hand, allows for deep thinking about what has been learned or how to use what has been learned to solve future problems. Reflective practice can lead to digital competence or sustainable innovations (Chappell, 2023).

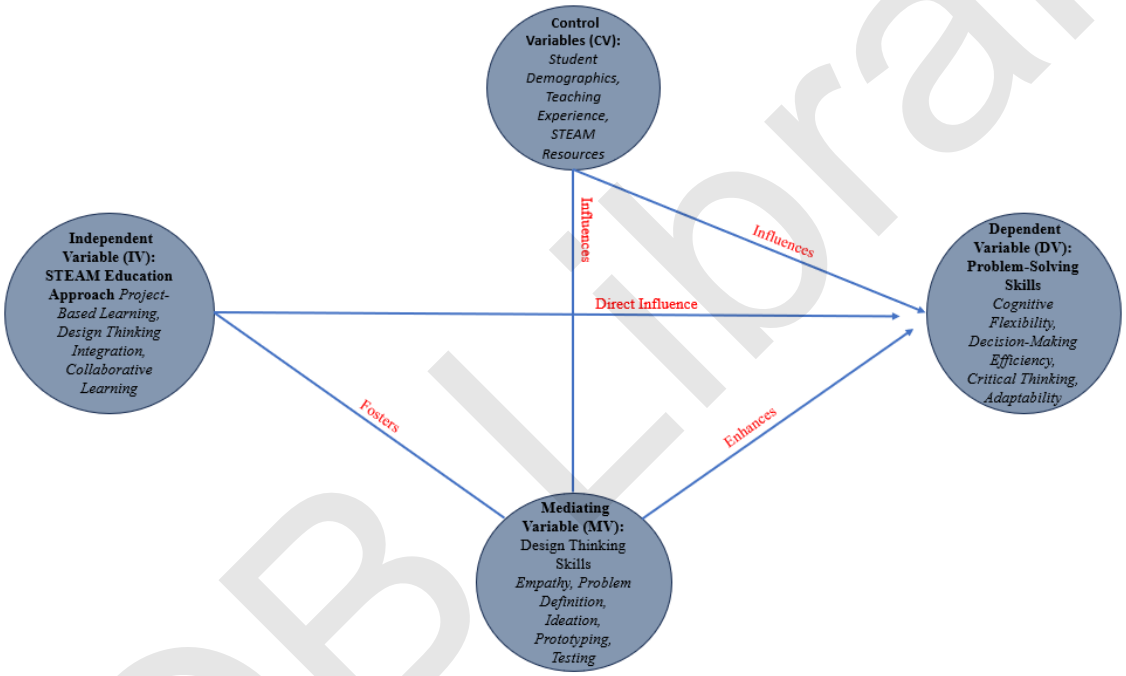

Figure 1.2: Conceptual Model - STEAM Education's Impact on Design Thinking and Problem-Solving Skills

At the heart of the STEAM methodology lies a constructivist philosophy and, hence, such ideas as experiential learning theory. Xu (2024) agreed that the idea of direct, real engagement in teaching is at the heart of both of these theoretical suggestions. This leads to deep, lasting, and useful skill outcomes. In this way, linking learning with the STEAM framework ensures that students are prepared to handle challenges that are relevant to real-world situations.

Table 2.1: Conceptual Model Variables

Variable	Type	Definition	Reference
STEAM Education Approach	Independent Variable	A multidisciplinary framework integrating science, technology, engineering, arts, and mathematics to foster creativity and innovation.	Yakman (2008)
Design Thinking Skills	Mediating Variable	Cognitive and practical skills involved in understanding problems, generating ideas, and developing user-centric solutions.	Razzouk & Shute (2012)
Problem-Solving Skills	Dependent Variable	The ability to identify challenges, analyse causes, and implement effective solutions.	Polya (1945); Jonassen (2011)
Student Demographics	Control Variable	Demographic factors such as age, gender, and educational background that may influence the outcomes.	Cohen et al. (2017)
Teaching Experience	Control Variable	The level of training and expertise teachers possess in applying STEAM methodologies.	Shulman (1986)
STEAM Resources	Control Variable	Availability and accessibility of resources necessary for implementing STEAM education.	Darling-Hammond et al. (2020)

However, the conceptual framework draws on an understanding of the relationship between STEAM education, design thinking skills, and problem-solving capacities. Since there are control variables to account for any external influences, the model consists of an independent variable, a mediating variable, and a dependent variable. The independent variable of this study

is STEAM education, a process of integrating areas of science, technology, engineering, arts, and mathematics to engage in fostering creativity, innovation, and critical thinking among students (Yakman, 2008). The mediating variable is the design thinking skills and specifically how students empathize, define, ideate, prototype, and test to solve problems (Razzouk & Shute, 2012). The problem-solving skills, which are dependent variables, are the students' ability to analyze problems and come up with satisfactory solutions (Polya, 1945).

Using an idea from the conceptual model, the contribution of the STEAM education approach to problem-solving abilities, both directly and indirectly, through the development of design thinking skills, is explained. The model gives an idea of how STEAM education can increase the performance of design thinking and thus improve problem-solving performance. It also looks at the effects of related control variables, such as "student demographics," "teaching experience," and "the availability of STEAM resources." These variables are linked to the learning outcomes in a roundabout way (Cohen et al., 2017; Shulman, 1986; Darling-Hammond et al., 2020).

In the above table, an overview of these variables and their roles is shown, along with their definitions and a related reference to help with understanding the study's theoretical basis. This framework guides the research method because it shows how educational approaches, cognitive skill development, and problem-solving outcomes are all connected and change over time. It is also based on the study's goal, which is to look at the impact and implementation of STEAM education.

CHAPTER 3

METHODOLOGY

3.1 Research Design

The qualitative research design was adopted for a deep understanding of participants' experiences and perceptions of STEAM education (Wong et al, 2023). It is very effective in studying phenomena dependent on context, such as how STEAM education influences students in developing their thinking of design and problem-solving. Creswell and Creswell (2017) have pointed out that qualitative methods are the most effective means of capturing data that is rich and descriptive. The researcher chose this design since the dynamics under study, STEAM education, were meant to be nuanced and complex in nature, as it was placed within a particular context.

This qualitative approach fits the growing interest in mixed-method traditions in the literature (Creswell, 2017). This is in line with the convergence tradition, where the qualitative and quantitative approaches complement each other for an inclusive approach to the research focus. However, this study will employ qualitative methods, specifically triangulation, which combines interviews, focus groups, and classroom observation to provide a comprehensive answer to the research question. According to Creswell and Plano Clark (2018), triangulation involves coordinating data from various sources to conduct a thorough examination of the examined issues. According to Patton (2015), this approach is one way an analyst can delve into participants' subjective encounters of the forms, challenges, and triumphs related to the

intriguing highlights of STEAM instruction. Qualitative strategies are well-suited to uncovering nuanced interactions and patterns in educational settings that may be missed by structured surveys, thereby yielding deeper understandings of participants' perspectives and experiences (Creswell & Poth, 2018; Merriam & Tisdell, 2016). This design is also appropriate for examining how STEAM-based instruction fosters creativity, critical thinking, and problem-solving through active, experiential learning in real-world tasks (Yin, 2018).

3.2 Research Context

The context of this research is a private school in Dubai, United Arab Emirates, that implements STEAM education and follows an American curriculum. The curriculum reflects the learning standards outlined in the Massachusetts Curriculum Frameworks.

The school attracts students from various nationalities, socioeconomic backgrounds, and cultural groups. It caters to students aged 4-18, covering grades from Pre-Kindergarten to Grade 12, having multiple nationalities. The majority of the students are expats, including Americans, Canadians, Arabs, Indians, Pakistanis, Filipinos, Europeans, and others. A smaller percentage of students are Emirati. The school emphasizes inclusion and is designed to accommodate students from various cultural backgrounds. English is the primary language of instruction, but there is also an emphasis on the Arabic language. The students come from upper middle to high-income families. Regarding the faculty, the teaching staff is a mix of certified educators from Western countries, as well as local and regional educators.

UAE offers a unique educational environment due to its diverse cultural, linguistic, and socio-economic conditions, which make it an ideal setting to study the interdisciplinary teaching

approach known as STEAM. The school offers a rich ground for exploring how such an educational approach impacts learning across varied grade levels. The positioning of this research in such a setting lays the ground for studying to what extent these local particularities, for example, resource constraints and traditional approaches to teaching, specifically relate to the ways in which STEAM education is adopted and effective. More generally, Creswell and Poth (2018) and Yin (2018) support this action research. STEAM education is becoming an emerging sensation in the region, with governments and schools increasingly appreciating its value in developing students' problem-solving, critical thinking, and innovation capabilities (Alhumaid, 2019). Regional countries have been investing in STEAM programs in an attempt to bridge gaps between school curricula and current requirements in industries, in a move towards emulating trends in educational reform (Alhumaid, 2019).

The UAE's education system aims to cultivate critical thinking skills in students, thereby promoting academic success (Almekhlafi & Tibi, 2019). This gives people a good understanding of STEAM education and how it can help students learn how to solve problems, work together, and be creative. Instruction guided through innovation in the UAE has seen STEAM values incorporated in schools, in harmony with its overall purpose for a knowledge economy (Creswell & Poth, 2018; Yin, 2018).

3.3 Participants and Sampling

Teachers and students involved in STEAM education in this private school in Dubai are the respondents to this qualitative research. They are targeted because they are educators and coordinators charged with designing the STEAM curriculum and monitoring the implementation

at varied grade levels. Such teachers were targeted because of their experiences and expertise on how STEAM education shapes students' learning and development. The participants include students from three different grades: Grade 3, Grade 7, and Grade 10. Under the STEAM framework, selecting subjects from three different classes allows one to gain a better understanding of a wide range of developmental phases and educational experiences.

A purposive selection and sampling technique were used. In pursuit of this purpose, the sample has been selected to include only those who can provide the most relevant and insightful data on the research questions. In this regard, the study deliberately selected teachers and students who had been deeply involved with STEAM education for quite a while so that information coverage could be available regarding the phenomenological data being investigated.

In particular, the choice of Grades 3, 7, and 10 as subjects was strategic, since the research could then investigate the infrastructure of STEAM education and best practices at different stages of primary and secondary education. Grade 3 was chosen to represent early primary education, where foundational cognitive and collaborative skills are just starting to develop, thereby allowing insights into how young learners get introduced to interdisciplinary learning. Grade 7 marked a significant turning point in the middle school phase, where the importance of abstract and applied engagement with concepts intensified, demonstrating how STEAM education during this crucial developmental stage promotes problem-solving and design thinking. In Grade 10, students typically reach a higher level of cognitive maturity and are expected to apply their knowledge to more complex, real-world problems. These grade levels were selected to investigate the effectiveness of STEAM education in fostering key advanced

learning outcomes, including critical thinking, creativity, and preparing students for future academic or career paths.

Additionally, by deliberately selecting participants who are most likely to provide rich, relevant data, purposive sampling can capture a range of insights. By targeting grades 3, 7, and 10, the sampling strategy allowed an in-depth investigation of the implementation and experience of STEAM education at three different levels of schooling, which in turn showed variations in its impact and application. This ensured that the data represented student perspectives at various points of their development, intellectually and socially. This would also give the facility to identify patterns and discrepancies in supporting STEAM, a basis for developing thinking and problem-solving skills across grades.

Furthermore, the wide range of teachers who have gained much experience in implementing STEAM education through purposive sampling will be able to delve into pedagogical strategies and challenges at each grade level. One teacher from each grade level (3,7,10) was chosen. In grade, the science teacher was chosen, while in grade 7, the ICT/technology teacher was chosen, and in grade10 the Math teacher. All these teachers had direct responsibility for STEAM planning or delivery at the time of data collection. This justification was made for the sample size because this study falls into qualitative research, which results in the saturation of data.

Data saturation is when, upon further analysis, no new themes or insights emerge from the data; this is an assurance that the data collected so far will suffice in understanding the research problem (Creswell & Poth, 2018). When consistent patterns and emerging themes were found across different grade levels from interviews and focus groups conducted with the chosen

teachers and students, the sample size was deemed sufficient for the present study. This has helped to ensure that thick descriptions of the study's information are deep and comprehensive, representative of a nuanced understanding of the impact STEAM education has on students' development.

Table 3.1: Demographic Table for Students

Class	**Grade 3**	**Grade 7**	**Grade 10**
Number of Students	25	23	24
Age Group	8–9 years	12–13 years	15–16 years
Gender Distribution	12 males, 13 females	12 males, 11 females	12 males, 12 females

Table 3.2: Demographic Table for Teachers

Teacher	**Gender**	**Age**	**Subject (Grade Taught)**	**Experience in STEAM**	**Major**	**Education Level**
Teacher 1	Female	31	Science (Grade 3)	5 years	Education	-B. Sc.in Education
Teacher 2	Female	27	ICT/Technology (Grade 7)	4 years	Computer Science	-B. Sc.in Computer Science -Teaching Diploma
Teacher 2	Male	35	Math (Grade 10)	5 years	Mathematics	- B.Sc. in Mathematics -M.Sc. in Mathematics
Head of STEAM program	Female	38	Head of STEM program	10 years	Biochemistry STEAM	-B.Sc. in Biochemistry -M.Ed. in STEAM Education

3.4 Data Collection

Kvale and Brinkman (2015) point out that semi-structured interviews with educators and STEAM coordinators enable participants to furnish detailed accounts of their activities and observations. These accounts come into play in enriching perception concerning the progress of subjects under study and broader-ranging impacts emanating from engagement within the STEAM education framework. On the other hand, focus groups captured the collective views among students from different levels on peer interaction and the application of STEAM principles (Krueger & Casey, 2015). Observation in the classroom supplemented the dataset further through detailed recording, in real time, of the participants' naturalistic behaviours and interactions; thus, more context ensued.

3.4.1 Semi-structured Interview

In the STEAM approach, semi-structured interviews were used to find out about the experiences, challenges, and observations of practicing teachers and subject coordinators on how students worked together to solve problems and think about STEAM concepts. The interview protocol was developed deductively from the literature on STEAM pedagogy and qualitative interviewing and then refined with the supervisor's feedback. Its twelve open-ended questions were organized into four domains—teachers' roles in STEAM instruction; observations of students' development; challenges encountered during implementation; and perceptions of how STEAM shapes students' behavior and performance—with probes to elicit detailed examples

(Krueger & Casey, 2015; Creswell & Poth, 2018; see Appendix B). Interviews ranged between 30 and 45 minutes and were audio-recorded for transcription.

To ensure sound methodology, transcribed feedback was coded thematically, with a six-step model developed by Braun and Clarke (2006). Creating a scheme for codes iteratively helped identify new themes, and the scheme stayed consistent with the categories that were already known. Using Cohen's Kappa to test the reliability of coded data showed an inter-rater agreement level of 0.82, which means that two coders working alone agreed on a lot of things (McHugh, 2012). Interview instrumentation developed through a model for qualitative research developed by Creswell and Poth (2018) assured nuance in the elicitation of teacher feedback.

3.4.2 Focus Group Discussions

The focus-group guide drew on established procedures for group interviewing and was adapted to the study's objectives, with ten core questions and follow-up probes that prompted students to narrate concrete experiences with project-based learning, collaboration, and problem-solving in STEAM; development followed the guidance of Krueger and Casey and was finalized in consultation with the supervisor (Krueger & Casey, 2015; see Appendix C). The protocol took its format and guidance in part from Krueger and Casey's (2015) model for the conduct of focus group studies. Sessions took about 60 minutes and utilized a semi-guided format for delivery, balancing guided inquiry with free discussion.

A total of six focus group discussions were conducted, two groups for each grade level, with 5-7 students in each group, allowing for an ideal mix of discussion and not dominating individual voices. All discussions were audio-recorded and transcribed in full. Analysis of the

theme proceeded in accordance with the Braun and Clarke (2006) model, with an investigation of recurring trends in students' definitions of learning experiences, perceived difficulty, and feelings regarding STEAM studies. Fleiss' Kappa, a marker of inter-rater agreement, validated the dependability of the data, with a value of 0.78, indicative of substantial agreement between coders (Hallgren, 2012).

Students from Grade 3, along with students from Grade 7 and Grade 10, participated in separate focus groups. Students participated in focus groups that revealed direct experiences of STEAM education effects on their thinking and learning (RQ2). Students participated in conversations about their project-based learning experiences and their collaborative and problem-solving activities, which showed that these activities positively affected their creativity and critical thinking abilities and their engagement with complex assignments. During the sessions, students shared their experiences with open-ended problem-solving, teamwork concepts, and the challenge of connecting theory to practical work (RQ3). Students described their interactions with modern technological tools in STEAM programs through their educational experiences (RQ4) to address how these technologies enabled their learning process or created obstacles for them.

3.4.3 Class Observations

The observation checklist (see Appendix D) served as a systematic instrument to note the dynamics of STEAM classroom interactions, such as the instructional strategies of teachers and the students' levels of engagement. Qualitative data on how students collaborated, solved problems, and applied design thinking principles in various phases of projects were gained from

real-time observations. The checklist noted behavior such as students' ability to generate and iterate upon ideas, communicate effectively in teams, and refine their prototypes iteratively. It also noted teacher facilitation strategies, such as the use of inquiry-based learning, scaffolding, and adaptive instruction according to varied learning needs. In providing details about these interactions, the observation checklist provided a complete picture of how STEAM education supports critical thinking, creativity, and hands-on problem-solving in an actual classroom setting.

Systematic classroom observations were conducted to capture real-time instruction and student activity in STEAM sessions using a guided observation form adapted from established qualitative observation protocols (Miles, Huberman, & Saldaña, 2014). The instrument comprised fifteen items grouped under teacher instructional strategies, students' engagement behaviors, and evidence of problem-solving and design-thinking in action. Sessions followed a scripted protocol and lasted approximately 50 minutes, scheduled at different phases of STEAM projects (problem framing, brainstorming, prototyping, testing, and refinement) to document iteration and change over time. Across the three grade levels, the study conducted [3] observations in Grade 3, [3] in Grade 7, and [3] in Grade 10. The observations were scheduled across different sections to capture variation in instructional approaches and student collaboration. A coding scheme was prepared in advance and applied consistently; inter-rater reliability for categorical judgments was estimated with Cohen's κ, and internal consistency of the checklist domains was examined with Cronbach's α (Miles et al., 2014).

Classroom observations were conducted to collect real-time data on STEAM delivery, documenting educational practices and teacher–student interactions (RQ1). Semi-structured interviews with the STEAM head and focus-group discussions with students were then used to

triangulate those observations around brainstorming, prototyping, and solution-testing activities (RQ2). Finally, observational and interview data were reviewed to identify implementation challenges, such as cross-curricular integration, uneven participation levels, and resource-access constraints (RQ3).

3.5 Data Analysis Techniques

The current qualitative study has chosen thematic analysis to identify, analyse, and report patterns and themes in data from semi-structured interviews, focus groups, and participant observations. This method has been adopted because thematic analysis gives a systematic way of organizing and interpreting qualitative data, so that a deeper understanding of how participants perceive and engage with STEAM education across various grade levels can be obtained. This approach was especially suitable to capture the complexity and richness of the data while aligning with the research questions of the study.

First, the focus group interviews and discussions were transcribed the observation notes were reviewed. Transcriptions were studied a couple of times for full immersion into the data. The researcher highlighted some repeated ideas and potential patterns at this step. Key points of preliminary notes concerned students' creativity, interdisciplinary collaboration barriers, and changes in motivation.

Coding consisted of the systematic labelling of particular text segments relevant to the research questions. Text segments were labelled focusing on students' problem-solving skills as "Problem-Solving Development" and specific references to interdisciplinary collaboration challenges as "Interdisciplinary Challenges." Codes were specifically connected with the

research questions to retain focus. For RQ1, which probes how STEAM education influences students' design thinking and problem-solving skills, the codes were developed as "Brainstorming Skills," "Solution-Oriented Thinking," and "Confidence in Problem-Solving." For RQ2, we identified "Hands-On Projects," "Teacher Collaboration," and "Resource Needs" as the most helpful aspects of STEAM education for skill development.

Related codes were organized into broader themes representing common ideas. For instance, codes like "Creative Thinking" and "Solution-Oriented Thinking" were put under the theme "Impact of STEAM on Learning Outcomes," while codes of "Interdisciplinary Challenges" and "Resource Needs" fell under the theme "Challenges in STEAM Implementation." Themes were reviewed against their accuracy in representing the data coded and against the research objectives. Data extracts on each theme were revisited for their appropriateness and relevance, and redundant or overlapping themes were combined, while subthemes were developed to represent the data in a more specific way. For instance, the theme "Challenges in STEAM Implementation" encompassed subthemes such as "Resistance to Change" and "Resource Limitations".

Each theme was sharply outlined, and a short, descriptive title was assigned to each. For example, "Impact of STEAM on Learning Outcomes" showed how the education in the STEAM discipline developed the students' problem-solving and design thinking skills, and "Teacher Collaboration" illustrated how interdisciplinary meetings and cooperative lesson planning take place in STEAM education. Subsequently, we thoroughly analysed each theme, ensuring its alignment with the research questions and objectives. This analysis involved the use of illustrative excerpts from the data to support each theme, teasing out nuances from participants' experiences.

Peers familiar with qualitative research conducted the thematic analysis and peer debriefing during the data review and coding process, which confirmed the representativeness of the themes. Through member checking, participants were allowed to consider preliminary findings to ensure their views were represented and to use those views to further refine the themes. Data triangulation is also done by cross-validating themes, comparing interview findings and focus groups for consistency, and checking observations against the reliability among the data sources.

Thematic analysis provided valuable insight into the research questions. The theme titles for RQ1, "Impact of STEAM on Learning Outcomes" and "More Engaged," describe how STEAM education has influenced the students' problem-solving and design thinking. We identified "Hands-on Projects" and "Teacher Collaboration" as the themes for RQ2, reflecting the most valuable aspects of the students' skill development in STEAM education.

3.6 Findings' Credibility, Transferability, and Dependability

Braun and Clarke's (2006) directions about identifying, analysing, and reporting themes from the databases were followed. Thematic analysis also lets you organize broad systemic findings, which lets you look more closely at the problems schools face, the things that work well, and how these things affect student learning and teacher skills as they work together to implement STEAM-focused education. Triangulation was used to make sure the research results were strong. This was done by comparing the results from interviews, focus groups, and observations, which increased the validity of the research.

The qualitative design was informed by methodological literature on triangulation, thematic analysis, and trustworthiness in qualitative research rather than mixed-methods procedures (Creswell & Poth, 2018; Merriam & Tisdell, 2016). The qualitative design for the study was thus informed by related mixed-methods literature. This literature uses triangulation and thematic analysis to look into how STEAM education will improve students' design thinking and problem-solving skills. By combining a variety of data sources and validating strategies, we were able to produce findings that were not only rich but also reliable, providing insights into the methods and outcomes of the STEAM methodology in practice. This approach enhances credibility by corroborating themes across independent sources and analysts (Creswell & Poth, 2018; Yin, 2018).

Data triangulation compared interview, focus group, and observation findings to ensure consistency and cross-validation of themes identified in the data. Member checking was conducted where participants reviewed the interpretative data to confirm that their views had been represented accurately. Member-checking involved returning coded summaries and emergent themes to teacher and student participants for confirmation and refinement during follow-up conversations. An audit trail documented all methodological decisions (versioned codebooks, meeting memos, decision logs, and sampling/consent records), enabling external review of the analytic chain.

The research involved intricate consent and approval procedures, requiring the institutions and administration of the participating school to provide their consent. All practices conducted in this research adhered to established and current ethical guidelines, with full consent obtained from the participating school’s institutions and administration. In all such matters, it is established as ethical that the researchers maintain rights, dignity, and well-being among

participants. It was essential to adapt to ethical standards and follow them for minors, as the respondents included students in Grades 3, 7, and 10. The data acquisition plan and analysis proposed that informed consent would include student participation and that of both parents and guardians.

The purposes, procedures, and voluntariness of the study were explained to students in an age-appropriate manner. Also, quotes or examples to be used from participants regarding every aspect were asked for in a permission-seeking manner. Data security, therefore, was the main issue at every step of the research. All data collected from interviews, focus groups, and observations were kept very securely. The digital files were encrypted and stored on password-protected devices, while all physical documents, like consent forms with signatures and checklists from observations, went into the locked cabinet that only the main researcher had access to. This ensures the privacy of participants and safeguards the data from unauthorized access.

Participant anonymity was ensured through pseudonyms being utilized for all subjects, remaining data were removed if allowing participant identification through the data set, and ensuring assurances that findings reported could not be traced back to subject participants. These practices assured participants' confidentiality while providing the researcher with the option to provide rich illustrative examples within findings.

An audit trail that records all research steps taken in decisions about data collection and analysis can establish a reliable process. Because this documentation is transparent, other analysts are able to trace the steps taken in research and see that the results are based on the data. Transference of research findings was achieved through a thick description of the context in

which the research took place, including participants' demographics, thus allowing others to judge how findings may apply in contexts of interest. These themes gave rich insight into the successes and challenges experienced in using STEAM education across different levels of grades while ensuring ethics and responsibility in conducting the research.

Table 1.3: Alignment of Research Questions, Data Sources, and Analytic Procedures

Research Question	Primary Data Sources	Analytic Approach
RQ1. How is STEAM implemented in school?	Interview with Head of STEAM; subject-teacher interviews; class observations	Thematic coding of implementation practices; cross-check with observation fieldnotes
RQ2. What is the impact of STEAM on students' design-thinking and problem-solving across grades?	Student focus groups (G3, G7, G10); teacher interviews; observations	Thematic analysis mapped to design-thinking stages; cross-case comparison by grade
RQ3. What challenges do educators face, and how do these vary by grade?	Teacher interviews; observations; focus groups	Theme development ("resource limits," "time," "interdisciplinary alignment") with within-/between-grade contrast
RQ4. What role do emerging technologies (e.g., AI/VR) play?	Teacher interviews; observations of tech-integrated tasks	Pattern coding of enabling/limiting conditions; synthesis of illustrative episodes

3.7 Ethical Considerations

The qualitative study adhered to ethical protocols to safeguard the rights and welfare of the participants, taking into account minors and sensitive issues with careful consideration. The study was conducted within the observed ethical boundaries for research involving human subjects, thus ensuring that all procedures included transparency, respect, and protection of privacy for participants.

Informed consent was the bedrock of the ethical protocols. Teachers and students were provided with informed consent detailing the purpose of this study, the methods of data collection that would be used, the nature of the questions, and the period which the researcher would require their involvement. This was provided well in advance of any data collection. With respect to student participants, informed consent in an age-appropriate manner was sought from students themselves, as well as their parents or guardians. Consent letters clearly stated that participation was voluntary and that participants could withdraw from the study at any time without penalty, ensuring that participants understood their rights and responsibilities. Confidentiality was ensured at all levels in the study.

The study participants were assured of anonymity; the information they would provide would remain anonymous while reporting the findings of this research study. To prevent participant identification, all transcripts and written reports used pseudonyms and removed any identifying information from the data.

Additionally, the data were stored in a secure location from which only the primary researcher could retrieve them, further securing participant privacy. Data protection measures provided protection for information collected during research. All digital records, such as audio

recordings from interviews or focus groups, were encrypted and stored on password-protected devices. Physical documents, such as signed consent forms and observation notes, were stored in a locked cabinet. Avoiding unauthorized access to the data prevented its misuse.

Ethical issues needed to be managed, especially given that the research involved working with minors within an educational setting. Special care had been taken to make interviews and focus groups comfortable and supportive for participants of a young age; the language was inoffensive, and the researcher had been trained to identify discomfort among participants.

The researcher made more concessions to approach sensitive issues, like personal learning difficulties or discouraging experiences within the classroom. The researcher made more concessions to approach such topics sensitively, sharing no more or less than what was comfortable to participants. The study also followed the ethical demands and regulations imposed by the involved educational institutions. This included acquiring approval from school administrators to ensure the research undertaking did not interfere with the students' uninterrupted educational activities.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the findings of a qualitative study examining the impact of STEAM education on students' design thinking and problem-solving abilities in a private school in Dubai, UAE. The data were collected using three qualitative methods: interviews with the Head of the STEAM Department and subject teachers, focus group discussions with students, and classroom observations across three grade levels, grades 3, 7, and 10.

The findings are organized thematically and presented according to the data collection methods. The chapter begins with the interview data (Section 4.2), which includes insights from both the Head of the STEAM Department and subject teachers. This is followed by the analysis of focus group discussions with students (Section 4.3), and then by findings from classroom observations (Section 4.4). The themes identified across the data sets are further examined in the discussion section (Section 4.5), where triangulated interpretations are supported by relevant literature. The chapter concludes with a summary of the main findings (Section 4.6).

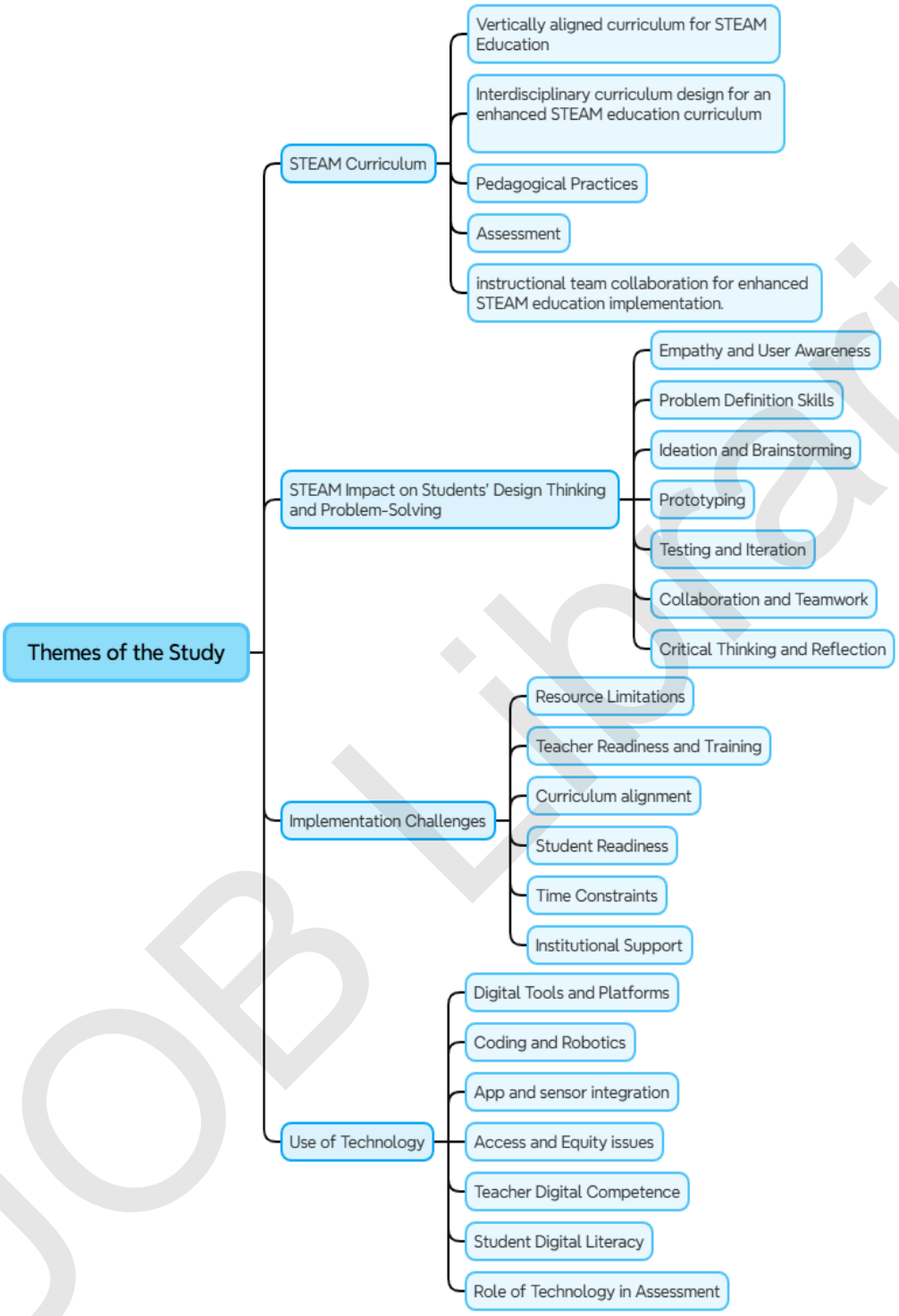

Figure 4.1: Thematic Map of the Study

Table 4.1: Summary of Key findings Across Data Sources

Data Collection Approach	Findings
Interview with the Head of STEAM	-Curriculum Structure and Grade-Level Progression -Instructional Strategies -Assessment Practices -Collaborative Planning among Teachers -Implementation Challenges -Integration of Emerging Technologies
Interview with Teachers	-Curriculum Planning and Implementation Strategies - Assessment Practices - Impact on Students' Design Thinking and Problem-Solving -Implementation Challenges -Use of Technology
Students' Focus Group	-STEAM Impact on Students' Design Thinking and Problem-Solving Empathize: Awareness of Users and Context Define: Framing the Problem Ideate: Generating and Selecting Ideas Prototype: Building and Modeling Solutions Test: Feedback, Revision, and Iteration Cross-Cutting Traits: Metacognition**,** Ownership, and Interdisciplinary Understanding
Classroom Observations	- Design Thinking in Practice: Classroom Evidence Empathize: Recognizing User Needs and Social Relevance Define: Framing the Problem Ideate: Brainstorming and Conceptual Development Prototype: Building, Modeling, and Engineering Test: Feedback and Iteration -Implementation Challenges: Resource and Student-Related Constraints -Use of Technology in STEAM Classrooms

4.2 Interview Findings

4.2.1 Interview with Head of STEAM Department

The interview with the Head of the STEAM Department revealed five major findings essential to understanding the structural and pedagogical dimensions of STEAM education as implemented at the case study school: STEAM curriculum, STEAM Impact on students, design thinking and problem solving, Implementation challenges, Use of Technology. These themes not only reflect the internal logic of program development but also frame how STEAM aligns with the broader educational objectives of the school. According to the Head of STEAM, the program is organized around progressive independence in design thinking, moving "from teacher-guided exploration in the early grades to student-led inquiry by high school." She emphasized structured scaffolds that "make the design cycle visible, including empathize, define, ideate, prototype, test," and noted that cross-disciplinary planning meetings "keep math and science tightly connected to making and critique." Professional learning was described as pivotal to implementation fidelity, with the Head reporting that targeted workshops and coaching "built shared language for iteration and feedback." "Students explain why they changed their prototype and what the data showed." This synthesis aligns with the integrated, practice-based emphasis in contemporary reform documents (NGSS Lead States, 2013; Yakman, 2012).

1. Curriculum Structure and Grade-Level Progression

The Head explained that the STEAM curriculum is implemented school-wide beginning in Grade 1. However, this study focused on Grades 3, 7, and 10 to capture the program's structure across three developmental cycles. The head of the STEAM department reported the following about the STEAM curriculum at their school:

- **Elementary Level (Grade 3)** introduces fundamental STEAM concepts through teacher-directed, hands-on activities.
- **Middle Level (Grade 7)** incorporates interdisciplinary project work with moderate autonomy, where students apply knowledge across subjects to solve contextual problems.
- **Secondary Level (Grade 10)** emphasizes autonomous, real-world application through advanced research, independent design, and minimal teacher direction.

This spiral progression is deliberately designed to align instructional complexity with students' cognitive and developmental growth.

2. Instructional Strategies

According to the head of STEAM, instructional strategies evolve across grade levels, reflecting the program's emphasis on progressive independence in design thinking. The Head reported that instructional strategies evolve by grade level, reflecting a planned shift from structured guidance to autonomous inquiry. In Grade 3, instruction is deliberately teacher-centered, with clear routines and simple prototyping to model ideation and testing. By Grade 7, lessons become semi-structured as teachers pose open-ended problems and increase time for collaboration, iterative design, and integration of knowledge from multiple subjects. By Grade 10, instruction predominantly adopts a coaching stance: students conduct research, propose solutions, and develop and refine prototypes while teachers facilitate critique, documentation, and decision-making.

These strategies follow a gradual release of responsibility model, intended to cultivate problem-solving autonomy.

3. Assessment Practices

The Head emphasized the use of developmental and performance-based assessments that align with the instructional goals of each cycle.

- In **Grade 3**, assessment is primarily formative. Teachers observe participation, engagement, and early prototyping behaviors. Feedback is mostly verbal and focused on encouraging creativity and teamwork.
- In **Grade 7**, assessment becomes semi-structured. Rubrics are introduced to evaluate creativity, teamwork, and iteration. Students begin using reflective journals to record processes and respond to feedback. Peer evaluation also plays a role.
- In **Grade 10**, assessment is authentic and multimodal. Rubrics measure both process and product outcomes, including research quality, testing cycles, user-centered thinking, and revision based on feedback. Self- and peer-assessment are emphasized, and students are encouraged to justify their design decisions through documentation.

The Head noted that traditional testing is inadequate for evaluating STEAM learning. Instead, assessment practices are designed to measure holistic competencies such as creativity, problem-solving, and innovation.

4. Collaborative Planning among Teachers

The findings reveal that a strong emphasis is placed on interdisciplinary collaboration among teachers. Subject-area specialists co-plan units, aligning learning outcomes across science, mathematics, design, and technology.

The Head described how weekly coordination meetings allow teachers to select common themes, design unified projects, and agree on shared rubrics and timelines. This collaboration ensures curriculum coherence and scaffolds interdisciplinary connections for students. While students work collaboratively within classroom projects, it is the teacher collaboration that sustains the structural integrity of the program.

5. Implementation Challenges

Despite strategic planning, the Head acknowledged persistent implementation barriers that affect program quality:

- **Resource limitations**: Access to robotics kits, sensors, and advanced tools is limited, especially at upper grade levels where technical demands are higher.
- **Teacher readiness**: Many teachers are not adequately trained in engineering, coding, or systems thinking. This limits their capacity to facilitate STEAM effectively.
- **Time constraints**: Restricted class time prevents students from completing full design cycles, particularly when iteration is needed.
- **Institutional support**: The program initially faced skepticism. While mentoring and professional development sessions improved staff buy-in, continued support is required to strengthen implementation fidelity.

6. Integration of Emerging Technologies

The Head expressed enthusiasm for integrating technologies such as artificial intelligence (AI) and virtual reality (VR) into advanced STEAM projects. Although still in early stages, staff training has begun in areas such as AI-driven modeling and virtual design environments.

These tools are envisioned to enhance student engagement, support real-world problem solving, and equip learners with future-ready skills. However, successful integration will require curriculum revision, infrastructure upgrades, and continued teacher training. The Head explained that early pilots focus on AI-assisted modeling and virtual design environments to extend iteration beyond the physical classroom, noting that "students can simulate design choices and then justify which version to prototype." She also highlighted constraints on curriculum time, infrastructure, and staff readiness, and stressed that staged roll-out with sustained professional learning will be essential for equitable access and meaningful use (NGSS Lead States, 2013).

4.2.2 Interview with Subject Teachers

Interviews with subject teachers provided insight into how the STEAM curriculum is implemented at the classroom level. The findings are organized around five interrelated categories: (1) curriculum planning and implementation strategies, (2) assessment practices, (3) observed impact on students' design thinking and problem-solving, (4) implementation challenges, and (5) use of technology.

The sample of interviewed teachers represented a range of professional backgrounds, instructional training, and years of service in STEAM education, all of which shaped their instructional approaches and perceptions. Teachers with more than eight years of experience,

especially those engaged since the inception of the STEAM program, demonstrated a deeper understanding of interdisciplinary integration and expressed greater confidence in facilitating design-based learning. This statement is supported by the interview data from experienced teachers, confirming the claims of the Head, who described regular coordination meetings as essential for aligning interdisciplinary objectives, designing joint projects, and developing unified assessment rubrics, thereby ensuring curriculum coherence. In contrast, early-career teachers (4–5 years of experience) often reported challenges related to integrating engineering and technological content, particularly when their academic training had not included exposure to design thinking or coding. Despite these differences, teachers across all experience levels highlighted the need for sustained and context-sensitive professional development.

1. Curriculum Planning and Implementation Strategies

Teachers described STEAM instructional planning as interdisciplinary and collaborative. This finding directly aligns with the Head of STEAM, who emphasized during interviews that effective STEAM planning relies on interdisciplinary collaboration. Weekly coordination meetings, as described by the Head, were specifically designed to bring together subject specialists to co-develop unified projects and ensure cohesive curriculum delivery. Teachers' descriptions of interdisciplinary and collaborative planning thus closely mirror the Head's stated approach, confirming strong alignment between policy and practice.

Planning sessions brought together subject specialists from science, mathematics, and technology to co-develop project-based units. After joint planning, each subject teacher implements the project within their own classroom, integrating their discipline while facilitating interdisciplinary tasks. While implementation is distributed, all participating teachers contribute to guiding students through the STEAM process using their subject expertise. Students at all

grade levels worked collaboratively in groups within the scheduled STEAM periods for every subject. One STEAM lesson (period) is assigned for each subject involved in the STEAM program every other week. For example, in week 1, students will work on their projects in one science period and one technology period. The second week, they will work during the ICT lesson and one Math lesson, and so on. No extra meetings outside class were required, although students in the same group could meet and work on their projects informally if they wished. A STEAM lesson period is a regular class session in the school timetable that's been repurposed for interdisciplinary STEAM work rather than its usual subject content. During that period, typically the same length as the subject's normal lesson (a 50-minute slot), students focus on the project-based activities that integrate Science, Technology, Engineering, Arts, and Mathematics. Each subject involved in the STEAM program contributes one such period every other week, ensuring that over the course of a month, students rotate through science, technology, English, and math all within the framework of collaborative, design-thinking projects.

Examples included:

- **Grade 3** students are grouped into teams and showed collaboration on projects like the eco-friendly house and robot-pathing task. Teachers designed structured activities such as building eco-friendly houses and programming simple robots to follow paths. During the Prototype phase of the design-thinking cycle, students built eco-friendly house models and programmed simple robots to follow predetermined paths. The science teacher guided learners in selecting recyclable construction materials and discussing sustainability concepts, while the math teacher developed measurement and spatial-reasoning skills by having students calculate dimensions, cut components, and assemble structures. The technology teacher was actively involved at this stage, teaching basic

coding, troubleshooting sensor errors, and ensuring each robot executed its path accurately. These integrated activities aligned with curriculum objectives by fostering environmental awareness, sharpening fine-motor skills, and applying core scientific and technological principles.

- In Grade 7, teachers collaboratively planned interdisciplinary units such as the Smart City and Smart Irrigation System. The science teacher introduced concepts like the water cycle and environmental sustainability, while the technology teacher guided students through basic programming to control irrigation systems using microcontrollers. The Math teacher contributed lessons on data collection and analysis, enabling students to interpret sensor readings and adjust irrigation accordingly. Each teacher's activity was mapped to their subject's learning objectives: for example, science (understanding plant needs and water conservation), math (data analysis and pattern recognition), and technology (programming and systems integration). The integration occurred as students worked on a shared project that required them to apply each subject's skills in a coordinated manner to solve a real-world problem.
- For Grade 10, students developed projects like an assistive navigation app for visually impaired individuals and a water filtration prototype. The computer science teacher taught app development and coding principles, the physics teacher explained sensor technologies and filtration processes, and the Math teacher instructed on algorithmic logic and data validation. Teachers set joint objectives such as designing solutions to real-world problems, integrating user-centered thinking, and demonstrating technical proficiency. Assessments were also interdisciplinary, evaluating students on their ability to synthesize knowledge and reflect on ethical and practical implications. The

collaborative planning ensured that students met learning outcomes from all relevant subjects, computer science (coding and interface design), physics (understanding sensors and filtration), and math (algorithm development and analysis), while addressing a unified, meaningful challenge.

Across grade levels, the teachers reported that instructional strategies shifted from teacher-guided in lower grades to student-driven in higher grades:

- In **Grade 3**, lessons were highly structured, with teachers leading students through idea generation and model building.
- By **Grade 7**, teachers facilitated more open-ended tasks, enabling students to lead brainstorming, testing, and refinement.
- In **Grade 10**, teachers served as mentors while students independently researched, developed, and iterated complex solutions.

This progression reflects a scaffolded release of responsibility, aligning with developmental expectations and increasing students' ownership over learning. This approach aligns with the Head's emphasis on progressively transferring responsibility to students, confirming that classroom practices reflect the intended developmental trajectory outlined by the STEAM leadership.

2. Assessment Practices

Teachers emphasized that assessment approaches evolved in alignment with students' developmental stages and project complexity. In most cases, grades for STEAM projects are distributed to all relevant subjects involved in the unit. Each teacher assesses students'

performance according to subject-specific rubrics that align with both the shared project goals and their own curricular standards. For example, in an interdisciplinary project, the science teacher may evaluate scientific reasoning and understanding, the math teacher may grade data analysis and calculations, while the technology teacher assesses programming and use of digital tools. Although the project is collaborative, students typically receive separate grades for each subject, reflecting their achievement of discipline-specific objectives as well as their overall contribution to the project. This approach ensures that assessment remains fair and relevant to each teacher's learning outcomes, while also reinforcing the value of interdisciplinary collaboration.

- **In Grade 3**, assessment was largely observational and formative. Teachers assessed student engagement, group collaboration during structured activities, and basic prototyping behaviors such as material selection, assembly skills, and iterative adjustments. Presentations and teacher-led reviews were used to gauge comprehension of both the design process steps and foundational scientific concepts introduced during project work.
- In **Grade 7**, assessment focused on three main components: students' presentations, prototypes, and reflective journals. Presentations were evaluated based on the clarity of communication, logical organization, the justification of design choices, and the students' ability to answer questions from peers and teachers. Prototypes were assessed for functionality, creativity, application of scientific and mathematical concepts, and clear evidence of iterative improvement based on testing and feedback. Reflective journals were reviewed for completeness, depth of reflection, thorough documentation of the design process, and the degree to which students engaged with and responded to peer or

teacher feedback. Teachers utilized detailed rubrics for each assessment component to ensure consistency and transparency. Peer feedback forms were also integrated during presentations and prototype reviews to promote constructive critique and support collaborative learning. This assessment structure was maintained across all grade levels, with rubrics and criteria adapted to match the developmental stage and complexity of each project. An example of the model rubric used is included in the Appendix (see Appendix D) for reference.

- In **Grade 10**, assessment practices were more formalized and performance based. Rubrics were collaboratively developed and addressed both process and product elements. Criteria included originality, problem-solving, ethical reasoning, and the quality of user-centered design. Self- and peer-assessment were embedded in final evaluations by having students use detailed rubrics to assess their own contributions and those of their teammates. For example, students completed self-evaluation forms at the end of each project, reflecting on their design process, decision-making, and areas for improvement. Peer assessment involved providing constructive feedback to group members based on specific criteria, such as teamwork, creativity, and technical proficiency. These peer-assessment sessions were conducted within each project team, meaning students evaluated and gave feedback to their own teammates rather than to members of other groups. Teachers emphasized the value of this practice; as one teacher noted, “Having students assess their own work and that of their peers not only makes them more accountable, but also helps them critically reflect on what quality looks like in real-world projects.” Another teacher explained, “Peer feedback sessions are structured using clear rubrics so students know exactly what to look for, and we encourage open

discussion so everyone can learn from each other's perspectives." Through this combination of teacher, self-, and peer-assessment, students developed a deeper understanding of the assessment standards and took greater ownership of their learning.

Teachers highlighted that traditional assessment models did not capture the multidimensional nature of STEAM work. As a result, alternative and authentic assessments were developed to align more closely with learning outcomes.

3. Impact on Students' Design Thinking and Problem-Solving

Teachers consistently reported that STEAM strengthened students' capacity to move through the design cycle with growing independence. In grade 3, students relied on teacher scaffolds to generate and test initial ideas; one teacher remarked that students "learned how to brainstorm, test, and revise—even when the changes were small—which helped them start thinking like designers." By grade 7, students showed increased independence and confidence; they frequently proposed solutions, justified material or method choices, and interpreted evidence from tests to inform the next iteration. Grade 7 ICT teacher reported: "They sketched, tested, and improved the irrigation model several times, totally self-driven." In grade 10, students framed problems with clearer criteria and constraints, negotiated design trade-offs, and referenced data to defend design decisions. They worked independently to address real-world challenges and used feedback to refine prototypes. A teacher explained; "The assistive navigation app was not only technically sound but also showed empathy. Students were clearly thinking about the end user."

Teachers linked these changes to explicit modeling of empathy and problem framing, structured critique, and regular opportunities to iterate. The teachers described a shift in talk from

mere descriptions of products to explanations of **why** a change was made and **how** results supported that decision, a hallmark of evidence-based design (NGSS Lead States, 2013). Teachers across the three grade levels noted growth in students' critical thinking, collaboration, and perseverance, attributing this to sustained exposure to STEAM learning cycles.

4. Implementation Challenges

Teachers identified several recurring challenges that hindered effective implementation of STEAM instruction.

- **Time constraints**: Teachers struggled to complete full design cycles within limited instructional periods. In some cases, projects were rushed or truncated.
- **Difficulty of interdisciplinary alignment**: Teachers noted that integrating content meaningfully across subjects was complex, especially in lower grades, where students had limited conceptual flexibility.
- **Resource limitations**: Teachers reported insufficient access to materials, tools, and digital platforms. This was particularly problematic in upper grades, where technical components (e.g., sensors, coding kits) were needed.

Additionally, some teachers highlighted a lack of consistent professional development in areas such as data analysis, AI integration, and systems thinking.

5. Use of Technology

Teachers recognized technology as a key enabler of STEAM learning but also as a constraint due to limited access and uneven capacity.

- In **Grade 3**, technology use was limited to visual aids and basic programmable kits. Students relied heavily on manual construction techniques due to hardware shortages.
- In **Grade 7**, students began experimenting with coding and digital inputs, particularly in the Smart Irrigation project. However, the limited availability of programmable sensors meant groups had to rotate devices or simulate testing.
- In **Grade 10**, students applied coding and data analysis to app development and filtration projects. Teachers praised the sophistication of these tasks but noted that access to appropriate platforms and tools was inconsistent.

While teachers expressed interest in integrating advanced technologies such as artificial intelligence into classroom projects, most reported needing further training and institutional support to do so effectively. They emphasized that the success of technology integration depends on both infrastructure and professional readiness. Many expressed the need for more sustained support and training.

The table below summarizes the interview responses from both the participating teachers and the STEAM head.

Table 4.2 Summary of Participant Responses

Research Question	**Findings**
RQ 1: How is STEAM education implemented in school?	Educators explained how they taught their classes while sharing their methods of connecting different disciplines along with their

	application of design thinking practices for student education
RQ 2: What is the impact of the implemented STEAM education on students' design thinking and problem-solving skills across different grade levels?	Improved student learning outcomes, such as enhanced problem-solving capabilities, creative thinking, and collaborative abilities across different grade levels.
RQ 3: What challenges do educators face in implementing STEAM education, and how do these challenges vary by grade level?	Insufficient resources, a lack of qualified teachers, and difficulty finding an integrated approach.
RQ 4: What role does the integration of emerging technologies, such as AI and virtual reality, play in enhancing the impact of STEAM education on students' design thinking and problem solving?	The integration of emerging technologies lead to the increase in students' participation and improved skill development in STEAM learning.

4.3 Focus Group Findings with Students

Focus group discussions were conducted with students from Grades 3, 7, and 10 to explore how they experienced and understood STEAM learning, particularly in relation to design thinking and problem-solving. The findings are thematically organized based on the five stages of the design thinking model: empathize, define, ideate, prototype, and test. Cross-cutting patterns related to metacognition, collaboration, and interdisciplinary thinking were also analyzed.

Students in Grade 10 demonstrated a mature approach to user requirements by articulating the target user, context of use, and acceptance criteria before proposing solutions. In assistive-technology projects, for example, teams described specific accessibility barriers, gathered feedback from potential users, and then translated that feedback into design constraints for their prototypes.

The Head specifically highlighted empathy-driven problem framing as a central goal of the curriculum, while teachers reported using guided questioning and real-life scenarios to foster this perspective in class. Thus, there is clear alignment between student experiences and the instructional intentions set out by educators and leadership.

Across grade levels, students' ability to independently define problems increased with experience. This developmental progression mirrors the observations of both teachers and the Head, who described a deliberate strategy of scaffolding problem-definition skills over time. Teachers reported providing significant support in lower grades and gradually releasing responsibility as students advanced. The Head of STEAM also noted that curriculum design intentionally embedded opportunities for students to identify and articulate real-world problems. These parallel findings confirm that the intended developmental pathway for problem definition is being effectively realized in practice.

Student reflections highlighted the growth of independence and sophistication in brainstorming and idea generation, from teacher-led sessions in Grade 3 to student-driven, evaluative ideation in Grade 10. This closely aligns with teacher reports that instructional strategies shift from structured support in early grades to more open-ended exploration and creativity in higher grades. The Head of STEAM described this as a key feature of the program's "release of responsibility" model, aiming to nurture both creativity and critical thinking. Overall,

there is strong consistency between student experiences and the pedagogical approaches described by teachers and the Head.

Students' descriptions of prototyping, from simple, scaffolded models in lower grades to advanced, multi-iteration prototypes in Grade 10, reflect the same progression noted by teachers and the Head. They both emphasized the importance of hands-on, iterative construction as central to the STEAM philosophy. The Head of STEAM referenced the increasing complexity of prototyping tasks as students move through the program. Thus, the student perspective on prototyping is highly aligned with both instructional design and observed teaching practice.

The iterative cycles of testing and revision described by students, particularly in Grades 7 and 10, closely correspond to the formative assessment strategies outlined by teachers and leadership. Teachers reported structuring opportunities for peer and teacher feedback and encouraging students to use this input for continuous improvement, a process also emphasized by the Head of STEAM. This strong alignment indicates that the intended emphasis on feedback and iteration is well implemented and recognized by students.

Finally, students' increasing ability to reflect on their learning, take ownership of projects, and articulate interdisciplinary connections is consistent with both teacher and Head expectations. Teachers noted that reflective journals and peer assessment were used to foster metacognition and self-regulation, while the Head of STEAM emphasized the ultimate goal of cultivating independent, interdisciplinary thinkers. Therefore, the focus group findings are well aligned with the overarching objectives of the STEAM program as described by all educator groups.

The next section analyses how STEM-integrated practices influence students' design-thinking development, discussing the impact of each phase. These phases include: Students' Empathy, Students' ability to define the problem, Students' ability to ideate, Students' ability to prototype, and Students' ability to test, individually.

4.3.1 Students' Empathy

Students in Grade 10 demonstrated a clear understanding of user needs, especially in projects involving assistive technology. One student explained:

"We wanted to help blind people walk safely, so we thought of making an app that talks and gives directions."

This quote illustrates the application of empathy-driven problem framing and the use of design for social good. Grade 7 students also showed early signs of user awareness, particularly when discussing environmental impact, as in the Smart Irrigation System. Grade 3 students, in contrast, primarily followed instructions without articulating clear connections to users.

4.3.2 Students' Ability to Define the Problem

Teachers and students reported a developmental progression in problem definition. In Grade 3, many students struggled to state the purpose of their projects without prompting, and teachers often re-phrased the challenge to make the underlying problem explicit. By Grade 7, students began to specify problems with greater precision—for instance, addressing inconsistent irrigation flow by identifying measurable criteria for success. By Grade 10, students framed

complex problems that incorporated stakeholder needs and constraints, such as accessibility and sustainability. One student shared: “We identified that people with visual impairments lack navigation tools, so our app needed to give voice guidance and obstacle alerts.” This demonstrates problem scoping and definition grounded in user research.

4.3.3 Students’ Ability to Ideate and Select Ideas

All groups described some form of idea generation, but the level of independence and complexity varied:

- **Grade 3**: Brainstorming was guided and limited to basic choices. One student said: “We came up with lots of ideas for our house and then picked the best ones we could actually build.”
- **Grade 7**: Teams generated alternatives and discussed which ideas to pursue based on feasibility and peer input.
- **Grade 10**: Students described advanced ideation techniques, including evaluating ethical implications and feasibility during the brainstorming phase. This indicates higher-order thinking and evaluative judgment.

4.3.4 Students’ Ability to Prototype

All student groups engaged in prototyping, with increasing complexity and autonomy:

- **Grade 3**: Built simple models using recycled materials. Their approach was experimental and playful but heavily scaffolded by teachers.

- **Grade 7**: Created functional systems (e.g., irrigation models) with partial technical integration. One group described changing materials after failed water trials.
- **Grade 10**: Prototyped software or tech-integrated systems. They described using coding, sensors, and multiple iterations of physical models. Prototyping was intentional and linked to both function and user experience.

4.3.5 Students' ability to Test, Give Feedback, Revision, and Iteration

Testing and iteration improved markedly with age and experience:

- **Grade 3**: Students tested prototypes informally and revised them with direct teacher input. Revisions were limited and typically based on observable issues (e.g., a model falling apart).
- **Grade 7**: Peer feedback and trial-based revision became prominent. One student described how sensor feedback required coding adjustments.
- **Grade 10**: Iteration was multi-layered and informed by structured testing, journaling, and external feedback. As one student explained during the water filtration project: "After testing our filter, we saw it wasn't working well. We changed the design to make the water cleaner." This illustrates data-informed decision-making and problem-solving refinement.

4.3.6 Cross-Cutting Traits: Metacognition, Ownership, and Interdisciplinary Understanding

Participants described increased metacognition as students progressed; Grade 10 teams narrated their decision points and referenced feedback or test data to justify design changes, showing awareness of how evidence shaped the next iteration. A parallel shift in ownership was

observed as older students took responsibility for project direction and quality. Interdisciplinary awareness also deepened: while younger students recognized that tasks involved more than one subject, older students articulated how mathematics, science, technology, and artistic choices interacted within a single solution, for example, by balancing structural stability with aesthetic communication in product design (NGSS Lead States, 2013; Yakman, 2012). One student remarked: "We came up with the idea ourselves, motivated to help those with vision impairments."

- **Interdisciplinary Awareness**:
    - **Grade 3**: Recognized the use of multiple subjects but could not articulate their integration.
    - **Grade 7**: Noted links between math and science and identified how different roles in a team corresponded to academic strengths.
    - **Grade 10**: Demonstrated mature interdisciplinary thinking. One student explained how coding, ethics, and math were blended in their assistive app.

Examples of students' focus group responses related to the stages of design thinking are presented in the following table:

Table 4.3: Student reported implementation of each of design thinking stages

Design Thinking Stage	Student Reflection (Paraphrased Quote)	Grade Level	Observed/Reported Skill

Empathize	"We wanted to help blind people walk safely, so we thought of making an app that talks and gives directions."	Grade 10	Real-world problem awareness; human-centered thinking
Define	"The problem was about too much or too little water for the plants. We had to fix that with something smart."	Grade 7	Problem identification; narrowing project focus
Ideate	"We came up with lots of ideas for our house and then picked the best ones we could actually build."	Grade 3	Brainstorming; basic prototyping; translation of ideas into physical form
Prototype	"We made our first robot house and tested it to see if it stands or needs something stronger."	Grade 3	Early modeling; trial-and-error construction
Test	"After testing our filter, we saw it wasn't working well. We changed the design to make the water cleaner."	Grade 10	Evaluating performance; refining the solution

This progression is captured in the following table:

Table 4.4: Comparison of students' interdisciplinarity awareness

Aspect of Interdisciplinary Understanding	Grade 3	Grade 7	Grade 10
Basic Awareness of Subject Connections	Limited; students recognized activities involved multiple subjects but could not clearly distinguish them	Moderate; students identified some connections (e.g., using math in science tasks)	Strong; students explained how multiple subjects supported one problem or goal
Integration During Project Work	Tasks were often compartmentalized; students completed parts without understanding links	Began to integrate knowledge across disciplines during brainstorming and building	Projects reflected deliberate use of knowledge from multiple subjects in cohesive ways
Language Used to Describe Links	Vague terms like "we used science and art," without elaboration	More specific, e.g., "we measured with math and designed with art"	Clear articulation of how science, technology, engineering, and math interact
Collaboration Across Disciplines	Viewed each task as separate and teacher-led	Noticed teamwork was needed to	Embraced interdisciplinary

		bring different knowledge areas together	teamwork as essential to problem-solving
Depth of Conceptual Understanding	Focused on surface-level tasks; lacked understanding of subject integration	Developing conceptual links between disciplines	Demonstrated critical thinking and synthesis across content areas

4.4 Classroom Observation Findings

Classroom observations were conducted across three grade levels, Grades 3, 7, and 10, corresponding to the three cycles of STEAM implementation. The observational checklist (see Appendix C) aimed to capture how students engaged in the design thinking process in real time, and how instructional strategies and environmental conditions supported or constrained their problem-solving development.

Regarding implementation, the observed interdisciplinary approach, where science, math, and technology are integrated within project-based units, proved effective for developing both content knowledge and essential 21st-century skills. Teachers and the Head consistently described the benefits of this model, noting that it fostered collaboration and real-world problem-solving, and was preferable to teaching STEAM as isolated, subject-specific sessions. This finding aligns with international research, which emphasizes the value of interdisciplinary integration over a compartmentalized curriculum for maximizing student engagement and

cognition. However, some challenges were noted, including the need for adequate planning time and professional development to maintain true integration across all subjects.

Findings are organized thematically based on five stages of the design thinking process: empathize, define, ideate, prototype, and test. Observations also reveal implementation challenges, including material constraints and space limitations, which are presented in Section 4.4.2.

4.4.1 Observation of First Stage of Design Thinking Process: Empathy

Grade 3: Classroom observations revealed very limited evidence of user empathy. Students were primarily focused on completing the assigned building or prototyping tasks, such as constructing simple houses from recycled materials, rather than considering the needs of end-users. For example, when teachers asked questions like, “Who do you think might live in this house?” or “How would someone use what you built?”, most students responded with generic answers such as “people” or “my family,” without offering further details. Teachers had to frequently prompt students to think about users, but responses generally remained vague and did not show a deeper understanding of empathy.

Grade 7: Some user awareness began to emerge, especially in projects with an environmental focus. During a Smart Irrigation System activity, students referenced the importance of sustainability and conserving water for “plants” or “farmers,” showing initial steps toward understanding the context in which their solutions might be used. However, while students mentioned concepts like “saving water for the community,” they often did not directly connect their designs to specific users’ experiences or needs unless prompted by the teacher.

Grade 10: empathy became a consistent and integral part of students' project work. Students routinely started their projects by identifying and discussing user-centered problems. For instance, during an assistive navigation project, observation notes recorded students explicitly stating, "Our goal is to help people with visual impairments move around safely," and "Let's make sure our app gives clear audio directions so it's really useful for blind users." In class discussions, students often referenced "real people" and described user scenarios based on interviews or research. This demonstrated a mature and authentic approach to empathy, reflecting the intended outcomes of the STEAM curriculum at higher grade levels.

4.4.2 Observation of Second Stage of Design Thinking Process: Define (Framing the Problem)

Grade 3: Students required frequent prompting from the teacher to articulate the core problem in their projects. For example, during a simple bridge-building activity, when asked, "What is the main challenge we're solving here?", students initially responded with "building a bridge" until the teacher rephrased and guided them to say, "making sure the bridge can hold weight without breaking." Teachers frequently helped restate the design challenge to move students beyond surface-level descriptions.

Grade 7: Most students could identify and articulate the problems their projects addressed. Observation checklists showed approximately 80% of students independently identifying problems during planning sessions planning by writing, "How can we make sure plants get enough water without wasting it?" or "How can we build a system that tells us when the soil is too dry?" This demonstrated a significant development in problem-framing skills and awareness of project goals.

Grade 10: All student groups clearly defined the problems they were addressing, often tying them to social issues or technical constraints. For instance, during the assistive navigation app project, students wrote in their design journals, “Our problem is that people with visual impairments face obstacles when navigating public spaces, so we want to create an app that uses audio cues to help them move safely.” This clear and purposeful problem definition was consistently documented and used to guide their project work.

4.4.3 Observation of Third Stage of Design Thinking Process: Ideate (Brainstorming and Conceptual Development)

Grade 3: Brainstorming sessions occurred in every class, though heavily scaffolded by the teacher. For example, during a lesson on building model houses, the teacher would ask, “What are some ways we can make the roof strong?” prompting students to suggest ideas. About 85% of students contributed verbally or through drawing simple sketches. The majority of ideas were inspired by teacher examples, such as “using two pieces of cardboard instead of one.”

Grade 7: Student-led brainstorming was observed. Groups generated multiple solutions for challenges like conserving water in the irrigation project, writing ideas on poster paper and discussing which were most practical. For instance, students debated between “using sensors,” “creating a timer system,” or “collecting rainwater.” Peer discussions helped groups decide which concept to pursue, reflecting greater autonomy and group collaboration.

Grade 10: Students demonstrated high-level ideation practices, including evaluating feasibility and ethical concerns. During the navigation app project, several groups used digital mind maps and graphic organizers to visualize their ideas and consider user scenarios. For

example, one group compared “voice command” versus “vibration alert” systems for accessibility, discussing the benefits and drawbacks of each. This structured and reflective approach highlighted their maturity in conceptual development.

4.4.4 Observation of Fourth Stage of Design Thinking Process: Prototype (Building, Modeling, and Engineering)

Grade 3: All groups engaged in hands-on prototyping with cardboard, tape, and recycled materials. Focus was on structural creativity more than functionality. Prototypes were typically simple. For example, students built houses with unique shapes and colors, but often needed help ensuring their models would stand up or hold objects.

Grade 7: Students used more sophisticated tools and materials. For the Smart Irrigation System, groups integrated sensors and tubing to simulate water flow and tested different configurations to see what worked best. One group, for example, successfully built a system where a sensor would turn on a water pump when soil moisture dropped below a set level, demonstrating an understanding of both coding and engineering.

Grade 10: Prototypes were both technically advanced and subject to multiple refinements. Students used microcontrollers and coding platforms to develop interactive prototypes, such as an app interface for the navigation project. Some groups also utilized water testing equipment to evaluate the effectiveness of their filtration models, adjusting design elements in response to test data. This iterative approach reflected a high level of engineering skill and integration of scientific knowledge.

4.4.5 Observation of Fifth Stage of Design Thinking Process: Test (Feedback and Iteration)

Grade 3: Only about 40% of students engaged in formal testing of their prototypes. Feedback was mostly given verbally by the teacher, such as “Try making the bridge wider so it doesn’t fall.” Redesign was infrequent and generally happened only if a model failed during demonstration, like when a cardboard bridge collapsed under a small weight.

Grade 7: Testing and iteration process became more structured. Teachers prompted students to test their irrigation systems, record the results, and then discuss adjustments with their groups. About 60% of observed groups made documented changes based on either peer suggestions or test outcomes, such as changing the position of sensors or reprogramming timers to improve performance.

Grade 10: Testing was systematic and embedded in the workflow. Students independently designed test procedures for their prototypes, collected performance data, and regularly consulted feedback from both peers and teachers. For example, in the app development project, one group recorded how quickly and accurately their app responded to simulated obstacles and adjusted their code accordingly. Approximately 85% of students were observed participating in structured iteration cycles, with multiple documented rounds of refinement and improvement.

These observations are summarized in the following tables:

Table 4.5: Observation Checklist Summary – Grade 3

Observed Behavior / Indicator	Design Thinking Stage	Frequency Observed	Percentage of Students (Approx.)	Notes
Students identifying the problem with teacher guidance	Empathize / Define	2 out of 3 sessions	60%	Needed frequent prompting to articulate the problem
Brainstorming ideas in groups	Ideate	3 out of 3 sessions	85%	Ideas generated but often guided by teacher suggestions
Creating simple prototypes using basic materials	Prototype	3 out of 3 sessions	90%	Focused on structure and creativity, less on function
Testing and observing the outcome	Test	1 out of 3 sessions	40%	Basic testing; often verbal rather than systematic
Responding to peer or teacher feedback	Reflect / Redesign	1 out of 3 sessions	30%	Few revisions observed; mostly verbal feedback acknowledged

Displaying collaborative behavior in group work	Collaboration (across stages)	3 out of 3 sessions	95%	Strong enthusiasm and teamwork across most groups
Expressing enjoyment and engagement during tasks	Engagement	3 out of 3 sessions	100%	Students were highly enthusiastic and attentive

Table 4.6: Observation Checklist Summary – Grade 7

Observed Behavior / Indicator	**Design Thinking Stage**	**Frequency Observed**	**Percentage of Students (Approx.)**	**Notes**
Independently identifying a real-world problem	Empathize / Define	3 out of 3 sessions	80%	Most students articulated the purpose of their projects clearly
Generating multiple creative solutions	Ideate	3 out of 3 sessions	90%	Brainstorming was diverse and mostly student-led

Developing functional prototypes using interdisciplinary knowledge	Prototype	3 out of 3 sessions	85%	Used math, science, and tech principles in construction
Testing solutions and recording results	Test	2 out of 3 sessions	70%	Some documentation; informal testing cycles observed
Iterating based on feedback and results	Reflect / Redesign	2 out of 3 sessions	60%	Revisions made based on observations or peer feedback
Integration of content from multiple subjects	Interdisciplinary Integration	3 out of 3 sessions	80%	Teachers prompted explicit connections (e.g., math and science)
Collaborating effectively within assigned teams	Collaboration (all stages)	3 out of 3 sessions	95%	Shared responsibilities and peer dialogue were evident

Demonstrating sustained focus and task ownership	Engagement	3 out of 3 sessions	90%	Students were highly involved and self-motivated

Table 4.7: Observation Checklist Summary – Grade 10

Observed Behavior / Indicator	**Design Thinking Stage**	**Frequency Observed**	**Percentage of Students (Approx.)**	**Notes**
Identifying authentic, user-centered problems	Empathize / Define	3 out of 3 sessions	90%	Students proposed complex, socially relevant problems with real-world relevance
Brainstorming and evaluating solution alternatives	Ideate	3 out of 3 sessions	95%	Demonstrated mature idea generation, including feasibility assessment
Constructing advanced,	Prototype	3 out of 3 sessions	90%	Integrated programming,

functional prototypes				engineering, and scientific principles
Conducting iterative testing with documented feedback	Test	3 out of 3 sessions	85%	Structured testing with results used to refine solutions
Revising designs based on test results and peer critique	Reflect / Redesign	3 out of 3 sessions	80%	Evidence of technical and conceptual iteration across multiple sessions
Applying integrated subject knowledge purposefully	Interdisciplinary Integration	3 out of 3 sessions	90%	Seamless use of science, math, tech, and humanities in solution building
Demonstrating leadership and team-based problem solving	Collaboration (all stages)	3 out of 3 sessions	95%	Roles were self-assigned; discussions reflected high-level collaboration
Sustained motivation,	Engagement	3 out of 3 sessions	95%	High ownership of learning; students

independence, and reflection				self-evaluated their work

4.4.6 Implementation Challenges: Resource and Student-Related Constraints

Across all grade levels, observations revealed logistical and material limitations that constrained students' ability to fully engage in the design process. The following constraints were commonly recorded:

Table 4.8: Observed Resource Constraints, Impacts, and Workarounds in STEAM Implementation Across Grade Levels

Grade	Constraint	Impact	Observed Workaround
Grade 3	Lack of digital kits	Projects limited to manual prototyping	Teachers provided recyclable materials
Grade 7	Limited number of sensors and coding devices	Delayed testing; reduced access for each group	Device sharing, simulation through role-play
Grade 10	Inadequate software/hardware for app development and filtration testing	Hindered prototype iteration	Free online platforms, reused components, simulated testing

Space was another recurring challenge in Grades 7 and 10, where group work required movement and collaboration. Teachers attempted to address this by rotating group work times and assigning stations for different tasks.

Table 4.9: Observed Resource Constraints and Teacher/Student Workarounds.

Grade Level	Observed Resource Constraint	Impact on Activity	Workaround by Teacher/Students
Grade 3	Lack of ready-made building kits and tools	Students struggled to build stable structures	Teachers provided recyclable materials (e.g., cardboard, bottle caps) to stimulate creativity
Grade 3	Limited access to digital devices	Inability to explore digital simulations or coding	Focus shifted to manual construction and visual presentations
Grade 7	Insufficient programmable sensors for all groups	Not every team could test the smart irrigation system in real-time	Groups rotated use of available devices; some used role-playing to simulate function
Grade 7	Shortage of electronic components (e.g., wires, connectors)	Delayed prototype completion	Students shared components across groups; teachers encouraged simplified models
Grade 10	Inadequate access to advanced software or coding platforms	Students faced challenges in app development	Teachers used free, browser-based platforms as alternatives; students coded basic prototypes

Grade 10	Limited lab tools for testing water filtration	Restricted experimentation and measurement accuracy	Students reused parts from older projects; testing was approximated using observation

4.4.7 Use of Technology in STEAM Classrooms

Classroom observations across Grades 3, 7, and 10 provided insight into the role and limitations of technology in STEAM implementation. While technological tools were intended to enhance students' design and problem-solving capacities, the actual use of these tools varied significantly across grade levels, primarily due to access limitations and technical constraints.

In **Grade 3**, the use of technology was minimal and largely teacher directed. Digital tools, when used, were primarily limited to visual presentations or demonstrations of basic concepts. Students engaged in some activities using simple programmable robots; however, these tools were not available consistently across all observed sessions. Most student engagement focuses on manual prototyping using recycled materials such as cardboard and bottle caps. Teachers often substitute for unavailable technologies by emphasizing hands-on construction and observational learning. As a result, students in this grade experienced technology more as a supporting resource rather than a central component of their design process.

In **Grade 7**, technology integration became more visible, particularly in projects like the Smart Irrigation System. Students engaged with microcontrollers and basic coding platforms to develop systems responsive to environmental input. However, observations revealed significant inconsistencies in tool availability. Most groups had to rotate the use of sensors or

microcontroller boards, which delayed prototyping and limited real-time testing opportunities. When access to devices was constrained, students improvised by simulating sensor behavior through verbal explanations, diagramming, or role-playing scenarios. Despite these challenges, the students demonstrated a growing familiarity with digital components and were generally motivated to incorporate coding and automation into their solutions.

In **Grade 10**, the intended level of technological integration was the highest, as students worked on complex tasks such as assistive navigation applications and water filtration systems. Students aimed to use advanced digital platforms, including mobile app builders, coding environments, and sensor-integrated testing kits. However, observations highlighted a mismatch between project ambition and technological availability. Several groups faced limitations due to a lack of access to required software, outdated hardware, and unreliable internet connection. In response, both teachers and students adapted by using free browser-based platforms, reusing components from previous projects, or developing conceptual models to simulate technological functionality. For example, in the app development project, students used slide-based prototypes to represent app interfaces when actual programming tools were not functioning.

Across all three grade levels, teachers played a central role in mediating students' use of technology, whether through troubleshooting devices, guiding digital tool use, or suggesting workarounds when equipment was lacking. The limitations observed in the classroom reflect broader infrastructural and systemic constraints that hinder the seamless integration of technology into STEAM practice. Nevertheless, students showed resilience and adaptability, often finding creative ways to meet learning goals despite the constraints. These findings underscore the importance of both resource provision and professional development in ensuring that technology fulfills its intended role in supporting 21st-century learning. This conclusion is

strongly aligned with teachers' perspectives, as many reported that effective technology integration depends not only on resource availability but also on their own readiness and ongoing professional development. Teachers frequently highlighted the need for consistent training and technical support to ensure that digital tools are used purposefully and equitably in the classroom. Their emphasis on adaptability and creative problem-solving in the face of constraints also echoed the resilience and flexibility demonstrated by students, reinforcing the importance of a supportive environment for 21st-century learning.

4.5 Discussion

The following section of this chapter utilizes triangulated data from Head of STEAM interviews together with subject teacher interviews, focus groups with students, and classroom observation records to explain each theme presented in the themes map. The findings receive support from suitable academic literature to present a complete interpretation of the research results.

4.5.1 STEAM Curriculum: Content, Strategies, and Assessment

4.5.1.1 Vertically Aligned Curriculum for STEAM Education

The findings indicate that a vertically aligned curriculum supported a gradual deepening of creativity, design thinking, and problem-solving as students progressed through grade levels. This approach is consistent with Yakman's STEAM framework, which sequences interdisciplinary competencies so that earlier experiences prepare learners for increasingly complex design work (Yakman, 2012), and with national reform guidance that emphasizes

coherent progressions of practices and concepts (NGSS Lead States, 2013). International models such as Finland's phenomenon-based learning and South Korea's integrated STEAM similarly organize learning around developmental milestones that connect inquiry with authentic problems (Halinen, 2018; Kim et al., 2015).

4.5.1.2 Interdisciplinary Curriculum Design for an e\Enhanced STEAM Education Curriculum

A second theme concerned interdisciplinary curriculum design. Teachers deliberately blended science and mathematics ideas with making, critique, and communication so that knowledge moved across subject boundaries during project work. Planning documentation and interviews showed that units were framed by real-world problems, with content outcomes mapped to the design cycle to maintain disciplinary rigor while enabling creative exploration (Yakman, 2012; NGSS Lead States, 2013).

4.5.1.3 Assessment

A third theme addressed assessment aligned with design. Participants described formative assessment embedded in critique, testing, and iteration; students justified design decisions with data, reflected on feedback, and documented changes over time. Such process-oriented assessment complemented product evaluation and helped make thinking visible, which is consistent with performance expectations highlighted in reform documents and contemporary STEAM practice (NGSS Lead States, 2013; Herro et al., 2019).

4.5.1.4 Instructional Team Collaboration for Enhanced STEAM Education Implementation

Project topics were designed to be agreed upon by teachers using joint-planning sessions. These planning sessions ensured that outcomes were simultaneously achieved in each of the subjects and constituted a unified, cross-disciplinary learning experience. This method highlights the importance of "design coherence" in STEAM units mentioned by Li (2024) and aligns with the trend of setting inclusive, cross-subject goals during lesson planning (Bertrand & Namukasa, 2020).

These findings demonstrate that STEAM was implemented through a well-structured curriculum design where instructional strategies, assessments, and content complexity were aligned with students' developmental stages. The instructional strategies mirrored a scaffolded release-of-responsibility model, progressing from teacher-led demonstrations and guided prototyping in the lower grades to student-driven, inquiry-based design projects in the upper grades. This progression was evident in the shift in assessment methods, which moved from observational and formative feedback in the lower grades to more authentic, process-driven evaluations in the upper grades. These later assessments incorporated self-reflection, peer feedback, and documentation of iterative design processes, practices that are strongly aligned with the STEAM assessment frameworks advocated in the literature (Wiggins, 1998; Guaman-Quintanilla et al., 2022; Honey et al., 2014; Liu et al., 2020).

Regarding implementation, the observed interdisciplinary approach, where science, math, and technology are integrated within project-based units, proved effective for developing both content knowledge and essential 21st-century skills. Teachers and the Head consistently described the benefits of this model, noting that it fostered collaboration and real-world problem-solving, and was preferable to teaching STEAM as isolated, subject-specific sessions. This

finding aligns with international research, which emphasizes the value of interdisciplinary integration over a compartmentalized curriculum for maximizing student engagement and cognitive growth (Halinen, 2018; Capraro & Jones, 2013). However, some challenges were noted, including the need for adequate planning time and professional development to maintain true integration across all subjects.

Continuous curriculum improvement was an established practice among the STEAM teaching team. The Head and teachers reported holding regular reflection meetings to review and modify curriculum designs in response to student needs, project outcomes, and logistical constraints. This approach aligns with findings by Black and Wiliam (2009) and Fullan (2016), who emphasize that ongoing teacher reflection and adaptive planning are essential for effective curriculum development and student-centered learning. As one teacher explained, “We meet every month to review what worked and what didn’t and then adjust the next unit so it fits our students better.” Such cycles of reflection and adaptation help ensure that instructional strategies and assessment practices remain responsive to students’ evolving needs and the specific local context, as recommended in the broader curriculum improvement literature (Darling-Hammond et al., 2020; Timperley, 2011).

4.5.1.5 Pedagogical Practices

Pedagogical approaches such as project-based learning, design thinking, and collaboration are not only consistent with best practices identified in international STEAM models (Aguilera & Revilla, 2021; Halinen, 2018; Capraro & Jones, 2013) but were also confirmed through classroom observations, teacher interviews, and student focus groups in this

study. For instance, students described gaining increasing independence and confidence in decision-making, as well as an improved ability to integrate knowledge from different disciplines and to revise their work based on peer and teacher feedback. One student reflected, "At first, our teacher would guide every step, but now we plan our own projects and decide how to solve problems," illustrating the intended developmental trajectory.

4.5.2 Impact on Students' Design Thinking and Problem-Solving Skills

Synthesizing interviews, focus groups, and observations shows a developmental progression across the design cycle. Younger learners relied on teacher scaffolds to empathize with users and articulate problem statements; by middle school, students proposed solutions, recorded test results, and used evidence to justify revisions; by high school, teams negotiated constraints, defended trade-offs, and framed problems with explicit criteria for success. These shifts reflect movement from guided participation toward increasingly self-directed design practices expected in integrated STEM/STEAM curricula (NGSS Lead States, 2013; Yakman, 2012).

Cross-cutting outcomes also emerged. Metacognition increased as students narrated decision points and referenced feedback or data to explain changes; collaboration improved through structured critique and shared documentation; and disciplinary integration became more explicit as learners connected mathematical models and scientific concepts to material choices and aesthetic communication in their solutions (Becker & Park, 2011; NGSS Lead States, 2013).

All STEAM projects studied exhibit consistent interdisciplinary collaboration patterns, especially within Grade 7 and Grade 10 levels. Teachers collaborated on subject planning, which

formed unified learning targets while integrating curriculum content delivery structures following Capraro and Jones's (2013) project-based cross-disciplinary model. The Smart City and Smart Irrigation activities combined arithmetic with science and coding while utilizing visual arts features to support the views of Bequette and Bequette (2012) about arts-based STEM learning. Recent literature also recommends integrating design thinking approaches directly into the curriculum, as this has been shown to significantly enhance student engagement, creativity, and problem-solving skills (Razzouk & Shute, 2012; Noweski et al., 2012). Integrating design thinking not only fosters deeper interdisciplinary connections but also empowers students to address real-world challenges more effectively. Additionally, research has emphasized the importance of incorporating Sustainable Development Goals (SDGs) into STEAM education, highlighting that aligning classroom projects with SDGs can further increase the social relevance and impact of student learning (Mansour & El-Deghaidy, 2021).

Observations within the classroom setting also demonstrated students using interdisciplinary content by making mathematical model-to-engineering design connections and scientific reasoning for sensor calibration purposes. Students showed a clearer understanding of how different subjects connect to overall learning goals through their self-reflections, which support the findings of Bertrand and Namukasa (2020) and Bushey (2024), who highlight the importance of combining subjects in STEAM education.

Synthesizing findings from focus groups, teacher interviews, and classroom observations confirms that STEAM education effectively nurtured students' design thinking and problem-solving abilities progressively across grade levels. This is consistent with a growing body of international research highlighting the positive impact of STEAM approaches on creativity, critical thinking, and innovation (Henriksen, 2014; Quigley et al., 2017). For example, studies

have shown that integrating the arts and design thinking into STEM curricula leads to higher student engagement and more sophisticated problem-solving strategies (Land, 2013; Razzouk & Shute, 2012). In the elementary level (Grade 3), students developed initial empathy by identifying simple user needs and practiced basic brainstorming and prototyping under teacher guidance, aligning with literature that stresses the importance of guided support in early design thinking education (Noweski et al., 2012).

As students advanced to Grade 7, they became increasingly capable of independently framing problems, generating diverse ideas, and iteratively refining prototypes based on peer feedback and initial testing. This developmental trajectory mirrors findings from STEAM initiatives in Finland's phenomenon-based learning (Halinen, 2018) and from project-based models in South Korea (Kim et al., 2015), both of which report that repeated cycles of inquiry and design result in deeper metacognitive skills and greater student autonomy.

By Grade 10, students demonstrated mature design thinking skills by integrating interdisciplinary knowledge, considering ethical implications, addressing real-world user challenges, and systematically documenting testing outcomes to inform redesign. These findings are supported by Aguilera and Ortiz-Revilla (2021), who noted that sustained participation in STEAM cycles leads to enhanced creative confidence and collaborative skills. Overall, both local and international literature confirm that a well-implemented STEAM curriculum can significantly improve not only design thinking but also broader 21st-century competencies, provided that the curriculum is authentic, interdisciplinary, and supports repeated opportunities for iterative learning.

As Segarra et al. (2018) emphasize, such iterative design thinking environments encourage students to analyze mistakes, revise solutions, and develop innovative responses, an

effect clearly visible across the student feedback and observed project work in this study. Besides bringing technical and creative skills, the students also developed their skills for teamwork, collaboration, and confidence. According to this study and research done at the OECD (2024) and worldwide, learning in STEAM education supports the development of reasoning as well as social skills needed to resolve difficult challenges in real-world situations (Henriksen, 2014; Anisimova et al., 2020; Flores-Nicolás, 2023).

These results show that a STEAM program planned to enhance STEM knowledge gives students the ability to use creative and critical thinking, collaborate in teamwork, and manage problems by themselves (Foster, 2019; Guaman-Quintanilla et al., 2022).

4.5.3 Implementation Challenges

Three persistent challenges framed implementation. First, time and alignment across subjects constrained interdisciplinary planning and limited opportunities for extended iteration. Second, variable teacher readiness slowed the uptake of integrated strategies, especially where staff were new to design-based pedagogies. Third, resource constraints, from materials to specialized space, restrict the scope of projects. These patterns mirror reports from Middle Eastern contexts showing that structural conditions often mediate the fidelity of STEAM enactment (Amiruddin et al., 2022; BouJaoude, 2020; Herro et al., 2019).

Teachers reported that curriculum delivery faced obstacles because they had inadequate facilities and not enough training on new technology, while dealing with short teaching periods. Herro et al.'s (2019) research supports the findings because they point to professional development gaps along with material shortages as major roadblocks for STEAM education.

Moreover, the teachers stated that the discrepancies in resources across different grades, combined with the limited time available to cover traditional lesson plans and student homework, significantly affected the implementation of STEAM (Herro et al., 2019). These challenges reaffirm the need for systemic support and a flexible curriculum to accomplish effective use of STEAM concepts for education.

Findings also revealed some challenges, mainly the scarcity of specific materials, which is documented by Meletiou-Mavrotheris (2024) and Conde-González et al. (2020). Teachers had to implement adaptive methods like role-level simulations and reused material modeling because project resources were limited, so students could maintain essential design elements as researched by both Flores-Nicolás (2023) and Hawari and Noor (2020). The modifications in instruction practice successfully maintained student interest levels, thus supporting research findings that show flexible teaching practices lead to sustained educational programs in limited circumstances (Bertrand and Namukasa 2020).

4.5.4 The Role of Technology in STEAM

Technology functioned as both a cognitive tool and a design medium. Teachers and students described how coding platforms, robotics kits, and virtual/augmented environments supported rapid prototyping, visualizing alternatives, and collecting evidence to justify design choices. In projects that incorporated AI-assisted modeling or virtual reality, students simulated modifications before building physical prototypes, which concentrated class time on analysis, critique, and iteration. Participants also noted that equitable integration depended on

infrastructure and teacher learning, reinforcing the need for staged adoption and ongoing professional development (NGSS Lead States, 2013; Herro et al., 2019).

Data from classroom observations and focus group discussions showed that technology access varied greatly among grade cycles. Upper-grade students used advanced platforms more often, while lower-grade students used digital prototyping based on the foundations of digital prototyping with teacher assistance. For example, in Grade 3, technology was mainly used to help show visuals and control robots, while in Grade 7, students independently changed their coding for smart irrigation systems based on ongoing feedback from sensors (Amiruddin et al., 2022; Flores-Nicolás, 2023).

Still, a lot of teachers reported that outdated hardware, occasional slow internet connection, and feelings of ignorance in new fields such as AI had a significant impact on their ability to offer contemporary technology-based learning. The problems became most apparent when students tried to experiment and analyze data regarding water filtration or coding projects because of a lack of access to simulation technologies (Leavy et al., 2023; Maas & Hughes, 2020). Herro and Quigley (2016) point out that successful teaching of STEAM with the use of technologies requires more than just reliable infrastructure; there should be constant support for teacher competency as well.

It was clear, however, that professional development programs were essential to close this divide. Some teachers participated in digital upskilling workshops, online training aimed at training teachers how to use digital tools in their project work, especially for training that included instruction on AI applications, and felt more adept at using technology tools in their project work (Algerafi et al., 2023; Spyropoulou, 2023). Even though there are attempts to

enhance digital resources, the absence of coordinated strategies at grade levels revealed uneven implementation and undermined the coherence of STEAM approaches.

Technology under the STEAM model did not just act as a resource; it created an ecosystem in which students could experiment, tinker, and refine iterations of their designs. However, it relied heavily on making sure everyone had fair access, providing specific training for teachers, and having support systems in place, similar to what global research shows about technology's ability to make noticeable improvements in the students' outcomes when used thoughtfully (Dyer, 2019; Aguilera & Revilla, 2021).

It was clear from the data that technology promoted different investigation methods, teamwork, and genuine problem-solving, consistent with recent research on STEAM integration.

CHAPTER 5

CONCLUSION

5.1 Research Questions

The subsequent part examines research data points that pertain to the study's four fundamental research questions. The research gathers information from interviews alongside live observations of classrooms and focuses group discussions, which enables connections between practical learning and academically established knowledge in STEAM education.

5.1.1 RQ1: How is STEAM Education Implemented in Schools?

This study revealed that the STEAM application within the institution takes a systematic and developmentally coherent design based on planning, combined content, and developing assessment measures. Interdisciplinary and coherent project-based learning is guaranteed through the regular co-planning of the units by the teachers of different disciplines. At the lower grade level, STEAM is presented in small, carefully scaffolded tasks that develop background skills such as observation, questioning, and curiosity, and the activities are introduced by the teacher in the form of scaffolding questions and formative assessment through the observation of student engagement and collaborative work.

The focus of instruction changes into supporting student independence as students advance, and learners will perform more complex, genuine problem-solving using many

disciplines. Instructional strategies focus on inquiry-based, iterative design and creative solution building. Evaluation is also modified, adding elements of creativity, critical thinking, teamwork, and peer and self-reflection as rubrics. This shift towards student-centered, project-oriented lessons, enabled by constant collaborative planning, makes STEAM education coherent, interconnected, and responsive to students' developmental needs.

5.1.2 RQ2: What Is the Impact of STEAM Education on Students' Design Thinking and Problem-solving Skills Across Different Grade Levels?

According to this study, the structure of the STEAM program guides students in developing age-appropriate design thinking and problem-solving skills. At lower levels (elementary grades), most of the prototyping and other practical activities were rather routine and aimed at the build-up of initial knowledge and development of brainstorming, group cooperation, and creativity in a comfortable and scaffolded environment. When students transitioned to middle school, they began to be much more independent in terms of problem selection, solution suggestions, and iteration of their designs, depending on both feedback and results testing—a manifestation of the gradual student-to-teacher-driven inquiry. At the secondary level, complex, realistic problems were offered, and students needed to learn how to combine knowledge, design solutions to those problems, and critically examine the process and result. Such development, which is found throughout classroom challenges and subsequently reinforced through interviews and focus groups, leads to a student capable of analyzing his own work, responding to criticism, and creating new and original solutions to problems in the real world. Finally, STEAM learning makes students innovators and strong, creative problem-solvers armed with the critical capacity that they should have in the future.

5.1.3 RQ3: What Challenges Do Educators Face in Implementing STEAM Education, and How Do These Challenges Vary by Grade Level?

The school's ability to fully utilize STEAM is hindered by a number of persistent obstacles. The lack of access to resources and funding is a major obstacle. Teachers and students may be forced to share equipment or substitute materials, and these constraints may limit the scope and depth of project work. In addition, there is a significant necessity for the professional development of the teachers, and because of the interdisciplinary nature of STEAM, specialized training and lifelong learning are necessary. These constraints imply that teachers often need to restructure their projects to accommodate limited resources, which may undermine the quality of education.

5.1.4 RQ4: What Role Does the Integration of Emerging Technologies, Such as AI And Virtual Reality, Play in Enhancing the Impact of STEAM Education on Students' Design Thinking and Problem-solving?

Technology is at the heart of the STEAM curriculum, particularly in the upper grades. Students will be divided into projects involving coding, robotics, and digital design tools. These technological elements play a crucial role in assisting students in addressing contemporary and real-life problems through innovative approaches. However, the full integration of technology into the institution is limited by a lack of access to equipment, inadequate infrastructure, and insufficient training for teachers in the new technology. However, even though teachers and students show outstanding skill and creativity in using the tools they have, the lack of support and investment means there is still a gap between the potential of technology-based STEAM

teaching methods and their actual use. However, the urge to adopt technology is still making the teachers and students come up with creative solutions, and a new environment is being created where computer literacy and technical expertise are slowly catching up.

5.2 Limitations and Future Research

Although the current research provides useful information regarding the introduction and the effects of STEAM education in the preselected establishment, several limitations ought to be considered. To begin with, the study was carried out in the context of one educational environment, limiting the extrapolation of its results to the rest of the environments with other resources, cultures, or educational policies. The institution's leadership investment in STEAM, curriculum design, and teacher formation may affect implementation and results.

Another limitation is related to the availability of resources and infrastructures. Through observational and interview data, it was demonstrated that technological and material limitations defined the range as well as the depth of STEAM projects. Consequently, there are learning opportunities, especially those that require advanced technology or multidisciplinary cooperation, that have not lived up to their fullest potential. The research was also supported by qualitative data collection strategies, including observing activities in classes, interviews with teachers, and focus group discussions with students. Although these methods provided rich descriptive data, they are also susceptible to various biases, including participant self-reporting bias and the researcher's interpretative bias.

The second limitation was the scope of the study, which was short-term. Although the research documented the development process of STEAM learning across different grade levels,

it did not track the performance of a specific cohort of students over time to provide evidence of long-term effects or learning pathways. Moreover, the study approach did not look systematically at the background of the student, such as gender, socioeconomic status, or prior achievement, that might affect access and improve on the yields of STEAM education.

At best, this study is limited in several ways which the subsequent studies should attempt to address. Comparisons in different schools, geographical areas, or educational systems would go along the way of understanding the role of contextual factors in the implementation process and the outcomes of STEAM. More solid evidence may be provided through longitudinal studies that trace students over several years to better understand the results of the development of STEAM approaches. Additionally, the research should be conducted in terms of a mixed-method that combines quantitative data, including academic performance, skills, and student engagement scores, with qualitative insights to truly capture the multidimensional aspect of STEAM training.

Future studies should also examine how factors such as teacher training programs, community partnerships, and technological investments impact the successful integration of STEAM. The focus should be placed on such topics as equity and inclusion because, in prospective studies, it is necessary to search for how the access and results of STEAM can vary according to student demographics and what specific interventions can fill the gaps.

5.3 Recommendations

To effectively address the identified challenges and opportunities in this research, recommendations should be directed toward individuals with the capacity to implement change within STEAM education systems. These stakeholders include national and regional

policymakers, curriculum developers, school leaders, classroom teachers, and educational researchers.

Policy makers are first and foremost being asked to prioritize maintaining funding specifically designed to build out the STEAM infrastructure. The governments and the ministries of the educational sector need to provide all learning institutions sufficient access to resources like technological devices, science kits, robotics tools, and quality digital platforms, especially in equitably distributed regional and socioeconomic backgrounds. Policy makers are additionally advised to formalize the systems to do annual needs assessments in a way that the allocation of resources would be informed by current and school-specific data as much as possible, and the inequalities between schools would be vigorously combatted.

Besides the provision of resources, policymakers and those in charge of the national curriculum ought to ensure the development of an extensive STEAM curriculum structure. The frameworks should clearly outline interdisciplinary learning outcomes, and they should also identify developmentally the right competencies in each grade. It is imperative that curriculum developers develop standards that introduce progressive design thinking, project-based learning, as well as authentic assessment practices. Keeping in touch with the best international practices and adapting them, e.g., as is the case with Finnish and South Korean STEAM programs, curriculum developers will be able to make globally informed and, at the same time, locally relevant frameworks.

The school leaders and the principals at an institutional level are crucial in the translation of policy into everyday practice. School leaders are being encouraged to fund long-term, high-quality professional development programs for their teachers with a concentration on interdisciplinary instructional approaches, integration of technology, and performance-based

evaluations. The task of school administration is to establish the environment in which the collaborative planning between the educational departments will become a normal practice, enabling teachers in science, mathematics, technology, art, and other education disciplines to develop, introduce, and iterate STEAM projects collaboratively. School leaders must also build internal mechanisms of monitoring and assessing the usage and effect of STEAM instruction and interventions with various sources of data, including student portfolios, teacher reflections, and standardized evaluations, to decide on ongoing improvement.

In the realization of this learning environment, classroom teachers and curriculum implementers must focus their efforts on embracing student-centered and inquiry-based instruction, which will enable learners to define practical issues, conduct iterative designs, and look back at their solutions. Educators are advised to promote experimental, collaborative, and reflective learning classroom culture. The teachers need to vary their pedagogy to address the needs of every student, including learners with disabilities, and underrepresented populations who must not be left behind in STEAM opportunities. Educators should also aim at expanding learning beyond a classroom with the help of forming partnerships with parents, community organizations, and local industries, thereby offering students real-life situations where they can apply STEAM knowledge and skills.

Lastly, the education researchers are called to undertake additional research that would assess the benefit of long-term enactment of STEAM education programs as well as re-examine the best modalities of interdisciplinary instruction, evaluation, and professional development. The providing of insights regarding conditions and strategies that best promote student engagement, creativity, and problem-solving capacity within STEAM frameworks by the researchers may serve as a crucial role in supporting evidence-based policy and practice. also,e is

also a need to build collaboration between the researchers, practitioners, and policymakers so that the research results can be transformed into action advice to continue innovation in education.

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APPENDIX A: Interview With Teachers and The Head of STEAM

Interview Introduction

"Good [morning/afternoon] and thank you for agreeing to participate in this interview. My name is Aya, and I am conducting research on the impact of STEAM education on students' design thinking and problem-solving skills, focusing specifically on private schools. Your insights as a [teacher/Head of STEAM] deeply involved in the STEAM program here are invaluable to my study.

Before we begin, I want to assure you that all the information you provide will be treated with the utmost confidentiality and will only be used for academic purposes. I also want to mention that this conversation may be recorded to ensure that I accurately capture your insights, but it will only be accessible to me. If you feel uncomfortable or wish to not answer a question at any time, please feel free to let me know. Do you have any questions before we start, or are you comfortable if we proceed?"

Background Information:

1. Can you tell me about your role and experience in STEAM education at this school?
2. How long has STEAM education been implemented in this school?
3. What inspired the integration of STEAM education into the school's curriculum?

Curriculum Design and Implementation:

4. How is the STEAM curriculum designed to foster design thinking and problem-solving skills among students?

5. Can you describe a project or lesson that exemplifies the essence of STEAM education in practice?

6. How do teachers collaborate across different STEAM disciplines (Science, Technology, Engineering, Arts, Mathematics) in planning and teaching?

Impact on Students:

7. In what ways have you observed an improvement in students' design thinking and problem-solving skills since the integration of STEAM education?

8. Can you share any specific examples or success stories of students applying their STEAM learning to real-world problems?

9. How does STEAM education affect students' attitudes towards learning and their future career aspirations?

Challenges and Solutions:

10. What challenges have you faced in implementing STEAM education, and how have they been addressed?

11. Are there any resources or support you find lacking in effectively delivering STEAM education?

12. How do you assess and evaluate students' progress in design thinking and problem-solving skills within the STEAM framework?

Professional Development:

13. How does the school support teachers in their professional development for STEAM education?

14. Have teachers participated in any specific training or workshops that have been particularly beneficial?

Future Directions:

15. Looking ahead, how do you see the role of STEAM education evolving in this school?

16. What improvements or changes would you like to see in the school's STEAM education program to better serve the students' needs?

Interview Closure:

"Thank you so much for sharing your valuable insights and experiences with me today. Your contributions have provided a deeper understanding of the impact of STEAM education on enhancing design thinking and problem-solving skills among students. It's clear that your dedication to fostering an integrated learning environment is making a significant difference.

Before we conclude, are there any final thoughts you would like to add or any aspects of STEAM education we didn't cover that you think are important for my research?

Once again, I appreciate your time and willingness to participate in this study. I will be compiling the insights from all interviews and analyzing the data to understand better the broader implications of STEAM education in your school. I would be more than happy to share my findings with you and the school once the research is completed. Thank you again for your

invaluable contribution to this study. Have a great day, and I look forward to potentially discussing the outcomes of this research with you in the future."

APPENDIX B: Specialized Questions and Responses Table For Teachers in Steam Program

Teacher 1: Science Teacher (5 years in STEAM)

Question	Response
How do you integrate hands-on experiments into your science classes?	" I always aim to have at least one major hands-on project each term. For example, students use recycled materials to build models in our eco-friendly house project."
What are the main challenges you face when implementing STEAM projects?	"One major challenge is the lack of resources. We often have to be very creative with what we have, and sometimes it feels like we're stretching things a bit too far."
How do you measure the impact of STEAM projects on your students' learning?	"I look at their engagement and understanding. If they can explain their project and the science behind it clearly, I know they've learned something meaningful."
Can you share a memorable success story from your STEAM classes?	" One of my students designed an easy-to-build purification system for water with everyday items. It was such a proud moment for both of us to see him demonstrate this at the science fair."
What additional support do you think would enhance your effectiveness in teaching STEAM?	"More funding for materials and more professional development opportunities would make a huge difference. It's tough to keep up with the latest advancements on a limited budget."

Teacher 2: Technology Teacher (4 years in STEAM)

Question	Response
How do you incorporate emerging technologies like AI and VR into your curriculum?	" We're just scratching the surface, starting to get involved in AI and VR. For example, I had students use a simple AI program to try their hand at developing a chatbot. It's amazing, their exuberance."
What are the biggest obstacles you face with tech integration in the classroom?	"Honestly, the biggest hurdle is access to up-to-date technology. We have to share a limited number of devices, and they get outdated quickly."
How do you ensure that all students, regardless of their tech proficiency, can participate fully in STEAM projects?	" I make sure to pair students with different skill levels together and offer extra help sessions after school. It's important that everyone feels capable and included."
Could you share an instance where a student project exceeded your expectations?	"One group created a smart irrigation system that adjusts water usage based on soil moisture. Their level of detail and understanding blew me away."
What kind of training or resources would help you improve your STEAM teaching methods?	" It would be wonderful to have access to more advanced tech tools, with a continued training regime on new technologies. How to keep up with the rapid advancement of technology is a challenge."

Teacher 3: Math Teacher (5 years in STEAM)

Question	Response
How do you integrate STEAM principles into your Mathematics curriculum?	" I integrate STEAM principles into my math curriculum. This means preparing lessons which relate math with real-world problems in which students might apply algebra or geometry to design models, analyze data, or simulate real-life scenarios with digital tools such as GeoGebra."
What are the unique challenges you face in blending STEAM with Mathematics?	"One of my unique challenges in integrating STEAM with Mathematics is the alignment of interdisciplinary projects with strict curriculum requirements and time constraints. Often, a math curriculum is densely packed and assessment-oriented with so little time set aside for exploratory activities through which students can learn STEAM skills firsthand."
How do you assess the effectiveness of STEAM projects in enhancing mathematical skills?	" I note applications of mathematical concepts into real-world problems such as linear equations for data modeling or geometry in design tasks, and students have to explain their reasoning for choosing these approaches. This gives me an opportunity to assess students' conceptual understanding versus application. Sometimes I use rubrics with mathematical criteria; these include accuracy in calculations, use of mathematical models, and problem-solving strategies**.**
Can you describe a student project that highlighted the success of your STEAM approach?	" One student developed an interactive math game app for her younger brother to teach him basic math through story formats, including audio effects and animations. The app was a massive hit as it showed that technology could be harnessed to make mathematical learning engaging, visual, and accessible-even for beginning learners."

What additional support would help you better integrate STEAM in your Math classes?	"There should be more access to technical tools like graphing software, dynamic geometry apps, and data visualization platforms together with professional development targeted toward enabling mathematics instructors to integrate these tools into their teaching approaches."

Head of STEAM Program (10 years in education)

Question	Response
How do you oversee and coordinate the integration of STEAM across different subjects?	"I hold regular interdisciplinary meetings and planning sessions. It's crucial to ensure all teachers are on the same page and collaborating effectively."
What are the main challenges in implementing a school-wide STEAM program?	"The biggest challenges are funding and getting buy-in from all teachers. Not everyone sees the value of an interdisciplinary approach right away."
How do you measure the success of the STEAM program as a whole?	"We look at student engagement, the quality of projects, and feedback from students and teachers. "When they're excited and proud of what they've done, those are great indicators."
Can you share a standout success story from your time leading the STEAM program?	"Our 'Smart City' project was a huge success. In the latter, students collaborated to design a model of a sustainable city that incorporated all STEAM disciplines. The collaboration and innovation that went into the task were simply outstanding."
What kind of support would enhance the STEAM program's impact?	"Increased funding, more professional development opportunities for teachers, and better access to advanced technologies would significantly boost our program's effectiveness."

APPENDIX C: Focus Group Protocol for Students

Question	**Rationale / Alignment with Research Objectives**
What does STEAM mean to you?	Warm-up question to assess baseline understanding of STEAM concepts (RQ1).
What comes to mind when you hear "design thinking" or "problem-solving" in class?	Encourages students to articulate their perceptions of key constructs under study (RQ1, RQ2).
Can you share an example of a STEAM project you worked on this year?	Captures concrete experiences and links them to design thinking skills (RQ2).
What did you enjoy most about working on this project? What was challenging?	Identifies affective responses, motivation, and perceived barriers (RQ2, RQ3).
How did you and your classmates work together during the activity?	Explores collaboration, teamwork, and communication as part of problem-solving (RQ2).
How did your group come up with ideas (ideation)?	Examines the *Ideate* stage of the design thinking process (RQ2).
Did you make a prototype or test your ideas? What was that like?	Assesses practical engagement with *Prototype* and *Test* stages (RQ2).
How did feedback from your teacher or classmates help you improve your project?	Explores iterative refinement, peer/teacher support, and reflection (RQ2, RQ3).
How did the project help you learn to solve problems in new ways?	Connects STEAM activities to development of problem-solving skills (RQ2).
Do you think STEAM changed the way you think about learning or working with others? How?	Captures perceptions of broader cognitive and social shifts (RQ2).
If you could improve STEAM classes, what changes would you suggest?	Invites constructive feedback on program implementation (RQ3).
What advice would you give other students starting STEAM projects?	Closing question, encouraging reflection and transferability (RQ2, RQ3).

Format:

- Group size: 5–7 students per group
- Number of sessions: 2 per grade level (Grades 3, 7, 10)
- Duration: ~60 minutes
- Recording: Audio-recorded with consent, transcribed verbatim

Ethical Considerations:

- Voluntary participation, with right to withdraw at any time.
- Confidentiality assured; pseudonyms used in reporting.
- No academic penalties or rewards linked to participation.

Reference

Krueger, R. A., & Casey, M. A. (2015). *Focus groups: A practical guide for applied research* (5th ed.). Thousand Oaks, CA: Sage.

APPENDIX D: Observation Checklist

Observed Behavior / Indicator	**Design Thinking Stage**	**Frequency Observed**	**Percentage of Students (Approx.)**	**Notes**
Students identifying the problem with teacher guidance	Empathize / Define			
Brainstorming ideas in groups	Ideate			
Creating simple prototypes using basic materials	Prototype			
Testing and observing the outcome	Test			
Responding to peer or teacher feedback	Reflect / Redesign			
Displaying collaborative behavior in group work	Collaboration (across stages)			

Expressing enjoyment and engagement during tasks	Engagement			

APPENDIX E: Model Rubric

Category	Mark
Accuracy and Relevance to the subject	3
Construction, Creativity and Neatness	2
Functionality and Demonstration	3
Overall Presentation	2
Total	10

Model's Categories

Kindly find the rubric attached to this document.

	Below Standard	Approaching Standard	At Standard	Above Standard
Accuracy and Relevance to Science Subjects	Model does not relate to scientific concepts nor make connections to real world applications.	Scientific concepts and connections to real world applications are unclear in the model.	Model represents scientific concepts with minor errors and shares connections for real world applications.	Model clearly represents scientific concepts and is scientifically correct, having connections to real world applications.
Construction, Creativity and Neatness	The model is poorly constructed. It lacks neatness and creativity.	The model is constructed with little neatness and creativity.	The model is carefully constructed but does not showcase student's creativity.	The model is carefully constructed with materials that showcase student's creativity and are appropriate.
Functionality and Demonstration	The model does not function at all (if applicable) or fails to demonstrate the concept clearly.	The model does not fully function or does not effectively demonstrate the concept.	The model mostly functions but may require additional explanation or slight adjustments.	The model functions as intended (if applicable) and clearly demonstrates the concept effectively.
Overall Presentation	The model is incomplete, lacks labeling or explanation, and shows minimal effort.	The model lacks clarity in labeling or explanation and appears rushed.	The model includes labels and explanations but could be improved in presentation or effort.	The model is presented professionally, with clear labels, explanations, and evident effort in design.