Exploring STEM and Coding Development for Thai Youth Through a System Theory Perspective

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Abstract

This study explores the development of STEM and coding competencies in Thai youth, employing a systems theory framework to examine various elements like input, process, output, and environment. Utilizing a mixed-method approach, the research gathered data from a diverse group including 1,400 respondents comprising K-12 teachers, educational supervisors, school administrators, higher education instructors, parents, pre-service teachers, and a general audience. The quantitative data, derived from a comprehensive 30-item questionnaire, revealed that 57.7% of the respondents were K-12 teachers, indicating a strong interest in STEM and coding education at the primary and secondary levels. Additionally, qualitative insights were gleaned from an expert focus group, consisting of eight multi-disciplinary STEM and coding experts. This group provided valuable perspectives on the current state of STEM and coding in Thailand, emphasizing its growing significance and identifying gaps in the development of innovative and entrepreneurial skills among youth.

The findings identify crucial areas for improvement in the Thai STEM and coding education ecosystem. It highlights the need for more inclusive and collaborative strategies that involve a wide range of stakeholders, including parents and non-educational sector individuals, to enhance the effectiveness of STEM education. The research suggests integrating coding into curriculums, developing comprehensive teacher training programs, and fostering partnerships between schools, universities, and industries. These steps aim to bridge the gap between theoretical learning and practical coding skills vital for the workforce. Moreover, the inclusion of Artificial Intelligence (AI) in education is emphasized as crucial for preparing students for future professional domains where AI plays a significant role. The study's findings and recommendations offer a roadmap for transforming STEM education and coding in Thailand, ensuring it aligns with the evolving demands of the digital age and contributes to the country's economic growth and workforce development.

Keywords: Ecosystem, Competency, Coding, System Theory, STEM Education

Introduction

STEM education and coding have gained significant attention in the field of education due to their increasing importance in preparing students for the rapidly evolving technological landscape. According to The National Academies of Sciences, Engineering, and Medicine (2019), STEM education plays a crucial role in preparing students for future careers and addressing the demands of a rapidly changing world. Coding, on the other hand, is an integral part of computer science education and is increasingly recognized as a valuable skill for problem-solving, creativity, computational and logical thinking. As stated by Wing (2006), computational thinking is a fundamental skill set for problem-solving and logical reasoning, providing learners with the ability to approach complex challenges systematically. Furthermore, a study by Voogt et al. (2013) highlighted the significance of coding education in fostering creativity, critical thinking, and collaboration skills among students.

According to Weintrop et al. (2016), STEM coding is closely intertwined, particularly as science and mathematics increasingly become computational endeavors. It involves using programming languages to instruct a computer to perform tasks, which can range from simple commands to complex algorithms. Coding facilitates the practice of computational thinking by providing a tangible way to design, test, and refine solutions to problems or to understand systems through simulation and modeling. In essence, coding is the vehicle through which the theoretical aspects of computational thinking are translated into practical and interactive technology-based experiences. This hands-on practice is vital for students to grasp the intricacies of STEM subjects and to develop the necessary skills for future technological and scientific pursuits. In recent years, there is growing recognition of the need to encourage STEM Education, coding skills, and computational thinking among young learners. This is particularly important in Thailand, where the government has emphasized the importance of digital literacy and the development of a workforce equipped with STEM competencies. This is in response to reports by the OECD and UNESCO (2016); and Vandeweyer et al. (2020) which discuss the challenges and opportunities in the Thai education system, particularly in relation to human capital development and the impact of technology on skill demands.

However, it is crucial to understand the underlying factors and mechanism that contribute to the development of Thai STEM and coding competency for more effective cultivating the skill. STEM and coding have become increasingly important in Thai youths' education. The integration of coding skills within STEM education equips students to think critically, solve problems, and engage in creative and innovative endeavors.

STEM education thrives on interdisciplinarity, reflecting the complex realities of the world. Understanding the concept of STEM learning ecosystems is critical as these are interconnected and collaborative networks designed to bolster education in science, technology, engineering, and mathematics. Morrison and Fisher (2018) highlight the immense value of collaborative ecosystems that integrate learning experiences across schools, museums, libraries, employers, and communities, ensuring STEM education is not siloed within the classroom but enriched through diverse, real-world contexts. Similarly, Timko et al. (2023) emphasize the significance of developing these ecosystems in rural areas, where unique challenges necessitate adaptable and sustainable educational models to nurture STEM capacities. Allen et al. (2020) further the discourse by advocating for a unified evidence base to guide the implementation and evaluation of STEM ecosystems, thereby fostering robust learning and developmental outcomes. Collectively, these works underscore the necessity for STEM ecosystems that are empirically grounded, inclusive, and responsive to the evolving educational landscape.

To comprehend the landscape of STEM and coding ecosystems, it is essential to adopt a thinking framework such as systems theory, which elucidates the complexity and interaction of components within these systems. Systems Theory has long been established as a scientific approach to understanding the interdependent structures and functions in ecosystems. It provides a lens through which the intricate relationships and processes of ecological components can be examined. According to Von Bertalanffy (1968) system theory emphasizes the interconnectedness of various elements within a system, including inputs, processes, outputs, outcomes, feedback, impact, and the environment (OECD, 2002). This research will provide an insightful recommendations for multifaceted nature of the factors influencing Thai youths STEM and coding competency through the lens of a system theory. Due to the connection to various factors, this phenomenon is influenced by external and environmental factors. Consequently, the results of this study should be conveyed in a manner that portrays them as representative ideas, presented in a comprehensible and manageable format. Kast and Rosenzweig (1972) as well as Hammond (2010) proposed that describing phenomena systematically is essential for comprehending, evaluating, and enhancing systems. In line with the proposed strategy for STEM educational policy implementation, as outlined by Khogkhao et al. (2023), the bioecological system theory offers a valuable framework for understanding and improving STEM education. This theory can guide policymakers and educators in creating effective STEM education policies and practices (Khogkhao et al., 2023). The system theory in Thailand's STEM and coding education system shows certain limitations, particularly regarding inclusivity. Key stakeholders such as parents and individuals outside the education sector are often not involved in important decision-making and development processes. On the contrary, the UNESCO document by Holmes et al. (2022) highlights the critical need to include a diverse group of stakeholders in discussions about artificial intelligence in education. This group encompasses children's representatives, teachers, parents, policymakers, industry professionals, and members of civil society. This approach suggests that inclusive policies are essential for educational ecosystems, extending to areas such as STEM and coding education through system theory lens. The absence of such inclusivity might impair the overall growth and efficacy of STEM education strategies in Thailand. Thus, it is vital to ensure that these ecosystems incorporate a wide range of stakeholders, taking into account various perspectives and needs in the creation and implementation of policies to improve the quality and accessibility of STEM education.

The study aims to investigate the system; input, process, output, outcome, feedback, impact, and environment in which Thai youths' STEM and coding competency has developed using system theory. This research's findings have the potential to contribute significantly to the transformation of STEM education and coding in Thailand. By identifying key stakeholders and understanding their perspectives, the study can offer targeted recommendations that align with the actual needs and challenges faced within the Thai education ecosystem. Specifically, insights from teachers, educators, and parents will be instrumental in developing collaborative strategies that can be integrated into existing educational frameworks.

The recommendations may include developing more robust training programs for teachers, integrating coding into the curriculum in a way that connects with students' real-world experiences, and creating partnerships between schools, universities, and industry. By doing so, the research aims to close the gap between the theoretical aspects of STEM education and practical, hands-on coding skills that are essential for the workforce. Moreover, the study's focus on stakeholder collaboration ensures that any proposed changes are sustainable and have buy-in from those who will implement them. This approach not only aims to enhance current practices but also to lay the groundwork for a more innovative and future-focused STEM education system in Thailand that can adapt to the evolving demands of the digital age.

Research Objectives

1. Investigate the current situations, challenges and opportunities concerning the potential integration of a systems theory framework to enhance science, mathematics, and coding education, facilitating the development of STEM and coding competencies.

2. Offer inclusive recommendations for aligning this integration with the specific requirements and hurdles encountered within the Thai education ecosystem.

Research Methodology

A mixed-methods approach was employed for this investigation. This approach combines both quantitative and qualitative data collection techniques, aiming to capture a comprehensive understanding of the research topic.

Development of Research Tools

In the study, two research instruments were utilized to gather data: a questionnaire and an interview protocol. First research tool, a questionnaire was developed based on system theory, focusing on input, process, output, outcome-the questionnaire comprised of two parts. The first part gathered general information about participants' status and experience. The second part includes 30 questions aimed at exploring the system of STEM and coding competency development in Thailand. The second segment of the questionnaire encompasses thirty questions designed to examine the STEM and coding competency development system within Thailand, which is organized into three distinct sections: "opinions on the general situation", "problems and obstacles", and "possibility of development". Each section is further broken down into five critical components: input, process, output, outcomes, and impact. This comprehensive structure is evaluated for quality using the Index of Item-Objective Congruence (IOC), ensuring each item's relevance and discrimination, alongside a reliability coefficient (α) to measure consistency. Three experts in technology, evaluation, and education reviewed and validated this tool to ensure its effectiveness and reliability. The results of the quality analysis indicate that, in terms of opinions on the general situation, there are 11 items with discriminative power (by item-total correlation method: r_{xy}) ranging from 0.590 to 0.772. In the case of problems and obstacles, there are 13 items with discriminative power (r_{xy}) ranging from 0.603 to 0.859. Lastly, in the area of possibility of development, the discriminative power (r_{xy}) ranges from 0.759 to 0.848. The questionnaire's reliability coefficient (α) is reported as 0.977.

The second research tool is an interview protocol developed within the framework of systems theory, consisting of nine questions. These questions are organized into three key sections: "opinions on the general situation", "problems and obstacles", and "possibility of development". each section divides into five critical components: input, process, output, outcomes, and impact. The quality of this research tool has been enhanced and validated through a rigorous review by three experts in the field.

Research Participants

The research participants were the individuals who had enrolled in the webinar event as part of the research project titled "Development of a Learning Platform to Incubate STEM and Coding Competencies via MOOCs and Innovation Camps for Fostering Start-Ups and Young Entrepreneurs for Middle School Students (Grade 7-9)". At the conclusion of the seminar, researchers extended invitations to 2,285 attendees to take part in the research by completing a questionnaire. Out of this group, 1,400 individuals responded to the questionnaire. All participants were informed and provided their electronic signatures to signify their willingness to participate in the research through Google Forms.

Data Collection

The research team conducted an online webinar on 21st July 2023 titled "Creating Future Innovators through STEM and coding". This engaging session, available for review here https://youtu.be/ZMl38YAJ1Ho, introduced the fundamental concepts of STEM and coding, complemented by illustrative examples.

Following the webinar, a questionnaire was distributed among the attendees, which included teachers, university instructors, educators, stakeholders, and parents, to garner pertinent data. A total of 2,285 participants attended the webinar, and 1,400 of them responded to the questionnaire. The respondents were asked to provide their insights on landscape of Thailand and ecosystem of STEM and coding development.

This research activity was carried out under the approval of the Chiang Mai University Ethics Committees (COA No.031/66, CMUREC No. 66/144), ensuring adherence to ethical guidelines. Participants were informed about their rights before taking part in the survey. They provided consent by clicking on "Understand and Accept", serving as an e-signature for their informed consent.

Data Analysis

The collected data was downloaded as a spreadsheet and analyzed using statistical software, specifically Microsoft Excel and SPSS. For the interviews with experts, these were conducted and recorded through Zoom meetings. Researchers took notes during these sessions, and subsequently, the recorded videos were transcribed into Microsoft Word for detailed content analysis. The qualitative data were analyzed using content analysis techniques within the ATLAS.ti software.

Expert Review

After analysis, in this part, the methodology was conducted with focus group interview discussion technique. There are eight experts from various research field: computational thinking, coding, STEM education, computer science, and multidisciplinary education. The role of experts was giving a feedback towards the data from questionnaire and suggest comment on the ecosystem of STEM and coding in Thailand.

The aim of this discussion was to scrutinize the results and formulate a framework that encapsulate STEM and coding ecosystem in Thailand. Guided by nine open-ended questions, the discussion delved into the present circumstances, challenges, and potential opportunities. Each topic segment was examined in terms of input, process, and output, aligning with the study's theoretical underpinnings. A focus group interview was conducted via a Zoom Meeting, and the video recording of the session was subsequently downloaded for in-depth analysis. Utilizing the video analysis features in ATLAS.ti, the data were coded, and themes were extracted to form the basis for our findings and discussion. Content analysis was employed to describe and interpret the conversation. To illustrate the intricate and dynamic nature of STEM and coding competencies among Thai youth, the findings were depicted through both diagrams and narrative explanations.

These findings were then used to provide recommendations for enhancing the STEM and coding ecosystem in Thailand. This methodological approach offered a comprehensive view of the ecosystem, contributed to our understanding of its multifaceted nature, and provided insightful recommendations for policymakers, educators, and researchers.

The Schematic diagram in Figure 1 showing the methodological process of conducting a research project.

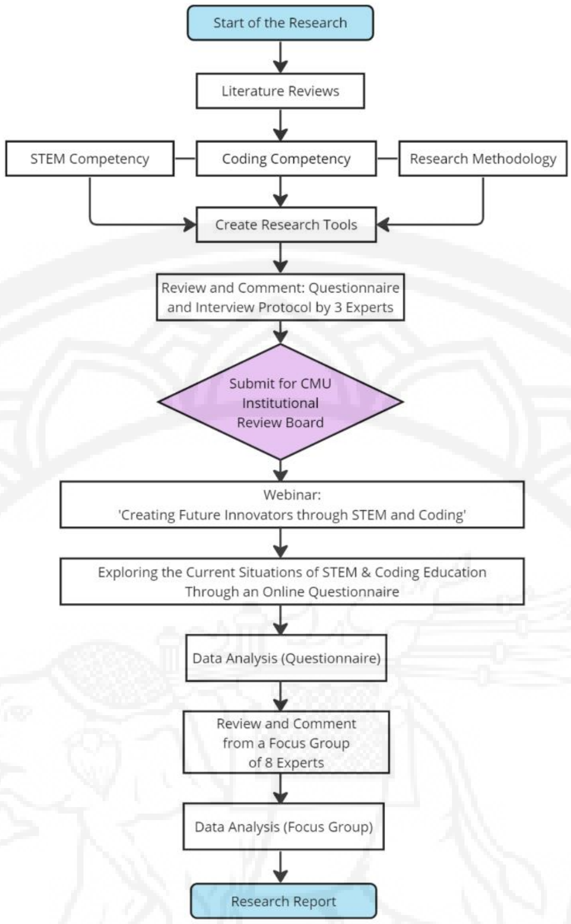

Figure 1 Diagram of the Methodological Process of Conducting a Research Project.

Research Results

The research results are presented in two distinct parts. The first part comprises the analysis of the system theory perspective data obtained from the questionnaire, which includes the assessment of 30 items of rating score, as well as insights derived from open-ended questions located at the end of the questionnaire. In the second part, the research includes an expert review, which is based on input gathered from an Expert Focus Group. Here is a breakdown of the research's two main components.

The System Theory Perspective

A total of 2,285 participants attended the webinar, with 1,400 responding to the questionnaire. These respondents shared their insights on Thailand's landscape and ecosystem for STEM coding development. The number of participants is shown on the Table 1.

Table 1 Distribution of Respondents by Status

Status / Role	Number of Participants	Percentage (%)
K-12 Teachers	808	57.7
Teachers (Other Levels)	150	10.7
Educational Supervisors, School Administrators, Educators	142	10.1
Higher Education Instructors	125	8.9
Parents and General Audience	117	8.4
Pre-service Teacher	58	4.1
Total	**1,400**	**100**

In the survey that gathered responses from 1,400 individuals, K-12 teachers were the most significantly represented demographic. They comprised 57.7% of the total respondents, which equates to 808 participants.

This significant proportion highlights a pronounced interest from primary to secondary educators in landscape of Thailand and ecosystem of STEM and coding development. In stark contrast, pre-service teachers with a mere 4.1% (58 participants). When considering other educational professionals, Teachers from other educational levels, educational supervisors, school administrators, educators combined formed a substantial 20% of the total respondents. Additionally, the combined representation of parents and general audience underscored the expansive reach of interest in STEM and coding, extending beyond the confines of the traditional classroom settings.

The predominant participation of K-12 teachers can be attributed to several factors. The global development towards integrating STEM and coding into K-12 curricula possibly propels teachers to equip themselves with contemporary knowledge in this domain. Additionally, as the nexus between technological advancements and education tightens, K-12 educators are likely to recognize the imperativeness of introducing coding skills at foundational levels. These webinars, viewed as avenues for professional enhancement, offer them insights into modern pedagogical approaches, potential teaching aids, and the latest educational trends.

The broad spectrum of interest in STEM and coding competency, as reflected in the diverse participant categories, underscores coding's burgeoning importance in today's educational schema. From teachers at varied educational levels understand the foundational value of coding to parents and general audiences who foresee it as career relevance for their children. The consensus leans towards coding as an essential skill set for the future. The participation students of other academic professional and students further emphasizes that curriculum and pedagogy of teacher has influenced on STEM and coding competency cultivating in the current education era.

The concept of an educational ecosystem encompasses the multifaceted and interconnected relationships among various stakeholders within the educational sphere, including but not limited to teachers, students, parents, administrators, governmental entities, and community organizations. By embracing this comprehensive perspective, policy-makers can engage with a nuanced understanding of the intricate interplay between these elements, thus facilitating the development and implementation of strategies that are uniquely tailored to the specific needs, opportunities, and challenges inherent within a given educational community. In each system elements framework proposed by Bybee in 2013, the data analysis explores the components of the system, gathers opinions on the current challenges and obstacles, and assesses the potential for development within the context of STEM policy (Bybee, 2013).

Table 2 Category System Analysis by Number of Items and Mean Opinions

System Component	Situation, Problem, and Opportunity Analysis	Number of Items	Mean	SD
Input	Opinions on the General Situation	1, 2, 3, 9, 11	5.458	0.643
	Problems and Obstacles	14, 16, 21	5.138	0.940
	Possibility of Development	28	5.262	0.970
Process	Opinions on the General Situation	4,5	5.387	0.719
	Problems and Obstacles	12, 17	5.164	0.928
	Possibility of Development	30	5.098	0.981
Output	Opinions on the General Situation	6,7	5.621	0.686
	Problems and Obstacles	22	5.194	0.907
	Possibility of Development	24	5.207	1.000
Outcomes	Opinions on the General Situation	8, 10	5.335	0.946
	Problems and Obstacles	15, 18, 19, 20, 21, 23	5.170	1.046
	Possibility of Development	25, 26, 27, 29	5.244	0.954

The table presents a summary of the data provided for each category, including the item count, opinions, means, and standard deviations. This information can be found in Figure 2.

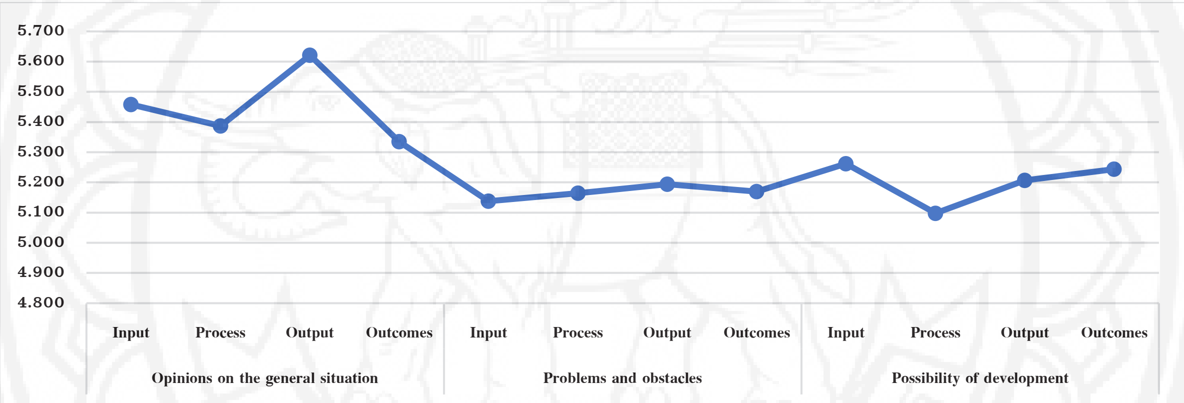

Figure 2 The Analysis of System by Mean Opinions.

The results, based on the data from the table above, indicate that when applying system theory to the categories of input, process, output, and outcomes in conjunction with opinions on the general situation, problems and obstacles, and possibility of development, the highest mean values are observed in the following order: opinions on the general situation, possibility of development, and problems and obstacles. Based on the results, it can be concluded that the current state of STEM and coding in Thailand is not as it should be. All respondents, including K-12 teachers, teachers from other levels, educational supervisors, school administrators, educators, higher education instructors, parents, general audiences, and pre-service teachers, agree on the importance of STEM and coding. However, there are significant concerns about the problems and obstacles, which are perceived as valuable and relevant.

Despite the high significance attributed to both input and output, respondents find it challenging to reach a consensus regarding the process and the outcomes remain unsatisfactory. Along with the system's output in the context of STEM and coding in Thailand.

Across the various system components, a consistent trend emerges when analyzing mean values. Specifically, "opinions on the general situation" consistently garners the highest mean score, signifying a predominantly positive assessment in this regard. Conversely, "problems and obstacles" consistently exhibit the lowest mean values, pointing out areas of concern or challenges within each component.

In the input component, the highest mean is attributed to "opinions on the general situation", highlighting the prevailing positive sentiment. Conversely, "problems and obstacles" register the lowest mean, indicating areas of potential difficulty. Within the process component, a similar pattern emerges. "opinions on the general situation" once again attain the highest mean score, indicative of a favorable outlook in this domain. In contrast, "possibility of development" receives the lowest mean, suggesting room for improvement. The output component follows suit, with "opinions on the general situation" maintaining the highest mean score, signifying a favorable evaluation. Meanwhile, "possibility of development" records the lowest mean, underscoring potential areas for growth and enhancement. Lastly, in the outcomes component, "possibility of development" takes the lead with the highest mean, portraying optimism in this aspect. Conversely, "problems and obstacles" still exhibit the lowest mean, underscoring persisting challenges. The analysis of mean values consistently highlights the prevalence of positive assessments for "opinions on the general situation" across all system components. Simultaneously, "problems and obstacles" consistently show the lowest mean values, indicating areas that may require particular attention or mitigation efforts. Notably, the "outcomes" component diverges from this pattern, as "possibility of development" garners the highest mean, suggesting promising prospects in this realm.

The process and outcome, particularly in terms of developing skills related to technology and innovation, are considered crucial in the digital era. It conveys that there are significant concerns regarding both the process and outcome in the context of developing technology and innovation skills, which are deemed crucial in the digital era. Additionally, there is uncertainty about Thai society's preparedness for adopting new technologies and innovations, and there are doubts about the effectiveness of human resources in developing these skills. While organizations involved in education and technology innovation have potential for youth development, there are concerns about the sufficiency of the budget to support STEM and coding education.

In addition to the key findings mentioned earlier, participants also shared comments in response to the open-ended question regarding the significance of driving learning in Coding and STEM Education. These comments are presented in the last section of the questionnaire, as illustrated in Table 3

Table 3 Additional Commentary Content Analysis Results

Additional Comment	Frequency
1. The guidelines of STEM and coding learning should be implemented all over the country, included online and on-site training which are in both formal and informal education system.	43
2. Students should be fully developed their ability for future readiness.	34
3. The government should support the budget, personnel, personnel development to have sufficient capacity and equipment to drive the development of teaching in STEM education.	34
4. Coding and STEM learning should be drove for developing student's competencies to let them apply knowledge into daily life.	33
5. It should provide more opportunity for professional training program for teachers, as well as constantly arrange exchanging program for in-depth mutual understand, especially schools in remote area.	32

The data reveals five key themes for advancing STEM education in Thailand. First, there is an urgent agenda for national expansion, emphasizing the need for both online and on-site training programs that are accessible across all regions. Second, the development of advanced student abilities is crucial, particularly in science education where skills like analytical thinking and research are essential. Third, government support and investment are viewed as vital, including budget allocation, personnel development, and equipment provision for STEM programs. Fourth, the integration of STEM and coding emerges as a transformative educational approach that enhances problem-solving skills and fosters creativity and innovation. Lastly, teacher professional development is seen as a critical component, with a focus on ongoing training programs, especially in remote areas. These themes collectively advocate for a multifaceted approach to strengthening STEM education in the country.

In conclusion, participants attended the webinar responding to the questionnaire, as shown in Table 1. Among these respondents, K-12 Teachers were the most significantly represented group, constituting 57.7% of the total respondents. This substantial representation highlights a pronounced interest from primary to secondary educators in Thailand's landscape and ecosystem for STEM and coding development, with pre-service teachers making up a smaller percentage. Additionally, teachers from various educational levels, educational supervisors, school administrators, educators, and parents, along with the general audience, showcased the expansive reach of interest in STEM and coding education. This widespread enthusiasm can be attributed to the growing recognition of the importance of equipping learners with STEM and coding competencies.

The analysis applied a systems theory approach to examine different components within stem policy discussions. The data suggests that in Thailand, while there is a recognition of the importance of STEM and coding across all educational levels and stakeholders, the actual state of these fields is not meeting expectations. There is a clear acknowledgment of the significance of both the input into and the output from STEM and coding education. However, there is a lack of agreement on the process and dissatisfaction with the outcomes. Analysis shows a consistently high appreciation for "opinions on the general situation", indicating an overall positive sentiment towards STEM and coding. Conversely, "problems and obstacles" are seen as significant yet challenging, consistently receiving the lowest mean scores across all system components, pointing to areas in need of attention.

Particularly, there are considerable reservations about the process of development and uncertainties regarding the outcomes, which are crucial for fostering technology and innovation skills. This includes concerns about the preparedness of Thai society in adopting new technologies, the effectiveness of human resource development in these areas, and whether there is adequate funding to support STEM and coding education.

Participants also provided valuable comments on the importance of driving learning in STEM and coding Education, emphasizing the need for national expansion, advanced student abilities, government support, integration of STEM and coding, and ongoing teacher professional development. These themes collectively advocate for a multifaceted approach to strengthening STEM education in Thailand, encompassing both formal and informal education systems and involving various stakeholders in the process

The STEM and Coding Experts' Review

Eight experts with multi-disciplinary backgrounds in STEM and coding participated in the focus group. Each expert brought more than a decade of experience in STEM, coding, and computer science at both national and international levels. All participants also had significant experience in STEM and coding education, training, and outreach. The focus group discussion was facilitated by one researcher acting as the moderator, who posed questions to the experts, while two additional researchers served as note-takers. The video recording of the discussion was downloaded and analyzed using ATLAS.ti to code segments and extract themes. The results reveal that:

Based on the focus group interview data, experts unanimously emphasize the significance of STEM and coding in the Thai educational landscape. The policy supporting STEM education, including coding, has been in place for a considerable period. STEM education began to take precedence approximately a decade ago, starting in 2012, and coding became an integral part of it in 2017 with the introduction of the new national science curriculum, which incorporated Computing Science into the Science subject. One expert aptly pointed out, "STEM and coding initiatives have been orchestrated and executed by numerous organizations, including newly emerging funding agencies". This indicates that the current state of STEM and coding in Thailand has garnered recognition, substantial value, and is continuing to expand nationwide.

However, experts have pointed out that the development of STEM and coding remains relatively disconnected from nurturing ideas and promoting startups and entrepreneurship among youth". They highlighted that coding is gaining more recognition compared to STEM due to its strong demand in the private sector, making it the top job category in Thailand and globally during the era of technology and digital transformation. Despite this, the STEM projects for youth have not yet translated into substantial innovation. Expert attributed this to the persisting traditional norms associated with science and STEM project competitions. These norms-have obstructed the progression towards creating new products or innovations. Moreover, one expert noted that even when startups generate novel STEM-related ideas, they can get entangled in regulatory constraints or legal acts that prevent the implementation of these innovative concepts or products.

Indeed, the complex landscape of legal approvals and adherence to industrial standards acts as a significant barrier to the implementation of innovative STEM ideas and projects in Thailand. Navigating these intricate regulations can be challenging for startups and individuals seeking to bring novel concepts to fruition. Simplifying and streamlining these processes could greatly enhance the potential for innovation and growth in the STEM field.

Table 4 Overview of the Experts' Perspectives on the Current Situations, Challenges, and Opportunities in STEM and Coding in Thailand

Categories	Input	Process	Output and Outcome
Current Situations	- Implementation of STEM and coding policies since 2012 and 2017, respectively.	- Operation by various organizations and the emergence of new funding agencies.	- Recognition and value attributed to in Thailand at a nationwide level.
Problems and Challenges	- Disconnect between STEM and coding and idea nurturing for youth. - Coding gaining more recognition than STEM.	- Persistence of traditional norms in STEM project competitions. - Regulatory constraints on new STEM ideas.	- Limited innovation and product development in STEM projects for youth. - Difficulty in implementing new STEM ideas. - Imbalanced recognition of coding over STEM.
Opportunities	- Robust demand for coding skills in the private sector. - Tech and digital transformation. - Emphasis on pre-service teacher education for STEM, coding, startup, and entrepreneurial mindset. - Promoting in-service teachers as innovation advocates. - Adoption of Design Thinking for creative incubation. - Holistic policy direction and planning.	- Integration of STEM, coding, startup, and entrepreneurial education into pre-service teacher programs. - Training and development of in-service teachers as innovation facilitators. - Implementation of Design Thinking methodologies in education. - Development of comprehensive policies supporting innovation.	- Enhanced potential for innovation and growth in the STEM field. - Cultivation of a more entrepreneurial and innovative workforce. - Fostering creative and problem-solving skills in students. - Transformation of the educational and policy landscape towards innovation.

In the Opportunities category, experts identify the potential for Thailand to foster startups and entrepreneurs through STEM and coding policies. They emphasize the importance of enhancing pre-service teacher education with a focus on STEM, coding, startup, and entrepreneurial mindsets. Additionally, experts suggest the development of in-service teachers who can promote these innovative ideas. The application of Design Thinking Processes is also recommended to incubate innovative thinking among young students. Importantly, experts concur that this initiative extends beyond education and necessitates a comprehensive policy direction and plan to drive meaningful change. The summary of the STEM and Coding Experts' Review is presented in Table 4.

In conclusion of this section, a panel of eight STEM and coding experts assessed Thailand's educational advancements since the official adoption of STEM in 2012 and coding in 2017. They acknowledged improvements but also noted a divide between academic learning and real-world innovation among young entrepreneurs, with coding becoming more prevalent due to job market needs. Current STEM education often does not lead to new creations, hindered by outdated thinking and legal roadblocks. The experts advise enhancing teacher training in STEM and coding, plus the adoption of design thinking, to spur innovation. They urge policies that better support the transition from education to innovation and entrepreneurship in the STEM domain within Thailand.

Discussion

The development of STEM and coding competency in Thailand represents a complex and multifaceted challenge, necessitating thorough study and research. Adopting a systems thinking approach offers a comprehensive methodology for examining this intricate ecosystem. Systems theory, as conceptualized by Wolkenhauer & Muir (2011), defines a system as an assembly of interconnected components, where organization emerges from the interdependencies among these components. This perspective is crucial in understanding the nuanced interactions within STEM and coding education. Furthermore, systems thinking, as outlined by Cook & Tõnurist (2016); and the OECD (2017), emphasizes understanding the nature and dynamics of complex systems. This approach is instrumental in exploring the interdisciplinary nature of STEM and coding, revealing how various educational, technological, and societal elements interact and influence each other within the Thai context.

STEM and Coding Landscape Ecosystem

Stakeholders actively involved in the STEM and Coding ecosystem in Thailand shed light on their perspectives regarding the overall state of affairs, indicating a favorable assessment, with a high level of green across all system components, particularly in terms of outputs and outcomes. This bears similarity to the "Lesson Learned" report on Coding Teaching and Innovation, which aims to cultivate the desired characteristics of Thai people 4.0 as per the national education standards outlined by the Office of the Education Council, Ministry of Education (2020). In this report, teachers acknowledge the paramount importance of coding education and concur on its role in shaping students' attributes aligned with Thai people 4.0. Nevertheless, they perceive a gap in the ecosystem, particularly in terms of available learning materials. Teachers emphasize the need for educational institutions to have access to media support and Internet of Things (IoT) resources to facilitate project-based learning and its integration into various subjects. According to the Thai education standard of 2561 B.E. (Office of the Education Council, Ministry of Education, 2019), three key characteristics are outlined: the learner as an individual, the innovative co-creator, and the active citizen. Among these, STEM and coding education have proven effective in nurturing the qualities of an innovative co-creator. In this role, their primary goal is to cultivate individuals, equipping them with vital skills encompassing 21st-century proficiencies, digital intelligence, creative thinking abilities, cross-cultural competencies, cross-disciplinary integration skills, and entrepreneurial traits. This collaborative endeavor is dedicated to generating technological and social innovations, thus paving the way for personal advancement and the betterment of society. Nguyen et al. (2023) conducted a mixed-method study in Thailand high schools to explore the components of a digital learning ecosystem. They identified four core components: learning community, learning atmosphere, active learning, and teaching and learning support. The study also highlighted seven factors that need improvement to enhance classroom transformation into a learning community.

According to the research finding, the challenges persist, including insufficient budget allocation, suboptimal conditions for fostering STEM and coding education within the Thai education system, and impediments to monitoring and enhancing students' technological and innovation skill development. In our perspective, there is a need for a stronger emphasis on developing entrepreneurial traits as desired outcomes. We believe that fostering innovators and entrepreneurs requires a transformation in the Thai ecosystem. For instance, "The Innovator's DNA" by Dyer et al. (2019) identifies five key capabilities exhibited by successful innovators: 1) Associating: Making connections between questions, problems, or ideas from unrelated fields, 2) Questioning: Challenging conventional wisdom by posing thought-provoking queries, 3) Observing: Scrutinizing the behaviors of customers, suppliers, and competitors to discover new approaches, 4) Experimenting: Creating interactive experiences and encouraging unconventional responses to uncover valuable insights, and 5) Networking: Engaging with individuals who possess different ideas and perspectives. To nurture these entrepreneurial traits effectively, it is essential for the Thai ecosystem to adapt and integrate these principles into its approach to innovation and entrepreneurship.

Matching STEM, Coding Competency with Curriculum and Business Sector

The linking of coding competency in curriculum and business sectors' requirement is essential for fostering innovation and creating valuable business opportunities. STEM and coding skills are a vital asset for individuals looking to venture into startups and entrepreneurship. To achieve this synergy, schools must undergo a transformation in their ecosystem. The success of promoting coding education or integrating it into school curriculum depends on the perceptions of teachers and headmasters in schools (Wong et al., 2015).

This includes embracing external influences, such as insights from the business sector and an understanding of the evolving landscape of learning. By doing so, educational institutions can effectively nurture the development of future entrepreneurs and startups. This shift allows the demand side, represented by the business sector, to actively engage and pull forth the skills and talents needed for a dynamic and competitive market.

Excerpts from the Case Study and Experts' Interview

In this case study, we draw insights from Estonia's pioneering education model (Savchenko, 2019), as experts mentioned in the focus group interview, which integrates coding and computational thinking. Estonia's government introduced coding as both a standalone subject and seamlessly integrated it into existing curricula. Extensive teacher training and enhanced technology access empowered students to transcend traditional classroom boundaries. The outcomes have been striking: a marked improvement in problem-solving abilities, heightened digital literacy, increased student engagement, and a diverse array of career opportunities. Estonia's tech-proficient workforce has also attracted startups, nurturing a dynamic entrepreneurial ecosystem. This model not only underscores coding's potential in educational reform but positions Estonia as a global tech leader, inspiring others to navigate the digital era and foster prosperity.

Thailand has a valuable opportunity to learn from Estonia's remarkable success in integrating coding and computational thinking into its education system to promote students' STEM and coding competency. Estonia's experience serves as a shining example of how such initiatives can not only enhance education quality but also nurture a thriving startup and entrepreneurial ecosystem. To seize this opportunity, Thailand has the opportunity to learn from Estonia's pioneering transformation with the Tiger Leap initiative (Tiigrihüpe) (Education Estonia, n.d.), which propelled it into a digital-based society 27 years ago. In our own plan, we have a 20-year strategy (Royal Thai Government Gazette, 2018). This led to our established '5 First S-Curve' industries – Aviation, Agricultural and Biotechnology, Smart Electronics, Affluent Medical and Wellness Tourism, and Automotive – while pivoting towards the '5 New S-Curve' industries that represent our forward momentum. These new industries include Biochemicals, Biofuels, Digital Economy, Medical Hub, and Automation and Robotics (True Digital Park, 2020). This strategic approach aligns with our national vision to advance Thailand's education system, adapting to the evolving global digital landscape and fostering a sustainable, knowledge-based economy.

Comprehensive Integration of Coding

Thailand can consider a holistic approach to integrating coding and computational thinking into its national curriculum. This means introducing coding as both a standalone subject and as an integral part of existing academic disciplines, such as mathematics, science, and technology. This multifaceted approach ensures that students are exposed to coding from various angles, enhancing their understanding and application of digital skills. Thai Education incorporated STEM in 2015 (Cheng, 2022) and coding into the national curriculum in 2017, emphasizing computing science based on learning indicators and core concepts from the 2017 science subject revision (Ministry of Education, 2017). STEM education begins in early childhood, incorporating science, mathematics, and technology into the curriculum. The primary and secondary curricula for mathematics, science, and geography have been revised. Design, technology, and information and communication technology are now part of the science curriculum. This integration emphasizes computational thinking. Various organizations, including corporations, NGOs, schools, and universities, actively support and drive STEM education in Thailand.

Despite this integration aimed at fostering computational thinking and interdisciplinary projects, the link between STEM education and economic growth, as well as the development of mid to high-skilled workforce, remains leave the potential for further aligning it with the country's economic growth and the enhancement of its mid to high-skilled workforce. in Thailand, as indicated by The World Bank (2021). A thorough integration of coding into the curriculum, teaching, and classroom learning is essential as World Bank highlights the importance of digital transformation and skills development for Thailand's future economic prosperity, which indirectly suggests the significance of incorporating digital skills like coding and STEM education in the curriculum.

Teacher Training

Drawing from the case study in Estonia, which emphasized prioritizing teacher training, Thailand should also focus on providing educators with the skills and knowledge needed for effective STEM and coding instruction. Organizing workshops, seminars, and online courses could be instrumental in ensuring that teachers are well-equipped and confident in teaching these subjects. Srikoom et al. (2017) highlighted a gap in professional development in this area, noting that in-service teachers in Thailand exhibited limited exposure to and awareness of STEM, thus necessitating improved training and communication strategies. Their study points to the urgency of enhancing STEM integration and awareness, particularly given STEM education's recent introduction in Thailand. It underscores the need for dedicated efforts in professional development to ensure teachers have a thorough understanding and can effectively implement STEM education.

Furthermore, Pimthong and Williams (2021) reinforced the role of teacher education programs in preparing STEM educators, not only for in-service teachers but starting from the preservice phase. They developed a STEM methods course for undergraduate preservice teachers, aiming to enhance their understanding and teaching capabilities in STEM disciplines. This approach underlines the importance of early, effective training in STEM education.

However, despite the progress in Thailand, as noted by The Institute for the Promotion of Teaching Science and Technology (n.d.), current training often focuses on individual disciplines, such as computing science, which is insufficient for comprehensive integration of coding with other subjects. To achieve a holistic approach, it is crucial that teachers from various disciplines have opportunities to engage in STEM and coding workshops designed in an integrated manner. This approach will ensure a more cohesive and effective delivery of STEM education across different subjects.

Access to Technology

Ensuring that students have access to technology is crucial. Thailand can invest in computer labs and provide personal devices for students, allowing them to practice coding and computational thinking inside and outside the classroom. This access enables students to apply their knowledge in real-world scenarios, reinforcing their skills. The integration of coding education into the curriculum could be facilitated by providing access to resources like the KidBright platform (Tan-a-ram et al., 2022). KidBright, as described in their study, offers an open-source embedded programming platform with a dedicated software framework designed to support ecosystems for learning to code. This resource can significantly contribute to enhancing coding education and fostering innovation in the classroom. The integration of coding and computational thinking into Thailand's educational curriculum holds significant potential benefits for the country. First, it is likely to improve problem-solving and critical-thinking skills among students, equipping them with the tools needed to tackle complex issues across various fields. Secondly, an emphasis on digital literacy will prepare students to navigate an increasingly digital world, although adapting new teaching methodologies like the flipped learning approach (Hung et al., 2020) may be necessary to address time limitations in the curriculum. Furthermore, introducing computational thinking opens up a multitude of diverse career pathways, empowering students to venture beyond traditional professions and meet the needs of the digital age. In terms of economic benefits, a national focus on coding and computational skills can also nurture a vibrant startup and entrepreneurial ecosystem. The government's role is crucial in this regard; by providing financial incentives such as grants, incubators, and tax benefits, the government can foster innovation and entrepreneurship, thereby stimulating economic development. Overall, the implementation of computational thinking and coding in education serves as a multi-faceted strategy to equip Thailand for the future. To promote proficiency in STEM and coding, various strategies can be adopted, such as the method employed by Singapore. As detailed by Seow et al. (2019), Singapore focuses on generating enthusiasm for computing among young learners through age-appropriate educational content. Rather than making it a mandatory subject, Singaporean policy provides schools the flexibility to opt into implementing computational thinking. This approach also emphasizes the importance of teacher training in computing and relies on a collaborative multi-agency system. Kaygısız et al. (2020) promoted access to technology in classrooms through the integration of robotics and coding into STEM education. In a similar vein, Ola et al. (2019) adopted the principles of maker-centered learning, which prioritize hands-on, collaborative experiences. This approach, rooted in the maker movement, fosters innovation, creativity, and learning through practical experiences. Meanwhile, Allen et al. (2019) implemented an afterschool program that involved 1,599 students from grades 4 to 12 across 158 STEM-focused afterschool programs in 11 state networks. Within this framework, students engaged in retrospective self-assessments to gauge their attitudes towards STEM and to measure their Social-Emotional Learning (SEL) and 21st-century skills. The program's quality and effectiveness were further evaluated through 250 standardized observations of STEM activities, providing a comprehensive analysis of the program's influence on enhancing student engagement and skill development in STEM disciplines.

The Future of Artificial Intelligence Era

Artificial Intelligence (AI), an increasingly integral part of daily life, is transforming the way we interact with technology. Systems like ChatGPT (2023) by OpenAI, harnessing deep learning technology, offer human-like interactions, emphasizing the importance of understanding AI's functionality for enhancing personal development and work efficiency (ChatGPT, 2023). In contemporary education, especially within STEM (Science, Technology, Engineering, and Mathematics), there is an increasing emphasis on integrating coding and AI interaction. It is vital for young learners, who are central to this paradigm shift, to develop a thorough understanding of AI. This encompasses learning about the operational principles of AI, the intricacies of automation, understanding the right data input formats, and how to customize AI systems. A critical skill is the ability to interpret and analyze outputs produced by AI technologies. The objective here is not to supplant human employment with AI; instead, AI is seen as a tool to enhance and augment human capabilities across various professional domains (Whipple, 2019). The Stanford AIRE Director (EO Channel, 2023) has put forward a concept termed "AI thinking", which comprises three key components: 1) Understanding the workings of AI, 2) Recognizing the differences between AI and human intelligence, and 3) Learning how to effectively collaborate with AI. This approach underlines the importance of not just technical proficiency but also a nuanced understanding of the symbiotic relationship between AI and human intelligence. It advocates for an educational framework where AI is not only a subject of study but also a partner in learning and problem-solving, preparing students for a future where AI is an integral part of the professional The Royal Thai Government's 20-Year National Strategy (Royal Thai Government Gazette, 2018) echoes this sentiment, proposing a vision for Thailand's development that parallels Estonia's emphasis on programming and coding. By integrating AI and coding into educational curricula and workforce training, Thailand aims to enhance its future workforce's preparedness and adaptability. This approach reflects a global trend where understanding and interacting with AI and coding are becoming fundamental skills, essential for navigating the evolving technological landscape. This strategic focus on AI and STEM education is poised to play a critical role in shaping a workforce that is innovative, technologically adept, and ready to tackle future challenges.

In terms of policy direction and planning, Thailand should consider adopting a holistic approach as we propose by system theory that encompasses STEM education, coding, startup incubation, and entrepreneurial education. Such comprehensive policies can create a synergistic effect, fostering a culture of innovation and preparing students for the digital future. In conclusion, Thailand has a golden opportunity to learn from Estonia's experience and embark on a journey to enhance its education system, promote STEM and coding competency among its students, and nurture a vibrant startup and entrepreneurial ecosystem. By embracing these lessons and tailoring them to its unique context, Thailand can position itself as a frontrunner in the global tech arena and create a prosperous future for its citizens.

Recommendations

Recommendations for Implementation

1. Collaboration between government agencies and the private sector is imperative to ensure alignment and effectiveness.

2. Beyond curriculum development, comprehensive training programs are essential, ensuring both accessibility and sufficiency.

3. A positive perception and a conducive environment are vital for the widespread implementation of STEM and coding competency development.

4. The rising prominence of digital technologies like AI underscores the demand-side benefits driving STEM and coding development.

5. Addressing the competency needs of the general population, offering intermediate skills for aspiring young programmers, and upskilling the existing workforce can be achieved through diverse platforms, including online, on-site, and hybrid solutions.

Recommendations for Future Research

1. Assessing long-term impact: Investigate the long-term effects of early exposure to STEM and coding on students' academic and career trajectories. Analyze how these skills influence their choices and success in higher education and the job market.

2. Pedagogical strategies: Explore innovative pedagogical approaches and teaching methods for effectively integrating coding and computational thinking into various subjects and grade levels. Assess the impact of different teaching strategies on student engagement, learning outcomes, and retention.

3. Collaboration between public and private sectors in promoting STEM: Investigate the collaborative efforts between public and private sectors in fostering STEM and coding education. Examine the effectiveness of joint initiatives and partnerships in promoting access, diversity, and quality in STEM and coding programs.

4. Impact, feedback and environment considerations in the STEM and coding ecosystem: Investigate the significance of environmental factors within the STEM and coding ecosystem, examining how the environmental context shapes and impacts the input, process, output, outcomes, and overall effectiveness of educational programs. Explore the sustainability and ecological implications of technology integration in education, with a focus on seeking feedback mechanisms to inform continuous improvements and environmentally responsible practices.

5. Workforce preparedness: Analyze the alignment between STEM and coding education and the evolving demands of the job market, including emerging technologies like AI and automation. Assess the preparedness of graduates in meeting industry needs while considering feedback from various stakeholders and the environmental context.

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Ethics Statement

All research activity by the authors included in the review have been undertaken with the approval of Chiang Mai University Ethics Committees, COA No.031/66, CMUREC No. 66/144.

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