

The Language of Innovation: Promoting STEM Literacy and Computational Thinking in the Digital Age

Nofouz Mafarja^{1*}, Mimi Mohaffyza Mohamad², Hutkemri Zulnaidi¹,
Haryanti Mohd Affandi³

¹ Department of Mathematics and Science Education, Faculty of Education,
Universiti Malaya, Kuala Lumpur, 50603, MALAYSIA

² Department of Professional Education and Postgraduate, Faculty of Technical and Vocational Education,
Universiti Tun Hussein Onn Malaysia, Johor, 86400, MALAYSIA

³ Faculty of Engineering and Built Environment,
Universiti Kebangsaan Malaysia, Bangi, Selangor, 43600, Malaysia

*Corresponding Author: nofouz@um.edu.my
DOI: <https://doi.org/10.30880/jtet.2025.17.01.002>

Article Info

Received: 4th December 2024
Accepted: 5th February 2025
Available online: 14th April 2025

Keywords

Computational thinking, digital age,
language of innovation, STEM literacy

Abstract

In the digital age, fostering STEM literacy and computational thinking skills is crucial for individuals to succeed in a technology-driven society. This research aims to assess STEM literacy and computational thinking among students in Malaysia's public universities. A quantitative survey was conducted involving 200 students in STEM fields. The study found a strong correlation between STEM literacy and computational thinking skills among students with a moderate level of literacy and thinking. However, there was no difference in the innovative teaching methods used in the classroom. The findings suggest integrating innovative language into STEM education and outreach initiatives can enhance STEM literacy and computational thinking skills. The study's implications extend to educators, policymakers, and stakeholders seeking to develop effective strategies for promoting STEM literacy and computational thinking in the digital age. This will equip individuals with the essential skills needed to succeed in a technology-driven world. However, the findings not only have implications for STEM educators or practitioners but also for TVET educators. TVET programs need to incorporate STEM literacy and computational thinking into their curricula.

1. Introduction

Science and technology wield significant influence in society, playing pivotal roles in shaping our world. Their absence would plunge us into chaos. Embracing scientific and technological knowledge empowers individuals to make informed decisions and choices. Technology's rise has transformed science into a potent instrument for analysis, exploration, and innovation, pertinent to contemporary times (Macanas & Rogayan, 2019). Digital literacy, the ability to navigate, understand, and create digital content, is essential in today's digital landscape (Macanas & Rogayan, 2019). Becoming digitally literate involves skills like locating and consuming digital content, creating and communicating, and critically evaluating information. Despite belonging to Generation Z, many students still exhibit low levels of digital literacy.

The rapid advancement of technology has transformed the world we live in, making STEM literacy essential for individuals to thrive in the digital age. Language innovation plays a crucial role in STEM education by bridging cultural and linguistic gaps (Miller & Roehrig, 2018). Integrating linguistic innovations in educational

processes, such as through the use of Information and Communication Technologies (ICTs) and multilingual approaches, enhances students' learning experiences and promotes inclusivity (Tieliezhkina et al., 2022; Schietroma, 2019). Multimodal approaches to language in STEM education can significantly enhance literacy skills while exploring STEM concepts, fostering better communication and understanding (Tippett et al., 2023). The integration of foreign languages with STEM, STEAM, and STREAM approaches in technical higher education institutions creates a dynamic environment for developing competitive technical specialists with a balanced skill set (Chapa, Albán & Stagg, 2021). By embracing language innovations, STEM education can become more accessible, engaging, and effective for learners from diverse backgrounds.

Digital technologies play a crucial role in enhancing STEM literacy among educators and learners. STEM teachers' digital literacy significantly influences their ability to integrate technology into teaching post-Covid-19 (Ramli & Arsad, 2023). The use of digital tools, such as translation tools and search engines, can aid STEM learners in reading tests, emphasizing the importance of incorporating digital technologies in educational assessments (Antoniuk & Zasiadivko, 2023; Ploisawaschai, 2022). Furthermore, the value of digital technologies in distance learning during quarantine conditions highlights the necessity of digital literacy for educators to adapt to modern learning environments (Ploisawaschai, 2022). Integrating digital literacy skills with STEM education can enhance students' independent learning abilities, emphasizing the importance of technology mastery in the curriculum (Hilyana et al., 2023).

Promoting STEM literacy in the digital age involves leveraging digital tools to enhance science, technology, engineering, and mathematics education (Ludwig et al., 2023; Jaramillo-Arévalo et al., 2023). Research emphasizes the importance of integrating digital technology into STEM education to improve students' knowledge perception and academic performance (Ludwig et al., 2023; Ran et al., 2023). Studies have shown that incorporating digital storytelling and multimodal elements can effectively integrate science concepts into narratives, enhancing students' understanding and engagement (Rehman et al., 2022). The use of innovative narrative techniques, critical responses to socio-scientific problems, and diverse science topic connections are key strategies identified in promoting STEM literacy through digital means. Overall, the expansion of technology in education, especially in STEM fields, has the potential to significantly impact students' literacy, communication, research skills, and academic performance.

All students should possess and develop their computational thinking skills as technology advances because they are crucial to their professional success in the modern digital age (Wong & Jiang, 2018). The ability to distinguish and extrapolate important information from larger sources is one of the "digital literacy" sub-skills that are crucial for the 21st century. It is connected to other 21st century empowerment skills, e.g., problem-solving, critical thinking, job effectiveness, and creativity. Cansu and Cansu (2019) propounded the view that this empowerment needs to be incorporated into all children's analytical capability which is the crucial backbone in their science, technology, engineering, and math learning. Advocating CT in the educational system will add a new ability to the student skill list they need in the not-too-distant future and which many institutes have initiated (Grover & Pea, 2017). For example, promoting CT was infused into the US Next Generation Science Standards (NGSS) and STEM courses in the level of K-12. CT was integrated into various educational programs in many countries, e.g., Finland, Norway, South Korea, Israel, Poland, New Zealand, and Estonia (Tikva & Tambouris, 2021). CT was also incorporated into the elementary school curricula in 52 countries according to the surveys of studies published between 2006 and 2018 (Tang et al., 2020). In Malaysia, CT was introduced as part of the National Standards Curriculum in 2017.

As computational thinking is expected to be one of the fundamental skills required for every individual in the 21st century and STEM education, which emphasizes learning strategies based on real-world problem solving, requires students to master and apply computational thinking skills, students' level of computational thinking skills needs to be evaluated to determine the extent to which students master these skills. This study discusses the level of computational thinking among students and their differences in terms of innovative teaching method use in classroom. The results are expected to help teachers plan more effective teaching and learning methods after determining students' computational thinking levels. In this context, the aim of this study is to assess the current level of STEM literacy among STEM education Students, to assess the current level of computational thinking among STEM education Students, to examine the relationship between STEM literacy and computational thinking and to assess the differences of STEM literacy and computational thinking among innovative teaching method use in classroom. The following hypotheses have been proposed in this study:

1. H_01 : No significant relationship between STEM literacy and computational thinking
2. H_02 : No significant difference in mean score exists in computational thinking based on the Innovative Teaching Method used in the classroom.
3. H_03 : : No significant difference in mean score exists in STEM literacy based on Innovative Teaching Method used in classroom.

2. Literature Review

2.1 Innovative Teaching Method

Hence, the educational institutions worldwide are thus seeking to innovate, improve, and make teaching and learning more effective (Shorbaji et al., 2015). The new teaching methods thus promote skill based, as well as self-directed learning and knowledge. The new teaching methods are based on adult education or Andragogy, defined as “the art and science of helping adult learn” (Asrizal et al., 2023). It focuses on self-directed learning, improves self-efficacy, self-motivation, encourage learners to formulate their own learning objectives and evaluate their own learning. The new method is an interactive teaching methodology, where the teacher strengthens the various skills of the students (Asl, 2017). The various innovative methods in STEM education include flipped classroom teaching method, problem-based learning, case-based learning, computer-based e-learning, evidence-based learning, virtual simulation, etc. These new methods enhance the team/collaborative learning, improve student’s self-confidence and also enrich their critical thinking, creativity, problem solving, and communication skills.

2.2 STEM Literacy

TVET and STEM are closely related as TVET can serve as a platform for the integration of STEM skills and knowledge. TVET programs can provide a strong foundation for the development of STEM competencies and skills, making it an ideal vehicle for facilitating STEM education. Integrating STEM in TVET can prepare the workforce to be more effective and productive in the knowledge-based economy. However, there are gender inequalities in access to STEM-related fields in TVET, with women being underrepresented in these areas. Increasing female participation in STEM programs and careers can contribute to their empowerment and drive social well-being. It is important for STEM teachers in TVET to integrate technology in their teaching practices to engage students in STEM disciplines. The level of ICT integration among STEM teachers in TVET is moderate, and there is a need to examine other factors that affect the success of ICT integration. Overall, TVET and STEM are interconnected and play a crucial role in advancing economies and technology (Tikly et al., 2020; Chan & Mohammad, 2019; Bakar & Mahmud, 2020; Kamonjo & Wamuga, 2022).

STEM literacy encompasses the ability to understand and apply concepts from science, technology, engineering, and mathematics in various contexts, both inside and outside the classroom. It is crucial for educators to possess strong STEM literacy to effectively support students' learning (Ramli et al., 2023; Tenney et al., 2023). Research highlights the importance of STEM teachers' digital literacy and technological integration skills, showing a significant correlation between digital literacy knowledge and technology integration in teaching post-Covid-19 (Huang et al., 2022). Additionally, the development of integrated teaching materials with a STEM approach has been proven to enhance students' scientific literacy, particularly in subjects like Basic Chemical Law Materials (Asrizal et al., 2023). Overall, STEM literacy plays a vital role in modern education, shaping how individuals engage with and apply knowledge in STEM fields.

2.2.1 STEM Concept

The STEM concept encompasses Science, Technology, Engineering, and Mathematics education, aiming to enhance academic performance and innovative thinking (Hao et al., 2022; Barragán Moreno & Guzmán Rincón, 2022). It involves integrating these disciplines to promote a holistic approach to education, emphasizing practical applications and real-world problem-solving (Qingduan et al., 2021). However, challenges exist in implementing STEM education fully, as indicated by gaps at both the conceptual and practical levels, including infrastructure issues and knowledge gaps (Hulai, 2021). To address these challenges, innovative methods like deep transfer learning have been developed to merge spatial transcriptomics and single-cell RNA sequencing data, enabling a detailed understanding of cellular composition and gene expression at a single-cell level (Kulakoglu & Kondakci, 2023). Overall, the STEM concept plays a crucial role in shaping educational practices and fostering critical skills for students in various fields.

2.2.2 STEM Practices

STEM practices encompass a wide range of teaching and learning strategies aimed at promoting creativity, critical thinking, and problem-solving skills among students. Studies have highlighted the importance of STEM education in developing interdisciplinary skills and practical knowledge (Nasir et al., 2023; Yurchenko et al., 2022). STEM teachers play a crucial role in implementing these practices, with a focus on engaging students through activities like programming, robotics, and interdisciplinary projects (Hladik, 2022). Furthermore, informal STEM facilitators in various settings, such as museums and after-school clubs, create learning opportunities by integrating constructivist and constructionist approaches, encouraging learners to connect

personal experiences with STEM concepts (Nikolopoulou, 2023). Challenges and good practices in real-life STEM professions have also been identified, emphasizing the need to address barriers faced by underrepresented groups in STEM fields (Christou et al., 2022). Overall, enhancing STEM practices is essential for fostering a generation of innovative and skilled individuals prepared for the demands of the future.

2.2.3 STEM Application

STEM applications encompass a wide range of educational and technological initiatives aimed at promoting Science, Technology, Engineering, and Mathematics. From developing mathematical models without simplifying assumptions (Ochkov et al., 2023) to integrating spatial transcriptomics data for single-cell resolution (Hao et al., 2022), STEM applications are diverse. Research indicates a growing trend in utilizing STEM in science education, with positive effects on students' academic achievement and skills (Eren & Dökme, 2022). Moreover, efforts are being made to address gender disparities in STEM fields through innovative solutions like mobile applications designed to motivate and educate girls about STEM careers (Ahumada et al., 2022). These applications often incorporate interactive modules, motivational content, and learning games to engage and empower young women in pursuing STEM-related paths. Overall, STEM applications play a crucial role in enhancing education, promoting diversity, and advancing knowledge in various fields.

2.2.4 STEM Attitude

STEM attitude refers to individuals' perceptions and feelings towards Science, Technology, Engineering, and Mathematics. Research indicates that STEM attitude plays a significant role in various aspects of education. Studies show that positive STEM attitudes are linked to improved computational thinking skills, which in turn enhance 21st-century skills (Richardo et al., 2023). Additionally, STEM students may experience math anxiety and negative math attitudes, potentially leading to dropout from STEM studies (Szczygieł, 2022). Monitoring and interventions to improve math attitudes and decrease math anxiety are recommended to prevent dropout. Furthermore, students' STEM attitudes are influenced by learning motivation and metacognition, with socioeconomic status playing a moderating role in shaping STEM attitudes (Martynenko et al., 2023). Positive attitudes towards specific STEM disciplines like science, technology, engineering, and mathematics contribute to the development of 21st-century learning skills, emphasizing the importance of valuing STEM attitudes across disciplines (Liu et al., 2022).

2.2.5 STEM Related Context

STEM education emphasizes problem-based learning in Science, Technology, Engineering, and Mathematics, aiming to enhance students' real-world problem-solving skills and future career readiness (Kostøl & Remmen, 2022). Hispanic undergraduates face challenges in STEM pathways, with a lack of evidence on effective interventions for this demographic, highlighting the need for improved research methodologies (Miteva et al., 2022). Integrating contextual structures in STEM education enhances the development of foundational, technical, and soft skills, leading to industry-aligned instruction and positive outcomes for students pursuing STEM careers (Bravo, 2021). Monitoring studies emphasize the importance of science and mathematics literacy in STEM education, showcasing the benefits of practice-oriented tasks and integrated subject content to improve educational quality and student motivation in STEM fields (Gale, 2021).

2.2.6 Interaction Technologies

Interaction through technologies in STEM education plays a crucial role in enhancing collaborative learning, student-teacher interaction, and concept visualization. Various studies emphasize the integration of interactive tools like Interactive Flat Panel Displays (IFPD), Digital Interactive Storytelling (DIST), and programming languages to improve learning outcomes in STEM subjects (Chien et al., 2023; Wang & Shen, 2023; Albano et al., 2022; Muntean et al., 2019). These technologies not only connect learners across distances but also promote group discussions, guide collaborative processes, and facilitate the development of new knowledge through dialogical interactions (Morgacheva et al., 2022). Additionally, the use of interactive tools such as stepper motors and drones in teaching mathematical concepts like linear algebra makes learning more engaging and links theoretical concepts to real-world applications, fostering a deeper understanding among students. Overall, integrating interactive technologies in STEM education enriches the learning experience and promotes effective student engagement and interaction.

2.3 Computational Thinking

Over time, computational thinking (CT) has surged in popularity, with Cansu and Cansu emerging as pivotal figures in its development. Cansu and Cansu (2019) characterized CT as a problem-solving methodology rooted

in computer science principles, essential for system design and understanding human behavior. Papert's seminal work in 1996 represents an early exploration of CT, emphasizing the importance of applying fundamental human cognition to intricate problems within object-oriented contexts. This problem-solving approach, deeply entrenched in computer science, has been echoed by scholars like Korkmaz et al. (2017) and elaborated upon by Cansu and Cansu (2019). CT embodies a cognitive process of delineating problems and devising solutions conducive to computational execution (Cansu & Cansu, 2019). It encompasses the capacity to dissect complex issues, recognize patterns, and devise systematic problem-solving strategies, aligning closely with the core tenets of computer science.

Similarly, according to Markandan et al. (2022), computational thinking (CT) is delineated as a foundational skill aimed at resolving human-centric problems, emphasizing the pivotal role of problem comprehension in generating practical solutions. CT encompasses a broad spectrum of competencies, including creativity, algorithmic thinking, critical thinking, problem-solving, collaborative reasoning, and communication skills, as highlighted by the International Society for Technology in Education. These proficiencies feature prominently in the literature on CT. In line with this, the Computer Science Teacher Association (CSTA) updated its definition of problem-solving mechanisms in 2016, underscoring its applicability across diverse domains within computer science. This systematic approach enables the analysis and development of computational solutions for a wide array of issues (CSTA, 2017).

Alternatively, computational thinking (CT) represents a fusion of multifaceted cognitive abilities, encompassing mathematical, engineering, and scientific thinking, as underscored by Law et al. (2021). This amalgamation fosters a capacity for innovative and original thought, as emphasized by Korkmaz & Bai (2019). While CT lacks a singular, precise definition, its significance is evident, as it is universally recognized as a fundamental skill alongside reading, writing, logic, and mathematics, according to Cansu and Cansu (2014). Integration of CT into the critical thinking processes inherent in reading, writing, and mathematics is deemed essential for every child, as advocated by the International Society for Technology in Education. The dimensions of the computational thinking abilities determined by Korkmaz et al. (2017) are shown below and include creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving.

2.3.1 Creativity

According to Grover & Pea (2017), creative thinking constitutes a significant dimension of computational thinking (CT). This cognitive process involves generating novel concepts or ideas and establishing fresh connections between existing ones. Creativity, often described as the "capacity for creation" or the "ability to create," involves the act of bringing forth something new from nothing, thus emphasizing the generation of fresh notions or ideas. It encompasses qualities such as originality and imagination, reflecting the ability to perceive novel challenges and devise innovative solutions. Creative thinking, therefore, is not an isolated skill but intricately linked to analytical and problem-solving proficiencies, as emphasized by Korkmaz et al. (2017).

2.3.2 Algorithmic Thinking

Algorithmic thinking serves as the cornerstone of computational thinking (CT). An algorithm, defined as a clearly specified process composed of sequential stages to solve a problem, lies at the heart of this concept. The ability to comprehend, execute, evaluate, and construct algorithms is encapsulated by algorithmic thinking (Yadav et al., 2017), rooted in the fundamental notion of designing a sequence of steps to achieve a desired outcome. This concept revolves around the development and understanding of algorithms (Yadav et al., 2017), with algorithmic reasoning emerging as a key feature of CT, facilitating the automated resolution of problems. It demands meticulousness, conceptual thinking, and problem-solving skills, involving the creation of step-by-step flowcharts leading to viable solutions, iterative refinement of these flowcharts, and exploration of alternative processes to ensure comprehensive problem resolution. Furthermore, algorithmic thinking is closely intertwined with the ability to define abstraction, a fundamental aspect of computational thinking (Wong & Jiang, 2018). Recognized as one of the core competencies in CT (Yadav et al., 2017), algorithmic thinking underscores the essence of systematic problem-solving through the design and execution of algorithmic processes.

2.3.3 Cooperativity

Cooperativity emerges as a vital component within the dimensions of computational thinking (CT), as highlighted by Grover & Pea (2017). According to Missiroli et al. (2017), cooperative thinking encompasses the ability to elucidate, recognize, deconstruct, and collaboratively resolve issues in socially sustainable ways, effectively intertwining cooperative thinking with the essence of CT. At its core, cooperative thinking is a problem-solving process that thrives on collaboration and teamwork, particularly crucial as problems increase in complexity. It becomes increasingly challenging for individuals to tackle intricate issues alone, necessitating

cooperation and collaboration among peers. In the context of CT, where students engage in higher-level reasoning (Mindetbay et al., 2019), social collaboration assumes paramount importance. Interoperability becomes essential as problems become more intricate, highlighting the need for seamless interaction and cooperation among individuals. Cooperativity stands out as a superior learning method due to its participatory nature, facilitating information sharing and the development of social relationships among learners (Korkmaz, 2019). This collaborative approach not only enhances problem-solving abilities but also fosters a supportive learning environment conducive to holistic skill development.

2.3.4 Critical Thinking

Critical thinking stands as a pivotal component of computational thinking (CT), encompassing higher-order cognitive abilities essential for problem-solving, as highlighted by Doleck et al. (2017). This multifaceted process involves the utilization of individual attitudes, information, and skills to reason and evaluate problem situations at a deeper level of thought. Csizmadia et al. (2015) define critical thinking as the assessment and evaluation of thoughts, aiming to identify opportunities for improvement. It entails probing "how" and "why" questions. Kules (2016) draws parallels between the eight-dimensional critical thinking framework and the Computer Science Standards proposed by CSTA (2017), identifying several overlapping concepts such as "concepts and abstraction," "formulation and question-at-issue," "information/data," "confidence and persistence," and "logic." While various problem-solving approaches exist, critical thinking remains indispensable, underscoring its significance within CT. In essence, critical thinking serves as a fundamental element of CT, providing a framework for rigorous analysis and evaluation essential for effective problem resolution.

2.3.5 Problem Solving

According to Doleck et al. (2017), problem-solving stands as the foundational dimension of computational thinking (CT), a notion reinforced by Grover & Pea (2017). Problem-solving is essentially synonymous with CT, serving as the mechanism through which individuals navigate everyday challenges. This process typically involves four key steps: defining the problem, generating alternative solutions, evaluating and selecting the best solution, and implementing and monitoring the chosen solution. The problem-solving process embodies several characteristics, including defining the problem in a manner conducive to computational assistance, logically organizing and analyzing data, abstracting data for visualization, employing algorithmic thinking for automated problem-solving, identifying and implementing feasible solutions efficiently, and transferring problem-solving strategies across diverse contexts (Doleck et al., 2017). These characteristics are intricately linked to the fundamental steps of problem-solving, reinforcing the close relationship between problem-solving and CT.

2.4 CT and STEM Literacy

The Korkmaz Computational Thinking Scale (CTS) has been widely adopted and employed in research worldwide to assess students' computational thinking (CT) abilities. For example, Law et al. (2021) investigated the correlation between academic achievement and CT among STEM students in Malaysia. Similarly, Doleck et al. (2017) examined the relationship between CT skills and academic performance among students in northeastern Canada. Günbatar (2019) conducted a comparative study of CT skills between in-service and pre-service teachers in Turkey. Mindetbay et al. (2019) explored the efficacy of CT and its relationship with academic achievement among 8th-grade students across 28 schools in Kazakhstan. Lemay et al. (2021) investigated the connection between CT and academic outcomes among students in Turkey.

Additionally, Srakaya et al. (2020) explored the association between CT skills, STEM attitudes, and thinking styles among secondary school students in Turkey. Paf and Dinçer (2021) examined the relationship between CT skills and creative problem-solving abilities among students in grades 8–12 in Turkey. Zgür (2020) investigated the correlation between CT skills, thinking patterns, and demographic variables among students in grades 5–12 in Turkey. Alyahya and Alotaibi (2019) studied the relationship between CT skills and 8th-grade students in Saudi Arabia. Lastly, Durak and Saritepeci (2018) assessed the relationship between CT skills and various factors in Turkey.

STEM literacy and computational thinking are crucial skills in modern education. STEM education integrates various disciplines like Physics, Mathematics, Computer Science, and Computational Science, promoting Quantum Literacy (QL) (Xenakis et al., 2023). It emphasizes problem-solving, critical thinking, and practical experimentation, aligning with the demands of the 21st-century society (Braun & Huwer, 2022). Innovative pedagogical approaches, such as integrating drone technology and block-based programming, enhance students' computational thinking by engaging them in real-world problem-solving tasks (Sattar & Nawaz, 2023). These approaches not only equip students with essential computational skills but also foster their ability to decompose complex problems into manageable parts and develop mathematical algorithms to solve them effectively. By

incorporating such practices, educators can effectively nurture students' STEM literacy and computational thinking skills, preparing them for the challenges of the modern world.

Embedding STEM literacy and computational thinking into the TVET context is increasingly recognized as a critical strategy for equipping learners with the skills needed in a rapidly evolving digital economy. TVET institutions play a pivotal role in bridging the gap between theoretical knowledge and practical applications, aligning educational outcomes with industry demands (UNESCO, 2021). By integrating STEM principles into vocational training, learners can acquire problem-solving skills and technical expertise applicable to diverse fields, such as advanced manufacturing, healthcare, and renewable energy (Okoye & Chijioke, 2020). Computational thinking, in particular, enhances the ability to analyze complex problems, design solutions, and automate processes—skills essential for thriving in technology-driven workplaces. Furthermore, embedding STEM into TVET programs fosters innovation and adaptability, preparing students not only for current workforce demands but also for emerging challenges in the digital age (World Bank, 2020).

Challenges in STEM literacy and computational thinking include the need for robust teacher preparation, the importance of integrating computational thinking into STEM Education, and the necessity of making quantum computing and technologies accessible to students and teachers (Sabo et al., 2022; Govender, 2022). These challenges stem from the evolving nature of technology and the increasing demand for computational skills in the workforce. Integrating computational thinking into education requires addressing the gap between theoretical knowledge and practical application (Markandan et al., 2022). Additionally, there is a need to enhance teachers' knowledge and implementation of computational thinking in STEM fields to meet the demands of the digital economy. Overcoming these challenges involves developing innovative teaching methods, such as gamification scenarios and inquiry-based learning, to engage students effectively in acquiring essential STEM and computational skills.

3. Methodology

3.1 Research Design

This study adopts a quantitative research design to investigate the promotion of STEM (Science, Technology, Engineering, and Mathematics) literacy and computational thinking in the digital age through an analysis of the language of innovation. The research design involves the administration of structured surveys to collect quantitative data on STEM literacy and computational thinking.

3.2 Participants

Through the lens of gaining mutual advantage from a research network, the random sampling technique was employed in the current study due to the expectation of the highest responses possible. Data were collected from public universities students in Malaysia using google form survey. During data screening outliers were observed using the Mahalanobis distance method with a critical point of 58.30, resulting in 30 responses dismissed from the dataset. The final total number of participants comprised 200 students; 104 (52%) of the participants were male whereas 96 (48%) were female. Most of the participant from Technology disciplines 68 students (34%), 59 (29.5%) students from engineering, 39 (19.5) mathematics students however; 34 (17%) science students. For the innovative teaching methods used inside the STEM classroom was Flipped classrooms 38 (19%), Hybrid learning environments 44 (22%), Gamified language learning 32 (16%), Interactive whiteboards 30 (15%) and Problem-based learning 56 (28%). For the educational level most of the participants degree students 108 (54%) and from University of Malaya 96 (48%).

3.3 Instruments

In this study, the researchers adopted the computational thinking skills (CTS) surver from Korkmaz et al (2017). The CTS consists of 29 items with a 5-level rating on a Likert-scale (1 = never, 2 = rarely, 3 = sometimes, 4 = often, and 5 = always). Each CT dimension consists of several items, e.g., creativity (8 items), algorithmic thinking (6 items), cooperativity (4 items), critical thinking (5 items), and problem-solving (6 items). The researcher adopted a STEM literacy questionnaire originally created by Chamrat, Manokarn and Thammaprteep (2019), with some modifications tailored to the context of physics education. The STEM literacy questionnaire comprised six domains: STEM Concept (13 items), STEM Practice (17 items), STEM Application (16 items), STEM Attitude (16 items), STEM-related Context (15 items) and interactive through technologies (5 items) which were used to assess the STEM literacy (Chamrat et al., 2019; Baterna et al., 2020). The initial questionnaire encompassed concepts of STEM. Permission was obtained from the authors to utilise the questionnaire, which consisted of 35 items rated on a five-point Likert scale ((1) Strongly disagree, (2) Disagree, (3) Neutral, (4) Agree, (5) Strongly agree)). As well as for both questionnaire the researchers had part for

demographic variables such as gender, fields, education level, institute and innovation method use in STEM classroom.

The data collection process was systematically designed to ensure the reliability and validity of the responses. A structured survey was administered online using Google Forms, a convenient platform for reaching a diverse participant pool efficiently. The survey targeted students from public universities in Malaysia, focusing on those enrolled in STEM-related disciplines. To maximize participation, a random sampling method was employed, which provided all eligible students with an equal chance of being included in the study.

The collected data were analyzed using descriptive statistical methods. Key metrics such as means and standard deviations were calculated to provide an overview of the participants' responses. Constructs were interpreted across three levels: low, medium, and high, to facilitate meaningful insights. This approach was chosen because it effectively highlights patterns and trends in participant responses, aligning with the study's goal of understanding STEM literacy and computational thinking in the digital age. The mean interpretation used in this study is based on a study by Lapammu and Mahamod (2018) as shown in Table 1.

Table 1 Mean interpretation

Mean Range	Interpretation
1.00-2.33	Low
2.34-3.67	Medium
3.68-5.00	High

The instruments used in this study was also reviewed and validated by experts in the field of Computational Thinking and STEM education. To assess its reliability, a pilot study was conducted involving 30 students who shared the same characteristics as the participants in the main study. Respondents were randomly selected, with 15 students from both the lower and upper forms. The reliability of the instrument was assessed through an analysis using Cronbach's alpha, as presented in Table 2. According to Taber (2018), a reliability value (Cronbach's alpha) of at least 0.70 is deemed acceptable for research purposes. The analysis of Cronbach's alpha revealed a high reliability value of 0.920, indicating that the instruments used in this study was reliable overall. With its strong validity and reliability, the data obtained from this study can be considered accurate and dependable.

Table 2 Cronbach's alpha value for each

Construct	Number of Items	Cronbach's Alpha Value
STEM Concept	13	0.805
STEM Practice	17	0.822
STEM Application	16	0.870
STEM Attitude	16	0.799
STEM related Context	15	0.850
Interaction Technologies	5	0.800
STEM Literacy	35	0.824
Creativity	8	0.899
Algorithmic Thinking	6	0.903
Cooperativity	4	0.877
Critical Thinking	5	0.889
Problem Solving	6	0.920
Computational Thinking	29	0.898

4. Results

Data were analyzed both descriptively and inferentially. The descriptive analysis, involving the mean value and standard deviation, was carried out to identify students' computational thinking and STEM Literacy levels.

Normality tests and histograms were used to ensure that the data were normally distributed. The results of the normality test analysis showed that the skewness values of all items were in between 0.004 and -0.83 whereas kurtosis values were between 0.861 to 2.037. Therefore, the data are considered to be normally distributed. The data distribution of students' computational thinking level is shown in Figure 1. The Levene test was conducted to determine the homogeneity of the variance. The test results show that the significant value for the variable of gender is $p=0.537$, which is $p>0.05$, indicating that the homogeneity of the variance is met for for

STEM Literacy. As for the gender variable for computational thinking, the homogeneity of the variance is $p=0.743$, which is $p > 0.05$, so indicating that the homogeneity of the variance is met.

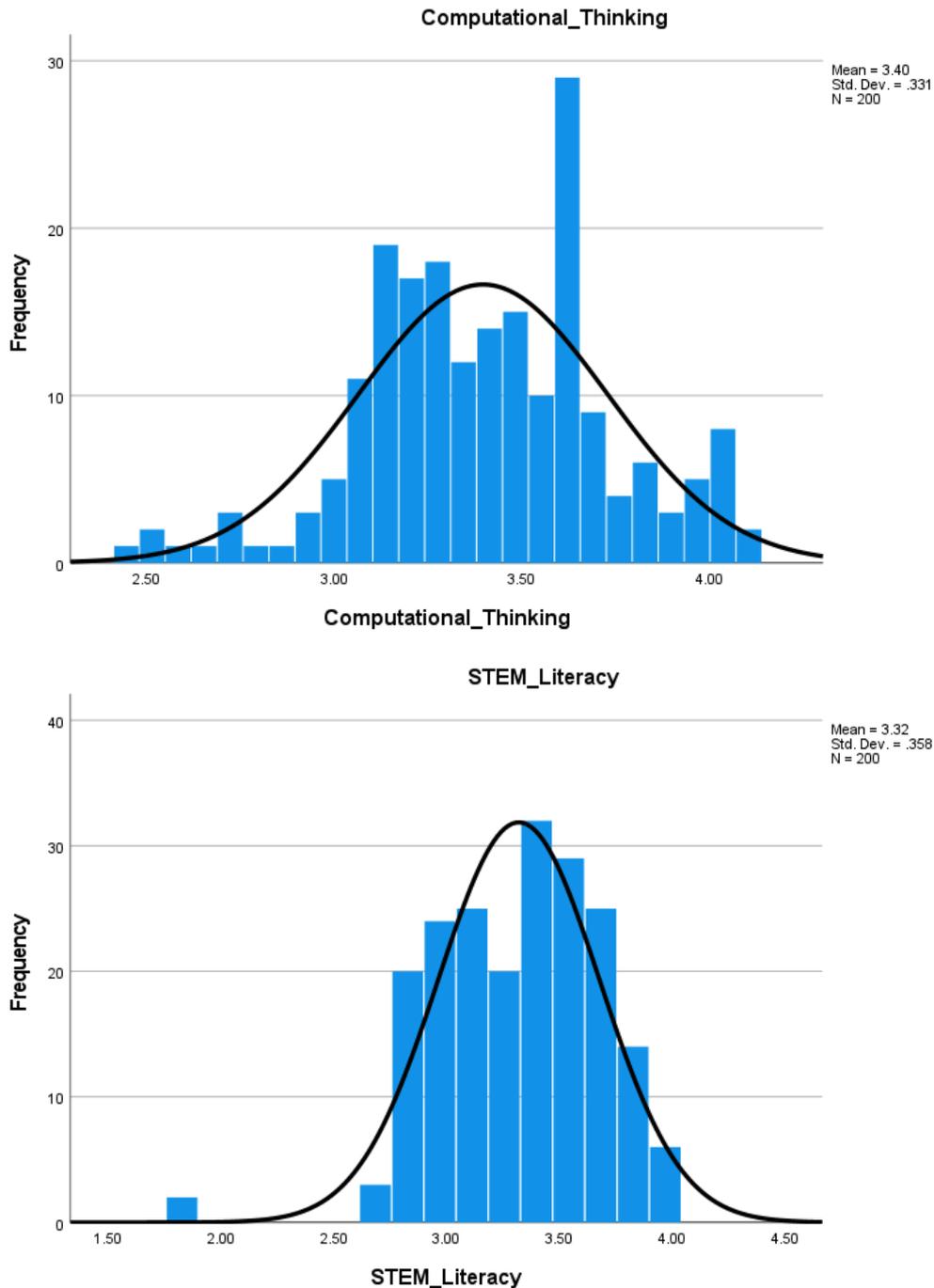


Fig 1 Normality test for computational thinking skills and STEM Literacy

4.1 Level of STEM Literacy Among Students

This study examined several elements of STEM Literacy: STEM concept, STEM practice, STEM application, STEM attitude, STEM related context and interaction through technologies. The results show that students' STEM Literacy at a Moderate level ($M=3.322$, $SD=0.358$). Table 3 shows that students' STEM concept, ($M=3.34$, $SD=0.397$), STEM practice ($M=3.351$, $SD=0.383$), and STEM application ($M=3.379$, $SD=0.385$) are at a Moderate level whereas their STEM attitude ($M=3.364$, $SD=0.396$) and STEM related context ($M=3.375$, $SD=0.382$) are at a moderate level. As well as, interaction through technologies ($M=3.068$, $SD=0.502$) at moderate level.

Table 3 Levels of STEM Literacy among students

Construct	Mean	Std. Deviation	Level
STEM Concept	3.34	.397	Moderate
STEM Practice	3.351	.383	Moderate
STEM Application	3.379	.385	Moderate
STEM Attitude	3.364	.396	Moderate
STEM related Context	3.375	.382	Moderate
Interaction Technologies	3.068	.502	Moderate
STEM Literacy	3.322	.358	Moderate

4.2 Level of Computational Thinking Among Students

This study examined several elements of computational thinking: problem solving, cooperative learning and critical thinking, creativity, and algorithmic thinking. The results show that students’ computational thinking techniques are at a Moderate level (M=3.397, SD=0.3307). Table 4 shows that students’ algorithmic thinking techniques (M=3.350, SD=0.4072), creativity techniques (M=3.242, SD=0.4485) are at a moderate level., and problem-solving techniques (M=3.853, SD=0.3659) at a high level whereas their cooperative learning (M=3.349, SD=0.4376) and critical thinking (M=3.190, SD=0.4531) are at a moderate level.

Table 4 Levels of computational thinking among students

Construct	Mean	Std. Deviation	Level
Creativity	3.242	.4485	Moderate
Algorithmic Thinking	3.350	.4072	Moderate
Cooperativity	3.349	.4376	Moderate
Critical Thinking	3.190	.4531	Moderate
Problem Solving	3.853	.3659	High
Computational Thinking	3.397	.3307	Moderate

4.3 Relationship Between STEM Literacy, Computational Thinking

The correlation analysis provides valuable insights into the relationship between various STEM concepts and practices, as well as their association with computational thinking skills. The Pearson correlation coefficients indicate the strength and direction of these relationships, shedding light on the interconnectedness of different facets of STEM education.

Table 5 Correlations between STEM literacy, computational thinking

Construct		Creativity	Algorithmic Thinking	Cooperativity	Critical Thinking	Problem-Solving	Computational Thinking
STEM Concept	Pearson Correlation	.674**	.481**	.429**	.246**	.390**	.600**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
STEM Practice	Pearson Correlation	.704**	.560**	.498**	.340**	.390**	.667**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000

STEM Application	Pearson Correlation	.687**	.534**	.483**	.335**	.394**	.651**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
STEM Attitude	Pearson Correlation	.721**	.574**	.506**	.308**	.395**	.671**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
STEM related Context	Pearson Correlation	.699**	.575**	.509**	.369**	.393**	.678**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
Interaction Technologies	Pearson Correlation	.357**	.423**	.317**	.212**	.131	.379**
	Sig. (2-tailed)	.000	.000	.000	.003	.064	.000
STEM Literacy	Pearson Correlation	.746**	.620**	.527**	.332**	.391**	.701**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000

Based on Table 5 the Creativity demonstrates strong positive correlations with STEM practice, application, attitude, related context, interaction technologies, and STEM literacy. Algorithmic thinking exhibits significant positive correlations with STEM practice, application, attitude, related context, interaction technologies, and STEM literacy. Cooperativity shows strong positive correlations with STEM practice, application, attitude, related context, interaction technologies, and STEM literacy. Critical thinking demonstrates positive correlations with STEM practice, application, attitude, related context, interaction technologies, and STEM literacy. Problem-solving exhibits positive correlations with STEM practice, application, attitude, related context, interaction technologies, and STEM literacy. However, Computational thinking demonstrates strong positive correlations with overall STEM literacy. there was significant relationship between STEM literacy and computational thinking Thus, Ho1 is rejected at the level of significance ($\alpha=0.01$).

4.4 Differences in Students' STEM Literacy and Computational Thinking Based on Innovative Teaching Method Use in Classroom

A Multivariate tests analysis was used to identify the differences in computational thinking skills among students based on Innovation method use in classroom. As Table 6 indicates, there was no significant difference emerged in the level of computational thinking ($F=0.348$, $p=0.845$) between the Innovation method used in the STEM classrooms. Thus, Ho2 is accepted at the level of significance ($\alpha=0.05$). However, a Multivariate test analysis was used to identify the differences in STEM Literacy among students based on the Innovative method used in the classroom. As Table 6 demonstrates, there was no significant difference in the level of STEM Literacy ($F=0.538$, $p=0.708$) between the Innovation methods used in the classroom, suggesting that Ho3 is accepted at the level of significance ($\alpha=0.05$).

Table 6 Differences in Students' STEM literacy and computational thinking based on innovative teaching method use in classroom

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Innovation method (Flipped classrooms, Hybrid learning)	STEM Concept	.118	4	.029	.184	.947	.004
	STEM Practice	.360	4	.090	.609	.656	.012
	STEM Application	.246	4	.061	.410	.802	.008
	STEM Attitude	.475	4	.119	.752	.558	.015
	STEM related Context	.418	4	.105	.712	.585	.014

environments, Gamified language learning, Interactive whiteboards and Problem-based learning)	Interaction Technologies	1.891	4	.473	1.908	.111	.038
	STEM Literacy	.278	4	.069	.538	.708	.011
	Creativity	1.297	4	.324	1.633	.168	.032
	Algorithmic Thinking	.423	4	.106	.633	.640	.013
	Cooperativity	.189	4	.047	.243	.914	.005
	Critical Thinking	.030	4	.007	.036	.998	.001
	Problem Solving	.093	4	.023	.170	.953	.003
Computational Thinking	.154	4	.039	.348	.845	.007	

5. Discussion

Overall, students possess a Moderate level of computational thinking, suggesting that they are able to master computational thinking techniques well, especially creativity techniques, critical thinking, cooperative techniques, and algorithmic thinking techniques. However, students possess a high level of problem-solving techniques possess. The findings show that the students indeed possess a Moderate level of STEM literacy, especially STEM Concepts, STEM Practice, STEM Application, STEM Attitude, STEM-related Context, and interactive technologies.

The results align with those presented by Korocu (2017), who also demonstrated the high level of computational thinking among students. The integration of hands-on activities in STEM education has been effective in fostering computational thinking skills. By applying these skills, students are trained to think creatively and critically, particularly when confronted with challenges. Furthermore, students gain a solid understanding of the subject matter by acquiring and implementing computational thinking techniques during learning.

Consequently, students with advanced computational thinking skills are more inclined to exhibit creativity and critical thinking when tackling complex real-world problems. Proficiency in problem-solving is crucial for addressing intricate issues, as it entails the ability to assess, comprehend, analyze, and strategize solutions. Thus, students who possess problem-solving mastery are equipped to manage and resolve complex problems, take calculated risks, and engage in advanced problem-solving thinking. Having a high level of creativity skills is crucial in the problem-solving process as it enables students to employ a diverse range of ideas and approaches to complete tasks and resolve issues. According to Kong et al. (2018), STEM learning, which focuses on finding practical solutions to real-world problems in everyday activities and environments, can cultivate students' creativity by building upon their existing knowledge and experiences.

Therefore, STEM learning methods have the potential to enhance students' creative problem-solving abilities. Algorithmic thinking skills play a significant role in developing problem-solving strategies. Rodriguez et al. (2017) note that while students may have a good understanding of problems, they often struggle with formulating appropriate and effective strategies to solve them. This is because algorithmic thinking involves using formulas, techniques, rules, or steps derived from analyzing multiple similar problems. In this context, STEM learning methods can effectively train and enhance students' algorithmic thinking techniques, enabling them to design more systematic and efficient solutions. Cooperative learning emphasizes collaboration and active engagement among students in small groups. Cooperative learning techniques foster cooperation and mutual support among students with varying abilities, allowing them to work together towards shared goals and reap collective benefits.

Cooperative learning provides skilled individuals with the opportunity to develop a deeper understanding and acquire skills beyond what they could achieve independently. This is achieved through collaboration, guidance, assistance, or the presence of an expert or more capable peer. Additionally, cooperative learning fosters the cultivation of critical thinking skills, including the ability to draw conclusions, make generalizations, and critically evaluate the logic and accuracy of decisions (Yağcı, 2018). It also enhances communication skills through the exchange of ideas among students and with their teachers (Young-Sik & Young-Hoon, 2019).

However, the level of cooperative learning techniques and students' critical thinking skills still remains moderate. Students' interest and attitude towards cooperative learning are significant factors in enhancing their self-efficacy in this approach. STEM education teaching and learning strategies have been shown to contribute to the improvement of students' abilities, self-efficacy, productivity, and comprehension (Lay & Osman, 2018; Khalil & Osman, 2017). Moreover, student-centric, inquiry-based, and hands-on learning approaches have been proven effective in boosting students' motivation and engagement in classroom participation (Saad, 2020). Therefore, fostering positive attitudes and a strong interest in cooperative learning can stimulate students' ability to master cooperative learning techniques and critical thinking skills.

The analysis demonstrates a strong correlation between STEM literacy and computational thinking skills among STEM education students. Proficiency in STEM subjects often lays the groundwork for developing computational thinking abilities, as concepts such as logical reasoning, abstraction, and algorithmic problem-solving are inherent in both domains. Furthermore, students who excel in STEM literacy tend to exhibit higher levels of computational thinking, indicating a symbiotic relationship between these skill sets. The correlation findings highlight the interconnectedness of various STEM concepts and practices and their association with computational thinking skills.

Educators should integrate activities and instructional strategies that foster creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving into STEM curricula to promote computational thinking effectively. Furthermore, the strong correlations between interaction technologies and STEM concepts/practices suggest the importance of leveraging technology-enhanced learning environments to support computational thinking and STEM education. By incorporating interactive technologies and real-world contexts into instructional design, educators can create engaging learning experiences that facilitate the development of computational thinking skills among students. Overall, these findings underscore the importance of a holistic approach to STEM education that integrates diverse concepts, practices, and technologies to foster computational thinking and prepare students for success in the digital age.

Meanwhile this study findings can be applicable in TVET settings; TVET programs need to incorporate STEM literacy and computational thinking into their curricula. This includes embedding these concepts into practical and theoretical lessons, ensuring that students not only understand the basics but also apply them in real-world scenarios. Educators in TVET must be trained in STEM disciplines and computational thinking. This might involve continuous professional development programs, workshops, and courses to keep educators updated with the latest advancements and teaching methodologies in TVET and STEM areas. As well as, TVET education should emphasize hands-on, project-based learning where students can engage in real-world problem-solving using STEM and computational thinking skills and its helps to developing critical thinking, creativity, and practical skills that are essential for the modern workforce. Encouraging students to think innovatively and entrepreneurially can prepare them to create and adapt to new technologies. TVET programs should foster an environment where students can develop and test their ideas, potentially leading to new startups and innovative solutions.

6. Conclusion

This research examines public universities in Malaysia who's offer STEM education fields students' computational thinking and STEM literacy level. As well as, the relationship between STEM literacy and computational thinking. Students have a moderate level of computational thinking in creativity, cooperative learning, critical thinking and algorithmic thinking whereas the level of mastery for problem solving is at the high level. However, students have moderate level of STEM Literacy. The study also found that no significant differences in the level of computational thinking occurred between the innovative methods used in the STEM classroom so most of the teaching method such as Flipped classrooms, Hybrid learning environments, Gamified language learning, Interactive whiteboards and Problem-based learning help teachers to promote the computational thinking and STEM literacy in the digital age especially with STEM students. Meanwhile the study confirmed there is strong positive relationship between computational thinking and STEM literacy.

The insights gained from this study have several implications for promoting STEM literacy and computational thinking in the digital age. Firstly, educators should prioritize the integration of innovative teaching methods that engage students in active learning experiences and foster critical thinking skills. By incorporating hands-on projects, problem-solving challenges, and collaborative activities, instructors can create an environment conducive to developing both STEM literacy and computational thinking. Secondly, curriculum designers and policymakers should emphasize the importance of interdisciplinary approaches to STEM education, recognizing the interconnected nature of STEM disciplines and the need for holistic skill development. By breaking down silos between subjects and promoting cross-disciplinary collaboration, educational institutions can better prepare students to address complex real-world problems that require both STEM knowledge and computational thinking skills. In conclusion, advancing STEM literacy and computational thinking in the digital age requires a multifaceted approach that involves assessing current levels, understanding the relationship between these domains, and leveraging innovative teaching methods to enhance learning outcomes. By empowering students with strong foundational knowledge in STEM subjects and robust computational thinking abilities, we can equip the next generation of innovators and problem solvers to thrive in an increasingly complex and technology-driven world.

Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia through Contract Grant (Vot Q615)

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **The idea, data analysis, conceptual framework, collecting data and findings, writing the final report:** Nofouz Mafarja; **literature review:** Mimi Mohaffyza Mohamad; **collecting data, and Editing:** Hutkemri Zulnaidi; **literature review:** Haryanti Mohd Affandi

References

- Ahumada, V., Peñabaena-Niebles, R., Salatarin, J., & Amaris, S. (2022, September). Design of a Mobile Application to encourage Women's participation in STEM careers. In *2022 XII International Conference on Virtual Campus (JICV)* (pp. 1-4). IEEE.
- Albano, G., Mollo, M., Polo, M., & Marsico, G. (2022). Dialogical interactions mediated by technology in mathematics education. *Dialogic Pedagogy: A Journal for Studies of Dialogic Education*, 10, DT22-DT40.
- Alyahya, D., & Alotaibi, A. (2019). Computational thinking skills and its impact on TIMSS achievement: An Instructional Design Approach. *Issues and Trends in Educational Technology*, 7. https://doi.org/10.2458/azu_itet_v7i1_alyahya
- Antoniuk, L., & Zasiadivko, V. (2023). Digital Literacy and Technologies for Education: Principles and Tools. *Grail of Science*, 26, 249-252.
- Asl. A. H. P. (2017). The status of modern teaching methods in the educational system of Iran. *IJSMR Arch Educ Pedagogical Sci*, 3, 16-26.
- Asrizal, A., N, A., Festiyed, F., Ashel, H., & Amnah, R. (2023). STEM-integrated physics digital teaching material to develop conceptual understanding and new literacy of students. *Eurasia Journal of Mathematics, Science and Technology Education*, 19(7), em2289. <https://doi.org/10.29333/ejmste/13275>
- Bakar, A. Y. A., & Mahmud, M. I. (2020). Profiling of aspiration and interest towards STEM and TVET careers among lower secondary students: A Malaysian case study. *Journal for the Education of Gifted Young Scientists*, 8(1), 489-500.
- Barragán Moreno, S., & Guzmán Rincón, A. (2022). Conceptual Model for Assessment in STEM Subjects in Higher Education. *TECHNO REVIEW. International Technology, Science and Society Review /Revista Internacional De Tecnología, Ciencia Y Sociedad*, 11(1), 41-55. <https://doi.org/10.37467/gkarevtechno.v11.3085>
- Baterna, H.B., Mina, T.D.G., & Rogayan, D.V. Jr. (2020). Digital literacy of STEM senior, high school students: Basis for enhancement program. *International Journal of Technology in Education (IJTE)*, 3(2), 105-117.
- Braun, D., & Huwer, J. (2022). Computational literacy in science education—A systematic review. *Front. Educ.* 7, 937048. doi: 10.3389/educ.2022.937048
- Bravo, E. I. (2021). *Culture and Context's Influence on Hispanic Undergraduates' Perceptions of Their Persistence toward STEM Degree Attainment*. FIU Electronic Theses and Dissertations, 4793. <https://digitalcommons.fiu.edu/etd/4793>
- Cansu, F. K., & Cansu, S. K. (2019). An overview of computational thinking. *International Journal of Computer Science Education in Schools*, 3(1), 17-30. <https://doi.org/10.21585/ijcses.v3i1.53>
- Chamrat, S., Manokarn, M., & Thammapruteep, J. (2019). STEM literacy questionnaire as an instrument for STEM education research field: Development, implementation and utility. *AIP Conference Proceedings*. 2081(1), 030013.1-9.
- Chan, F. L., & Mohammad, F. S. (2019). ICT Integration practices of STEM teachers in TVET. *International Journal of Recent Technology and Engineering*, 8(4), 11011-11015.
- Chien, Y. H., Chang, Y. J., Huang, H., Lin, H. C., & Chien, J. T. (2023, July). Using Interactive Flat Panel Display for STEM Education Based on SAMR Model. In *International Conference on Human-Computer Interaction* (pp. 225-234). Cham: Springer Nature Switzerland.
- Christou, E., Parmaxi, A., Economides, A. A., Perifanou, M., Manchenko, M., & Mazaj, J. (2022, March). Challenges and good practices in STEM: A systematic review and implications for higher education institutions. In *2022 IEEE Integrated STEM Education Conference (ISEC)* (pp. 215-220). IEEE.

- CSTA. (2017). *CSTA K-12 Computer Science Standards*. <http://www.csteachers.org/standards>
- Doleck, T., Bazelais, P., Lemay, D., Saxena, A., & Basnet, R. (2017). Algorithmic thinking, cooperativity, creativity, critical thinking, and problem solving: exploring the relationship between computational thinking skills and academic performance. *Journal of Computers in Education*, 4, 355–369 <https://doi.org/10.1007/s40692-017-0090-9>
- Eren, E., & Dökme, İ. (2022). Evaluation of STEM Applications Used in Science Education. *Muğla Sıtkı Koçman University Faculty of Education Journal*, 9(2), 669-681. <https://doi.org/10.21666/muefd.1080617>
- Gale, T. (2021). Contextualized STEM workplace learning in career centered educational training. *New Directions for Community Colleges*, 2021(193), 71-81.
- Govender, I. (2022). *Research status in computational thinking in STEM education*. In *Advances in Research in STEM Education*. Intech Open.
- Grover, S., & Pea, R. (2017). Computational Thinking: A Competency Whose Time Has Come. *Computer Science Education*, 3, 20-38. <https://doi.org/10.5040/9781350057142.ch-003>
- Hao, M., Luo, E., Chen, Y., Wu, Y., Li, C., Chen, S., Gao, H., Bian, H., Wei, L., & Zhang, X. (2022). STEM: A Method for Mapping Single-cell and Spatial Transcriptomics Data with Transfer Learning. *bioRxiv*, 2022-09. <https://doi.org/10.1101/2022.09.23.509186>
- Hilyana, F. S., Ermawati, D., & Riswari, L. A. (2023, February). Analysis of STEM Ability and Digital Literacy of Students for Development of STEM-Based Digital Assessment Applications for Prospective Digitally Capable Teachers. In *ICONVET 2022: Proceedings of the 5th International Conference on Vocational Education and Technology, ICONVET 2022, 6 October 2022*, Singaraja, Bali, Indonesia (p. 266). European Alliance for Innovation.
- Hladik, S. (2022). *Facilitation in informal STEM education as a complex practice*. In *Oxford Research Encyclopedia of Education*.
- Huang, X., Erduran, S., Luo, K., Zhang, P., & Zheng, M. (2022). Investigating in-service teachers' STEM literacy: the role of subject background and gender. *Research in Science & Technological Education*, 1–21. <https://doi.org/10.1080/02635143.2022.2153243>
- Hulai, O. I. (2021). STEM concept in the work of the materials research groups of the small academy of sciences. *Scientific Notes of Junior Academy of Sciences of Ukraine*, 3(19), 10–19. <https://doi.org/10.51707/2618-0529-2020-19-02>
- Jaramillo-Arévalo, M., Alvarez-Risco, A., De-La-Cruz-Diaz, M., de las Mercedes Anderson-Seminario, M., & Del-Aguila-Arcentales, S. (2023). *Digital Tools to Promote STEM Education in New Normality*. In *Sustainable Management in COVID-19 Times* (Vol. 30, pp. 107-121). Emerald Publishing Limited.
- Kamonjo, F., & Wamuga, J. (2022). *Empowering Women through TVET Training in Male Dominated Trades: A Project Supported by Canadian Embassy at Nakuru Training Institute, Kenya*, 1-9.
- Khalil, N., & Osman, K. (2017). STEM-21CS Module: Fostering 21st Century Skill through Integrated STEM. *K-12 STEM Education*, 3(3), 225-233.
- Kong, S., Chiu, M. M., & Lai, M. (2018). A Study of Primary School Students' Interest, Collaboration Attitude, and Programming Empowerment in Computational Thinking Education. *Computers & Education*, 127, 178-189.
- Korkmaz, Ö., & Bai, X. (2019). *Adapting Computational Thinking Scale (CTS) for Chinese High School Students and Their Thinking Scale Skills Level*. Participatory Educational Research.
- Korkmaz, Ö., Çakir, R., & Ozden, M. (2017). A validity and reliability study of the Computational Thinking Scales (CTS). *Computers in Human Behavior*, 72. <https://doi.org/10.1016/j.chb.2017.01.005>
- Korucu, A. T. (2017). Examination of the Computational Thinking Skills of Students. *Journal of Learning and Teaching in Digital Age*, 2(1), 11–19.
- Kostøl, K. B., & Remmen, K. B. (2022). A qualitative study of teachers' and students' experiences with a context-based curriculum unit designed in collaboration with STEM professionals and science educators. *Disciplinary and Interdisciplinary Science Education Research*, 4(1), 26.

- Kulakoglu, B., & Kondakci, Y. (2023). STEM Education as a Concept Borrowing Issue: Perspectives of School Administrators in Turkey. *ECNU Review of Education*, 6(1), 84-104.
<https://doi.org/10.1177/20965311221107390>
- Kules, B. (2016). Computational thinking is critical thinking: Connecting to university discourse, goals, and learning outcomes. *Proceedings of the Association for Information Science and Technology*, 53(1), 1-6.
<https://doi.org/https://doi.org/10.1002/pra2.2016.14505301092>
- Lapammu, S., & Mahamod, Z. (2018). The Level of Knowledge, Attitudes, and Readiness Form 4 Students to The Using of Virtual Learning Environment VLE Frog in Malay Language Learning. *Malay Language Education Journal-MyLEJ*, 8(1), 53-62.
- Law, K. E., Karpudewan, M., & Zaharudin, R. (2021). Computational thinking in STEM education among matriculation science students. *Asia Pacific Journal of Educators and Education*, 36, 177-194.
<https://doi.org/10.21315/apjee2021.36.1.10>
- Lay, A.-N., & Osman, K. (2018). Developing 21st Century Chemistry Learning through Designing Digital Games, *Journal of Education in Science. Environment and Health (JESEH)*, 4(1), 81-92.
- Lemay, D.J., Basnet, R. B., Doleck, T., Bazelais, P., & Saxena, A. (2021). Instructional interventions for computational thinking: Examining the link between computational thinking and academic performance. *Computers and Education Open*, 2, 100056.
<https://doi.org/https://doi.org/10.1016/j.caeo.2021.100056>
- Liu, S. J., Zhou, S. N., Xu, S. R., & Xiao, H. (2022). Exploring Effect on Primary School Students' STEM Attitude Determined via Structural Equation Modeling. *Journal of Baltic Science Education*, 21(6), 1052-1068.
- Ludwig, M., Barlovits, S., Caldeira, A., & Moura, A. (Eds.). (2023). Research On STEM Education in the Digital Age: *Proceedings of the ROSEDA Conference (Vol. 6)*. WTM-Verlag Münster.
- Macanas, G.A., & Rogayan, D.V., Jr. (2019). Enhancing elementary pupils' conceptual understanding on matter through Sci-vestigative Pedagogical Strategy (SPS). *Participatory Educational Research*, 6(2), 206-220.
<http://dx.doi.org/10.17275/per.19.22.6.2>
- Markandan, N., Osman, K., & Halim, L. (2022). Integrating computational thinking and empowering metacognitive awareness in STEM education. *Frontiers in Psychology*, 13, 872593.
- Martynenko, O. O., Pashanova, O. V., Korzhuev, A. V., Prokopyev, A. I., Sokolova, N. L., & Sokolova, E. G. (2023). Exploring attitudes towards STEM education: A global analysis of university, middle school, and elementary school perspectives. *EURASIA Journal of Mathematics, Science and Technology Education*, 19(3), em2234.
- Miller, B. G., & Roehrig, G. (2018). Indigenous cultural contexts for STEM experiences: Snow snakes' impact on students and the community. *Cultural Studies of Science Education*, 13, 31-58.
- Mindetbay, Y., Bokhove, C., & Woollard, J. (2019). What is the Relationship between Students' Computational Thinking Performance and School Achievement? *International Journal of Computer Science Education in Schools*, 2(5), 3-19. <https://doi.org/10.21585/ijcses.v0i0.45>
- Missiroli, M., Russo, D., & Ciancarini, P. (2017). Cooperative Thinking, or: Computational Thinking Meets Agile. *2017 IEEE 30th Conference on Software Engineering Education and Training (CSEE&T)*, 7-9 Nov.
- Miteva, M., Zlatanovska, B., & Kocaleva, M. (2022). Some examples for teaching Mathematics in STEM context. *STEM Education Notes*, 1(2), 31-39.
- Morgacheva, N., Sotnikova, E., Shcherbatykh, S., & Shcherbatykh, L. (2022, November). Interactive technologies of teaching disciplines of the natural science cycle as a means of forming a socially adapted student's personality. In *AIP Conference Proceedings* (Vol. 2647, No. 1). AIP Publishing.
- Muntean, C. H., Bogusevski, D., & Muntean, G. M. (2019). *Innovative technology-based solutions for primary, secondary and tertiary STEM education*. Paragon Publishing.
- Nasir, M. A., Talib, R., Latif, A. A., Hanid, M. F. A., & Harmeni, H. A. (2023). STEM Productive Learning of Lower Secondary School in Southern Zone, Malaysia. *International Journal of Learning, Teaching and Educational Research*, 22(2), 281-301.
- Nikolopoulou, K. (2023). STEM activities for children aged 4-7 years: teachers' practices and views. *International Journal of Early Years Education*, 31(3), 806-821.

- Ochkov, V., Vasileva, I., Borovinskaya, E., & Reschetilowski, W. (2023). Application of STEM Technologies on the Example of the Problem of a Thread with a Load. *Mathematics*, 11(12), 2755.
- Okoye, K., & Chijioke, U. (2020). "STEM Education and TVET: A Synergistic Approach for Workforce Development. *Journal of Technical Education and Training*, 12(3), 15-27.
- Özgür, H. (2020). Relationships between Computational Thinking Skills, Ways of Thinking and Demographic Variables: A Structural Equation Modeling. *International Journal of Research in Education and Science*, 6, 299-314. <https://doi.org/10.46328/ijres.v6i2.862>
- Paf, M., & Dinçer, B. (2021). A Study of the Relationship between Secondary School Students' Computational Thinking Skills and Creative Problem-Solving Skills. *Turkish Online Journal of Educational Technology*, 20, 1-15.
- Ploisawaschai, S. (2022, July). The Use of Digital Technologies for Reading Tests by STEM Learners. In *2022 7th International STEM Education Conference (iSTEM-Ed)* (pp. 1-4). IEEE.
- Qingduan, F., Zhongtuan, Z., & Guoqiang, W. (2021, August). Exploration and Practice of College Mathematics Teaching Based on STEM Education Concept. In *2021 5th International Seminar on Education, Management and Social Sciences (ISEMSS 2021)* (pp. 897-901). Atlantis Press.
- Ramli, F. N. A., & Arsad, N. M. (2023). STEM Teacher Digital Literacy: Relationship Between Digital Literacy and Technology Integration in Teaching and Learning Post COVID-19. *Journal of Nusantara Studies (JONUS)*, 8(2), 316-333.
- Ran, H., Shen, J., Smith, B. E., & Wang, C. (2023). Creating Digital Sci-Fi Narratives through Multimodal Composing to Promote Adolescent Students' STEM Education. *Disciplinary and Interdisciplinary Science Education Research*, 5(1), 7.
- Rehman, A., Burki, M. H. K., & Khan, S. (2022). Literacy in the Digital Age and Pakistani Youth. *Journal of Social Sciences Review*, 2(4), 260-272.
- Richardo, R., Dwiningrum, S. I. A., Wijaya, A., Retnawati, H., Wahyudi, A., Sholihah, D. A., & Hidayah, K. N. (2023). The impact of STEM attitudes and computational thinking on 21st-century via structural equation modelling. *International Journal of Evaluation and Research in Education*, 12(2), 571-578.
- Rodriguez, B., Kennicutt, S., Rader, C., & Camp, T. (2017). Assessing Computational Thinking in Cs Unplugged Activities. *SIGCSE*, 501-506.
- Saad, A. (2020). Students' Computational Thinking Skill through Cooperative Learning Based on Hand-on, Inquiry-based, and Student-centric Learning Approaches. *Universal Journal of Educational Research*, 8(1), 290-296.
- Sabo, H. C., Odden, T. O. B., & Gregers, T. F. (2022, September). Challenges of preparing secondary STEM pre-service teachers in computational thinking. In *Proceedings of the Physics Education Research Conference (PERC)* (pp. 395-400).
- Sattar, F., & Nawaz, M. (2023, May). Developing Computational Thinking in STEM Education with Drones. In *2023 IEEE Global Engineering Education Conference (EDUCON)* (pp. 1-5). IEEE.
- Schietroma, E. (2019). Innovative STEM lessons, CLIL and ICT in multicultural classes. *Journal of e-Learning and Knowledge Society*, 15(1).
- Shorbaji, N. A., Atun, R., Car, J., Majeed, A., & Erica, W. E. (2015). *learning for undergraduate health professional education-A systematic review informing a radical transformation of health workforce development*. Switzerland: World Health Organization.
- Sirakaya, M., Alsancak Sirakaya, D., & Korkmaz, Ö. (2020). The Impact of STEM Attitude and Thinking Style on Computational Thinking Determined via Structural Equation Modeling. *Journal of Science Education and Technology*, 29(4), 561-572. <https://doi.org/10.1007/s10956-020-09836-6>
- Szczygieł, M. (2022). Math Attitude and Math Anxiety of STEM Students Needs More Attention. *Polish Psychological Bulletin*, 53(3).
- Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in science education*, 48, 1273-1296.

- Tang, K.-Y., Chou, T.-L., & Tsai, C.-C. (2020). A Content Analysis of Computational Thinking Research: An International Publication Trends and Research Typology. *The Asia-Pacific Education Researcher*, 29(1), 9-19. <https://doi.org/10.1007/s40299-019-00442-8>
- Tenney, K., Stringer, B. P., LaTona-Tequida, T., & White, I. (2023). Conceptualizations and limitations of STEM literacy across learning theories. *Journal of Microbiology & Biology Education*, 24(1), e00168-22.
- Tieliezhkina, O., Naumenko, L., Zhyglo, O., Babkina, M., & Voloshyn, M. (2022). Linguistic innovations in the educational process of universities. *Revista Tempos e Espaços em Educação*, 15(34).
- Tikly, L., Vogel, E., & Kurvers, C. (2020). *Boosting Gender Equality in Science and Technology: A Challenge for TVET Programmes and Careers*. UNESCO-UNEVOC International Centre for Technical and Vocational Education and Training.
- Tikva, C., & Tambouris, E. (2021). Mapping computational thinking through programming in K-12 education: A conceptual model based on a systematic literature Review. *Computers & Education*, 162, 104083. <https://doi.org/10.1016/j.compedu.2020.104083>
- Tippett, C. D., McDermott, M. A., & Milford, T. M. (2023). The multimodal affordances of language in STEM education. In *International Encyclopedia of Education* (pp. 42-49). Elsevier Ltd
- UNESCO. (2021). *Reimagining TVET in a post-pandemic world*. Paris: UNESCO.
- Wang, C., & Shen, J. (2023). Technology-enhanced collaborative learning in STEM. *International Encyclopedia of Education*, 207-214. <https://doi.org/10.1016/B978-0-12-818630-5.13005-2>
- Wong, G., & Jiang, S. (2018). Computational Thinking Education for Children: Algorithmic Thinking and Debugging. *2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)*, 328-334, doi: 10.1109/TALE.2018.8615232
- World Bank. (2020). *Skills for a Changing World: Transforming Education for Global Opportunities*. Washington, DC: World Bank.
- Xenakis, A., Avramouli, M., Sabani, M., Savvas, I., Chaikalis, C., & Theodoropoulou, K. (2023, May). Quantum Serious Games to Boost Quantum Literacy within Computational Thinking 2.0 Framework. In *2023 IEEE Global Engineering Education Conference (EDUCON)* (pp. 1-9). IEEE.
- Yadav, A., Stephenson, C., & Hong, H. (2017). Computational thinking for teacher education. *Communications of the ACM*, 60, 55-62. <https://doi.org/10.1145/2994591>
- Yağcı, M. (2018). A Valid and Reliable Tool for Examining Computational Thinking Skills. *Education and Information Technologies*, 24(1), 929-95.
- Young-Sik, J., & Young-Hoon, S. (2019). The Effect of Network-Based PUMA Teaching-Learning Model on Information Literacy, Computational Thinking and Communication Skills. *Universal Journal of Educational Research*, 7(5A), 103-113, 2019.
- Yurchenko, A., Yurchenko, K., Proshkin, V., & Semenikhina, O. (2022). World Practices of STEM Education Implementation: Current Problems and Results. *International Journal of Research in E-learning*, 8(2), 1-20.