Developing Computational Thinking Competencies through Constructivist Argumentation Learning: A Problem-Solving Perspective

Xin Pei Voon, Su Luan Wong, Lung-Hsiang Wong, Mas Nida Md. Khambari, and Sharifah Intan Sharina Syed-Abdullah

***Abstract*—Argumentation is a scientific literacy practice focused on developing scientific thinking skills associated with problem-solving. As computing has become an integral part of our world, computational thinking skills are requisite for successful problem-solving. The significant effect of computational thinking applications on the efficacy of scientific literacy practices is increasingly acknowledged. In this article, we propose a framework that conceptualizes the constructivist argumentation as a context for problem-solving by applying five computational thinking dimensions, viz. algorithmic design, decomposition, abstraction, evaluation, and generalization. The framework emphasizes two aspects, students' problem-solving capability and quality of argumentation. Drawing from the literature on scientific argumentation and problem-solving, we argue that the application of computational thinking dimensions in science learning is currently overlooked in the instructional environment. To nurture higher order thinking skills and to engage effective problem-solvers, our framework incorporates four Computational Thinking-Argumentation design principles to support instructional innovation in the teaching and learning of science at the secondary school level, viz. 1) developing problem-solving competencies and building capability in solving uncertainties throughout scientific inquiry; 2) developing creative thinking and cooperativity through negotiation and evaluation; 3) developing algorithmic thinking in talking and writing; 4) developing critical thinking in the processes of abstraction and generalization.**

***Index Terms*—Argumentation, computational thinking, computational thinking competencies, constructivist, problem-solving.**

I. Introduction

Argumentation is fundamental to scientific activities. It is, essentially, informal reasoning central to the intellectual ability involved in solving problems, constructing arguments, evaluating evidence, discussing alternative explanations, making judgments and decisions, as well as formulating ideas and beliefs [1], [2]. Argumentation thus supports cognitive and metacognitive processes, develops communicative and critical thinking skills, achieves scientific literacy, and improves the language (verbal and written) of science and scientific culture [3].

Argumentation is a critical skill desired in K–12 students [4], and students at the middle school are at a critical age when argumentation skills need to be developed [5], [6]. Theoretically, young students are supposed to be able to comprehend and construct arguments [7]. However, empirical evidence does not support these expectations. Studies have reported that students are not capable of generating valid evidence to support their claims [8]. Additionally, they are not competent in analysing and debating their arguments [9], or revising them based on peer comments [10]. Therefore, specific strategies should be implemented to help teachers integrate instructional strategies into their pedagogical approaches to develop their students' argumentation [11] and problem-solving skills [12]. In this article, we propose four Computational Thinking-Argumentation design principles to support teachers' instructional innovation in science education.

In recent years, Computational Thinking (CT) has emerged as a 21st century critical competency, attracting the attention of educational researchers and practitioners. Some scholars explain it as a problem-solving approach [13], [14], others highlight CT as a cognitive process [15]. The acquisition of CT is vital for Computer Science (CS) and, essentially, all sciences [16]. Thus, individuals should explore and acquire CT competencies [17] to function effectively in the digitalized world.

A. Bounding Our Focus: Developing Computational Thinking Competencies through Argumentation Learning

This article focuses on "argumentation as a problem-solving context", and the relevant elements include "CT dimensions" [18], "CT competencies" [19] and "Private and public landscape of learning" [20]. We aim to distil a framework from the copious literature on CT in education to conceptualize constructivist argumentation learning as a problem-solving context. The application of CT in argumentation thus makes CT competencies useful in the classroom. The following sections will unpack and explain the framework of argumentation learning with the application of five CT dimensions, viz. algorithmic design, decomposition, abstraction, evaluation, and generalization. The article then proposes CT-Argumentation learning design principles to develop students' CT competencies, viz. critical thinking, problem-solving, cooperativity, algorithmic thinking, and creativity.

Manuscript received September 19, 2021; revised December 23, 2021.

Xin Pei Voon, Su Luan Wong, Mas Nida Md. Khambari, and Sharifah Intan Sharina Syed-Abdullah are with Universiti Putra Malaysia, Malaysia (e-mail: xinpeivoon@gmail.com, suluan@upm.edu.my, khamasnida@upm.edu.my, sharifahintansharina@upm.edu.my).

Lung Hsiang Wong is with Nanyang Technological University, Singapore (e-mail: lhwong.acad@gmail.com).

doi: 10.18178/ijiet.2022.12.6.1650

II. Constructivist View of Science as Problem-Solving

The constructivist view in science learning emphasizes the importance of the individual's attempt to construct meaning and make sense of a concept or phenomenon. Hence, the individual making sense of any event needs to take into account not only the situation itself but also his or her purpose and the process of active meaning construction [21]. These constructions are seen to be tentative models as the individual, aided by experience, would make modifications whenever necessary. The constructivist view of teaching and learning science emphasizes the individual's responsibility and effort required throughout the process of meaning construction [21]. In this context, the teacher's critical role is to facilitate activities that will guide the learner to develop higher-order thinking skills (HOTS) [22]. Teachers are key actors who need to shape students' thinking when implementing new approaches to learning [23].

The constructivist approach to science education stresses that while students need to construct a rich and varied sample of scientific content knowledge, they also have to understand and experience the processes that produce the knowledge to solve problems. Researchers [24] who study heuristics for discovery and theory construction often associate science with problem-solving, and thus investigate scientific problem-solving as a particular case of general problem-solving. Furthermore, the "science as problem-solving" perspective is advocated by scholars who study the psychology of scientific reasoning [25]. Hence, it is essential to "infuse" problem-solving into the science curriculum by introducing a set of heuristic techniques that learners can use in their scientific endeavours [26].

Teachers' tactful inquiry instructions would help students construct meaning and reasoning when learning scientific concepts. The goal is to ensure that students are able to think like scientists rather than just act like scientists. When teachers explicitly acknowledge science as problem-solving while acting as facilitators in a problem-solving community, what they do and say would encourage students to overcome learning challenges and foster problem-solving skills [27].

A. Constructivist Argumentation: Individual Cognitive Dynamic versus Social Interaction

In argumentation, scholars emphasize the importance of engaging students in group or whole-class discussion [28], [29]. Some scholars stress the mechanisms in scaffolding individual students' construction of written arguments [30], [31]. The public landscape focuses on active knowledge construction through social interaction and the physical world; private learning occurs when students are in self-reflection mode, thinking about their interaction or learning process [32].

In terms of private landscape, individual argumentation includes a cyclic-cognitive process of making a claim, marshalling evidence to substantiate the claim, and evaluating evidence to determine the validity of the claim [33] by weighing the evidence and considering relevant scientific theories to back the claim [32]. Thus, one would experience the dissonances of the cognitive process while comparing and contrasting evidence to validate the claim.

From the perspective of the public landscape, argumentation in the social environment encourages students to construct, evaluate, critique, defend, and challenge their peers throughout their conversation [34]. The scholar stresses the importance of social interaction when constructing arguments [4]. Learners' scientific understanding is enhanced when they are able to share tasks or problems during social activities. Hence, the dialogic process that involves 'person-in-conversation' facilitates the individual's meaning-making. Knowledge can be co-constructed, or (re)constructed as learners expand their understanding of a particular concept or share their problems through 'collaborative argumentation' [35].

Cognitive and social processes are critical epistemic practices that nurture the construction of scientific knowledge and promote the articulation of alternative perspectives, reasoning, cognitive dissonance, and learning reflection [36]. In essence, this is the belief underlying the view that argumentation involves both cognitive dynamics and social interaction processes. Along this line, learners experience cognitive processes when they make meaningful construction of their argument while interacting and debating with others.

Furthermore, social interaction stimulates higher-order thinking (HOT) skills embedded in argumentation [37]. Frequent collaboration and communication help learners attain a more in-depth level of thinking [38] since the collaborative inquiry-based learning context has a direct effect on HOTS [39]. As such, problem-solving and decision-making competencies can be developed by frequently engaging students in discussions on topical scientific issues in their daily lives or social problems that are prevalent [2].

B. Reconceptualising Constructivist Argumentation Learning from the Problem-Solving Perspective

This article reconceptualizes argumentation from the problem-solving perspective, consistent with researchers, philosophers and science educators [12], [40], [41], [42]. Argumentation enables individuals to be problem-solvers, to be able to identify alternative viewpoints and opinions, develop and select reasonable solutions, and to provide relevant data and evidence to support the purported solution to the problem at hand [43].

Three types of argument interventions can be adopted in a problem-solving context [44]: 1) argument structure intervention, i.e., learning to use the structure of argument and apply it across various explanatory activities, 2) immersion-oriented intervention, i.e., using the argument as a learning tool (integrated argument as a component of scientific investigations), and 3) science- and society-based intervention using socio-scientific issues, i.e., getting students to experience the interaction between science and society-based issues in scientific argumentation. The first two interventions focus on knowledge construction through problem-solving activities, whereas the third intervention emphasizes the use of socio-scientific issues to learn argumentation.

The future directions for studies on scientific argumentation should focus on teaching HOTS [41], such as problem-solving through argumentation [45], [46]. HOTS is defined as a critical thinking skill, logical thinking, reflectivity, metacognition, and creativity [47]. These capabilities will develop when people have problems that are not familiar, uncertainties, or a new phenomenon that requires solutions that have never been thought of before. As a result, the nurturing of HOTS among students guides them to think critically when attempting to solve problems. Acquisition of scientific knowledge is manifested when the learner is able to apply the new knowledge to another scenario by using various science process skills together with problem-solving skills [45], [48].

CT is a new problem-solving skill set that engages individuals to think critically and construct knowledge to solve complex problems [49]. Hence, in line with the concept of ‘CT as a problem-solving process’ [50], this article proposes argumentation as a learning context with the application of five CT dimensions. In this instance, CT is recognized as a way individuals think about problem-solving [16], and plays a complementary role in facilitating argumentation learning.

III. Framework of CT-Argumentation

A. Computational Thinking as a Problem-Solving Approach

The CT concept introduced by Papert [51] is aimed at developing cognitive ability in problem-solving through programming language [52]. In 2006, Wing expanded the concept of CT by defining it as a way that humans think about solving problems, adding that it is a fundamental skill suitable for almost everyone [16]. CT is rooted in unplugged (non-digital) human approaches to problem-solving [53], and can be taught using two approaches: (1) CT plugged approach, mediated by technologies, and (2) CT unplugged approach, without using digital tools [54]. In the proposed framework, the CT unplugged approach is employed.

CT involves product-oriented as well as problem-solving activities [18]. In other words, CT is a focused approach to problem-solving, with emphasis on the thinking aspect. It incorporates five thought processes that employ abstraction, decomposition, algorithmic design, evaluation, and generalization. These terms obtained a consensus in the literature and are well defined across disciplines [18]. Additionally, studies have shown positive results with learning gains by integrating the respective thought process in the learning of science [55], [56].

B. Framework of CT-Argumentation: Incorporation of Computational Thinking with Argumentation Practices

Studies have emphasized the need to break CT into “a set of well-defined and measurable concepts, skills or practices’’ [57] (p. 130) to overcome the challenges in advancing and integrating CT in the academic field. Valid CT measures are essential to evaluate the efficacy and value of integrating CT skills in the teaching and learning processes [58].

Fig. 2 illustrates our conceptualisation of the incorporation of CT dimensions in the learning process of scientific argumentation. The framework depicts CT-driven argumentation learning premises on private (individual) and public (social) landscapes. In terms of learning, students are engaged in written (individual) and spoken (social) argumentation scaffolded by CT dimensions to solve scientific problems. For teaching, argumentation is used as a problem-solving context guided by CT dimensions to develop CT competencies. Table I presents the role of CT dimensions in fostering students’ CT competencies. Teachers are the ‘change agents’ in the teaching reform process who decide on the critical aspects of learning and shape the nature of classroom instruction to make learning visible for students [59].

The ‘rotatable’ star in the framework (see Fig. 2) represents the cycle of thinking processes (abstraction, decomposition, algorithmic design, evaluation, and generalisation) without sequential order. The purpose of the five arrows radiating outward is to bring home the message that students experience the five dimensions of thought processes, leading them to develop the CT competencies that can be measured throughout their argumentation learning.

CT competencies are defined as the joint reflection of creativity, algorithmic thinking, critical thinking, problem-solving, cooperative thinking and communication skills [60]. Since communication skills are established in a cooperative environment, cooperativity can be categorised as one of the CT components [19]. It is expected that individuals in a team would communicate with each other as cooperativity is crucial to developing creative solutions for problems [19]. Within the frame conducted by scholars [19], an individual’s CT competencies can be defined and measured by examining creativity, cooperativity, critical thinking, algorithm thinking, and problem-solving skills using CT scales (CTS). To summarise, the application of the five dimensions of thought processes, viz. abstraction, decomposition, algorithmic design, evaluation, and generalisation into argumentation learning is aimed at developing CT competencies, viz. algorithm thinking, creative thinking, creativity, critical thinking, and cooperativity.

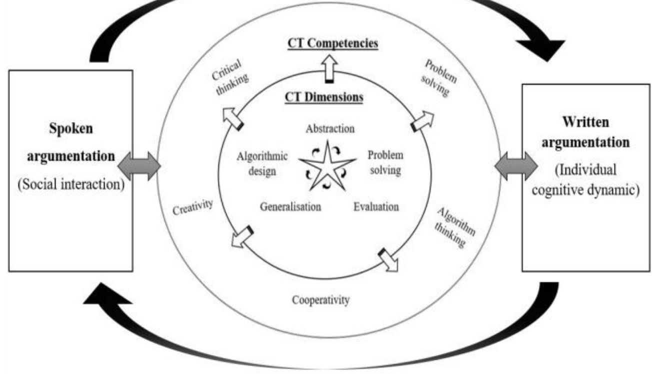

Fig. 2. The framework of CT-argumentation.

C. The Complementary Roles of Spoken and Written Argumentation

Spoken argumentation in the public landscape occurs when social interaction in a cooperative learning environment impacts the students’ cognitive development.

Additionally, engagement in spoken argumentation increases students' awareness of the claims and evidence, thus facilitating their knowledge construction [61]. On the other hand, the knowledge construction and written argumentation in the private landscape facilitate individual cognitive dynamics through meaning-making, reasoning, and learning reflection.

TABLE I: THE DEVELOPMENT OF CT COMPETENCIES THROUGH THE APPLICATION OF CT DIMENSIONS

Computational Thinking dimensions	Definition and description	Computational Thinking competencies
Abstraction	Focuses on hiding complexity and individuals' ability in conceptualising and then representing an idea or a process by foregrounding the essential aspects of the idea.	Critical thinking
Algorithmic design	Relates to the idea of procedural thinking, devising explicit instructions (or step-by-step procedure) for accomplishing tasks.	Algorithmic thinking
Evaluation	Concerns individual or group analysis: (1) when a problem is analysed and (2) when a solution is analysed. In the context of problems, the term 'analyse' fits the category of problem-solving; in the context of solutions, the term 'analyse' is interpreted as 'evaluate'.	Cooperativity, creative thinking
Generalisation	Concerns the ability to move from specific to broader applicability. It emphasises the step of recognising how small pieces of a solution may be reused (by recognising common patterns) and subsequently be applied to solve similar problems.	Critical thinking
Problem decomposition	Creates solutions by breaking problems down into smaller parts of particular functionality and sequencing the part to be solved (NRC, 2011).	Problem-solving

It has been suggested [62] that the operationalisation of argumentation is a combination of both construction and critique to systematically assess individual students' competency of written argument using a quantitative approach. Students did not engage in any dialogue while completing the tasks for the study [62]. However, spoken argumentation indirectly occurred as two clarifications were reported: Firstly, the results from the think-aloud interviews showed that the students did engage in a 'simulated dialogue' while completing their tasks; they were able to verbally describe which argument they agreed with more, especially when they were weighing multiple arguments, and ultimately constructing a defence of one and a critique of another. It has been pointed out that spoken argumentation occurs because students might engage in self-talk or inner dialogues [63]. Secondly, written arguments are often the foundation of the practice of (spoken) argumentation; scientists always practise (spoken) argumentation explicitly in writing, such as publishing an article. Therefore, the rubric used in written assessments (including spoken argumentation implicitly) measures students' ability in written argumentation and reflects how (spoken) argumentation is undertaken in the scientific community [62].

Social interaction among peers can be very motivating [64]. During spoken argumentation, students are aware of their peers' ideas, and this prompts them to become interested with the most defensible ideas. Social interaction supports content learning in several ways, such as engaging in a variety of explicit elaborative processes (e.g., explanation to promote learning) [36] and modification of ideas (or receiving learning support from others) [61]. Students learn from their peers during social interaction and the process of argumentation provides them with evidence of claims; this not only promotes a better understanding of ideas but also provides more reason to believe the claims they are developing [65]. Hence, spoken argumentation and written argumentation are complementary to each other, supporting and making sense of the claims.

D. Summary

Individual and social argumentation activities are integral to improving the students' scientific literacy and developing CT competencies. CT is a conceptual way to solve complex problems by "processing the information systematically, correctly, and efficiently" [66] (p. 261). Moreover, CT requires students to develop both domain-specific and problem-solving approaches [67].

Indeed, the 21st century sees a shift in the working world, from being labour intensive to being knowledge-based, relying on the knowledge of workers to drive innovation, entrepreneurship and dynamism of the country's economy. Henceforth, education should switch from emphasising domain-specific content mastery to 21st-century competencies such as creativity, critical thinking and problem solving [67]. For example, the Programme for International Student Assessment (PISA) evaluates problem-solving ability, targeting skills that enable students to successfully handle real-life problems, such as finding the shortest route between two cities without relying on domain-specific knowledge, for example, from mathematics [68]. Furthermore, vocational education prepares students for their careers by focusing on 1) the application of vocationally relevant knowledge in typical problem situations and 2) the awareness of potential problems associated with practical routines, problem-solving strategies and an encompassing set of personal and social competencies to overcome them [69]. This article explores the opportunities to scaffold the CT-Argumentation instructional design in facilitating the students' development of CT competencies through scientific argumentation. Scaffolds help to make tacit scientific argumentation rules more explicitly addressed to students so as to simplify the task to make it easier to achieve [70].

IV. OPPORTUNITIES

The following subsections present the four CT-Argumentation design principles aimed at fostering argumentation learning more effectively by providing students with opportunities to develop CT competencies. The four design principles are: a) developing problem-solving competencies and building capability to solve uncertainties throughout a scientific inquiry; b) developing creative thinking and promoting cooperativity through negotiation and evaluation; c) developing algorithm thinking in talking and writing; d) developing critical thinking in abstraction and generalisation. In practice, these opportunities are intricately related, but they are categorised separately to illuminate the role of each in instructional design. In recent years, some studies have been grounded in middle schools to address possible learning gains in science with the application of CT [55], [56]. These opportunities can be capitalised on as productive entry into argumentation, even among students in the early grades.

A. Design Principle 1: Developing Problem-Solving Competencies and Building Capability to Solve Uncertainties throughout a Scientific Inquiry

Fostering argumentation requires sensible use of evidence [71]. The study [71] reported that there is a need to 1) create the necessary conditions for students to connect claims and evidence so as to nurture their ability to use appropriate evidence to solve problems; 2) help teachers to design data-rich investigations for which multiple claims can be investigated and supported. For instance, teachers could ask their students to explain scientifically whether the objects observed using the microscope were living things. In order to carry out this task, the students would need to synthesise the data they have collected from their observations through the microscope. There could be different claims constructed based on the students' interpretations from their observations and different implicit definitions of a living thing. It is important to focus on the conflicts raised and to resolve them so that students can make progress in learning [72].

Project-based learning is another approach that involves data rich investigations which requires students to integrate and explain what is known and unknown using an abundance of data [73]. This approach to learning presents new challenges for students as they engage in authentic investigations. However, students could get overwhelmed by the richness of data and information [74], and they might fail to monitor their progress and findings [75]. To minimise problems in managing data-rich environments, students need external support to organise, articulate, and reflect upon ongoing ideas throughout long-term investigations [76].

Problem decomposition in the application of CT refers to breaking down a complex problem into manageable or more familiar sub-problems [77]. In this way, students would be able to better manage and solve complex phenomena. The earlier learning task regarding the observation under the microscope can also be used in this instance: the application of problem decomposition enables the students to break down the problem, clarify the underlying arguments for what constitutes a living thing, and evaluate specific evidence to support their claims. Decomposition involves finding structure in the problem and determining how the various components will fit together in the final solution. Problem decomposition seeks to focus not only on the ability to decompose a problem but also on composing the solution after the sub-problems have been addressed, modifying the solution later by changing individual components, and enabling the reuse of components in solving other similar problems.

Chen [20] (p. 55) states that "science is about managing uncertainty". From a cognitive perspective, uncertainty is interpreted as the individual's subjective awareness of the gap in knowledge that needs to be narrowed or bridged to make sense of a phenomenon [78]. The scholar defines this cognitive state as a "disequilibrium"; the individual recognises the conflict between what he already knows and what he encounters [79]. This experience of uncertainty prompts the individual to acquire new knowledge, skills, or solutions to resolve the problem of uncertainty [80].

Based on the microscope observation example cited earlier, we can expect different claims constructed by students based on their observations and interpretations resulting from uncertainty. Uncertainty provides the opportunity and space for argumentation, thus helping the development of scientific literacy and HOTS. HOTS can be developed through self-regulation in knowledge construction. [81]. Uncertainty is more than extracting students' prior knowledge through questioning and stimulating curiosity about issues raised during discussions [82]. The purpose of questioning is not to just get the correct solution but more importantly, to prompt uncertainty in students and to create a space for them to express their ideas, and gather more evidence to resolve their uncertainty [20]. Therefore, in preparing future-ready students to be scientifically literate, i.e., to be "learning how to think and practice like a scientist" [83] (p. 459), teachers should design and incorporate uncertainty in argumentation practices similar to the practices of scientists.

B. Design Principle 2: Developing Creative Thinking and Promoting Cooperativity through Negotiation and Evaluation

A complex question may trigger students to use copious data when constructing their claims. Nevertheless, it does not necessarily create a context that requires students to overcome their conventional ways of interacting with their peers' ideas [71]. The concept of scientific literacy can be mapped onto public and private landscapes mentioned earlier. In the science classroom, the public landscape suggests that negotiations allow students to exchange ideas and establish a consensus so that they can work together with their teacher as a community to solve conflicts and improve ideas. In contrast, in the private landscape, students are engaged in self-reflection on what makes sense to them through a comparison between external data and their existing knowledge, as well as arguments that arise [10]. Students would then develop coherent knowledge, thus further advancing their scientific literacy when engaging in both landscapes. Learning environments "designed to prompt argumentation should engage students in knowledge evaluation practices" [84] (p. 97), i.e., learning environments need to be conducive and supportive so that students will be encouraged to question and challenge ideas put forth by others. Classroom activities should make the goal of consensus-building explicit to students [71]. Activities that promote cooperativity can be explained as a structure of interaction designed to facilitate the accomplishment of a specific end product or goal through group work [85].

Evaluation in CT plays a critical role in ensuring successful moves between private and public landscapes. Before students reach a consensus, they need to analyse the questions and the solutions contributed by their peers. In the context of solutions, the term 'analyse' could be interpreted as 'evaluate' [18]. The activity should be structured and highlighted to gain insight on students' thinking and decision-making. For instance, if a disagreement occurs, the students need to work together to resolve the conflict. Moreover, the learning process facilitates the development of creative thinking as an individual's creative insight ''arises from a reintegration of already existing materials or knowledge, but when it is completed, it contains elements that are new'' [86] (p. 311). Such an approach involves social judgment [86]. For instance, the design of an "argument jigsaw" activity provides students with a question to work in pairs to construct an initial claim. They then join another pair to form a group of four to construct a joint explanation that they all endorse. New ideas may emerge during the discussion. This strategy aims to help students negotiate and evaluate the data used during their discussion; subsequently, they need to reflect on what they have learnt when revising their original claims. In this way, students are provided with an opportunity to summarise their learning internally [20] as well as draw on their connections with the new knowledge constructed.

C. Design Principle 3: Developing Algorithmic Thinking in Talking and Writing

The study suggested that the synergic use of talking and writing in the Science Talk-Writing Heuristic (STWH) based on two conditions, namely the use of talking and writing synergistically, and the use of talking and writing in sequence [20]. The latter refers to students completing one language task followed by another, either writing before talking or talking before writing.

Talking and writing simultaneously are often student-driven, occurring in collaborative group settings, especially when students defend their claim, evidence, or reasoning [20]. In this strategy, writing is used as a visual support or representation tool for the students' arguments [87]. Collaborative learning can be employed as a learning strategy to develop algorithmic thinking [88]. Algorithmic design can be used in a designated learning task with explicit instructions provided to facilitate students' participation in the talking and writing processes. The steps of argumentation using talking and writing that are helpful to enhance students' scientific literacy are as follows: 1) exploring the big idea and identifying problem, constructing claims (they may put them down on paper), 2) exploring their peers' arguments through group discussion (listening to their peers and critiquing their arguments), 3) comparing their argument with information from experts, and finally 4) revising and reflecting on their arguments [20]. Therefore, guided by these steps, algorithmic thinking can be developed throughout scientific inquiry as students generate questions, interpret data as evidence to support claims, and construct and critique evidence-based knowledge claims.

Algorithmic thinking occurs when the individual thinks in a purposeful and detailed manner to produce a solution in any subject [19]. From the teachers' perspective, understanding the rationale of the sequence of talking and writing allows them to facilitate their students' argumentation and guide them towards problem-solving. From the students' perspective, explicit instructions on how to construct an argument, participate in argumentation, and the sequence of learning activities promote their algorithm thinking in constructing and revising their argument throughout the writing and talking processes.

D. Design Principle 4: Developing Critical Thinking in Abstraction and Generalisation

There are two interrelated components to engage students in argumentation, viz. the big idea and the question(s) [20]. The big idea is the statement that encompasses the main objective of a particular lesson and the essential concepts of a particular unit. The inquiry question(s) should be aligned with the big idea to guide the study area, stimulate interest, and drive investigations and scientific arguments.

In terms of the big idea, the Science Writing Heuristic (SWH) approach states that students should "link arguments to the 'big ideas' of the topic being investigated" [89] (p. 140). These big ideas should be presented as generalisations related to the data constructed by students; however, they became "the major concepts the students leave the classroom with after completion of the unit" [89, p. 20). Thus, the study reported that more guidance is needed to support students in constructing generalisations that reflect their evidence-based understanding of phenomena [56].

"Critical thinking is reasonable reflective thinking focused on deciding what to believe or do." [90] (p. 180). The application of abstraction and generalisation is aimed at developing critical thinking. Before students generalise their claims, they need to create abstractions. Hence, they need to think critically by defining the scope or scale of the problem at hand, generating visualisations of data to communicate findings or ideas, or creating models to further understand or explore a given phenomenon [57]. It is imperative to understand the relationships between scientific practices and abstractions in CT [91]. Creating an abstraction requires students to conceptualise and subsequently represent an idea in more general terms by foregrounding the critical elements of the idea, while backgrounding less important aspects [57]. Abstraction is a crucial step before generalisation.

To be able to generalise, students are required to reflect critically by "incorporating the meaning in claims and extending the meaning beyond the particular data to which the claims are related" [56] (p. 2). Argumentation learning in the classroom should focus on generalisation because "science is fundamentally about theories, and theories are general explanations the quality of arguments indicating the degree to which extended meaning of some kind is warranted" [56] (p. 3). Generalisation in CT allows learners to recognise patterns and examine different parts of a problem, whether it is similar to something that has already been solved before, and extends or transfer the idea to other problem-solving settings. Generalisation is complementary to HOT, which involves critical and evaluative thinking, decision-making, knowledge transfer to similar situations [92]. The use of concept mapping has been suggested for the development of critical thinking and application of knowledge in new contexts; this is done by transferring students' knowledge to real-life situations [92]. It is important for students to be able to apply their understanding of science to solve problems [45].

To summarise, these four design principles (DP) are interdependent. The uncertainties in a complex problem motivate the argumentation by prompting the students to construct evidence-based claims (DP 1). Without argumentation activity that motivates teacher-to-students and student-to-student interactions, the private and public landscapes criteria become unnecessary because students do not need to negotiate and evaluate one another's argument(s) (DP 2). By understanding the sequence of activities required in the argumentation process, students will engage in more in- depth discussions, respond appropriately to one another's ideas and revise their arguments whenever necessary (DP 3). Finally, by understanding the components or structure of the argument, students can create abstractions and generalise their ideas by reflecting and comparing their evidence-based understanding of the phenomenon with experts (DP 4).

V. Discussion

The framework proposed in this article is aimed at developing CT competencies by engaging students in scientific argumentation practices. The design principles imply the structuring of argumentation as a problem-solving context with the application of CT to facilitate constructing and critiquing arguments within both public and private landscapes. In terms of problem-solving, "CT involves structuring and manipulating data sets to support the solution process" [93] (p. 1]). The processes reflect the cognitive structure of CT, which involves a strategic way of thinking and problem-solving [94] such as pattern recognition, breakdown or decomposition, and generalisation, abstraction, evaluation, and algorithmic thinking.

A. Contributions to Constructivist Argumentation Learning

Framing constructivist argumentation learning as processes of problem-solving, viz. constructing, sequencing, presenting, evaluating, critiquing and revising argument through the application of CT exposes new constituent practices that need to be taught. For instance, students should learn how to operationalise and rearrange the sequence of activities in argumentation, abstract and evaluate them before deciding what data to provide as evidence and how to structure them to support a claim. There is a high degree of complementary links between CT (problem-solving processes), constructivism and argumentation learning. The application of CT in constructivist argumentation learning is based on the following procedures: identify the problem, break it down into manageable steps, construct possible claims (solutions), participate in argumentation by following instructions in sequence to present the claims, evaluate and critique arguments put forth by others, and finally revise the original claims by creating abstractions as well as generalizable concepts.

The framework of CT-Argumentation provides students with the opportunity to scientifically examine their uncertainty by critically interpreting data using justifiable evidence, managing their uncertainty, negotiating ideas which conflict claims, and making scientific decisions with evidence. Finally, this framework shows that constructivist argumentation learning, problem-solving and CT are inextricably intertwined, as discussed in the learning design principles mentioned earlier. For instance, the students' algorithmic thinking can be developed when constructing arguments in problem-solving during the talking and writing processes.

To develop CT competencies, CT must first be considered a problem-solving process that can be applied to a particular context. In this article, the focus is on scientific argumentation learning. Our contribution shifts the focus on what CT is to the way CT can be taught, and how evidence of its acquisition can be observed as well as assessed in learners. It is crucial to move further by integrating CT across disciplines in K-12 education. Thus, the proposed framework serves as a scaffold to understand constructivist argumentation learning in a problem-solving context while developing CT competencies.

B. Relationship between Argumentation, Problem-Solving and Computational Thinking

The importance of problem-solving skills is increasingly acknowledged as evidenced by extensive research on this topic over the decades. Problem-solving can be explained as transforming from an unacceptable initial state to an acceptable or desirable final state by conquering obstacles [95]. The process requires individuals to operate using high-order thinking and reasoning. In supporting this, the scholar [96] states that CT processes can be assigned to Bloom's Taxonomy—Cognitive Domain levels. Decomposition can be assigned to the creation and analysis levels as learners need to create solutions by breaking down a problem into smaller parts based on particular functionality, and sequencing the parts to be solved [96]. This is then followed by an evaluation, i.e., the issue is assigned to the evaluation level; next, algorithm design is allocated to the synthesis level; subsequently, abstraction is allocated to the analysis level; finally, generalisation is assigned to the application level [96].

A key criterion for the achievement of scientific literacy is the capability to solve problems and make evidence-based decisions about current and future science applications while considering ethical issues and social implications [97]. Furthermore, there is a significantly close relationship between argumentation and problem-solving [12]; argumentation is explained as informal reasoning central to the intellectual ability involved in solving problems, making decisions, and formulating ideas and beliefs [1]. The importance of CT as a goal in science education is currently a favourite topic of discussion. Along this line, CT is a new problem-solving process that synthesises critical thinking and knowledge to solve complex problems [49]. The integration of CT into the science context presents students with a more authentic image of science; it also increases access to powerful modes of thinking and marketable skills for many careers. Therefore, the CT-Argumentation framework can develop HOT and CT competencies by engaging students in meaningful collaborative discussions and self-reflection.

VI. CONCLUSIONS

The proposed framework of CT-Argumentation and the design principles support teachers in engaging students' argumentation learning as a context of problem-solving through the private and public landscapes. Recent efforts have made visible the learning experience with the application of CT dimensions to help educators instantiate scientific activities; for instance, generalisation and algorithm thinking (algorithmic explanation) support the concept of 'science-as-practice enterprise' [55], [56].

With the design principles and scaffoldings provided for students and teachers, more empirical research will be required to substantiate which CT competencies are more productive in engaging students, and which strategies to support argumentation learning. In this article, the researchers propose that it will be more productive to begin by focusing on the intersections of a particular task and CT dimensions to be generalised based on the results of empirical studies.

Finally, research needs to emphasise the broader role of CT competencies in the K-12 education context. There is a need to introduce CT in academia [98], and more empirical studies are required to provide an informed perspective of the effects of CT skills on students' learning outcomes across disciplines. ''How and when should people learn this kind of thinking and how and when should we teach it?'' [14, p. 3720]. These efforts are crucial as they could provide more insights into the implications of CT in the teaching and learning process. Along this line, students need to be engaged in CT learning and ideas apart from the scientific argumentative contexts they used to construct, critique, and revise their argument. In order to frame a long-term agenda for developing CT-competencies, it is essential to ask: What can we hope students will construct and apply when they come across new concepts? How can students' HOTS be enhanced through problem-solving?

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Xin Pei Voon was the main author of the paper who wrote the major part of the paper. Su Luan Wong and Lung Hsiang Wong revised and edited the manuscript. Mas Nida Md. Khambari and Sharifah Intan Sharina Syed-Abdullah finalised the manuscript. All authors offered crucial ideas in conceptualising the research.

ACKNOWLEDGEMENT

The authors are grateful that the study is supported by the research grant from Universiti Putra Malaysia: Geran Putra Berfokus (6301001-10901).

REFERENCES

[1] J. S. Turner, "New directions in communications," *IEEE J. Sel. Areas Commun.*, vol. 13, no. 1, pp. 11-23, Jan. 1995.

[2] W. P. Risk, G. S. Kino, and H. J. Shaw, "Fiber-optic frequency shifter using a surface acoustic wave incident at an oblique angle," *Opt. Lett.*, vol. 11, no. 2, pp. 115–117, Feb 1986.

[3] D. Kuhn, *The Skills of Argument. Cambridge*, England: Cambridge University Press, 1991, pp. 169-179

[4] D. Kuhn, "Science as argument: Implications for teaching and learning scientific thinking," *Science Education*, vol. 77, no. 3, pp. 319-337, 1993.

[5] E. Capkinoglu, S. Yilmaz, and G. Leblebicioglu, "Quality of argumentation by seventh-graders in local socio-scientific issues," *Journal of Research in Science Teaching*, vol. 57, no. 6, pp. 827-855, August 2020.

[6] R. Driver, P. Newton, and J. Osborne, "Establishing the norms of scientific argumentation in classrooms," *Science Education*, vol. 84, no.3, pp. 287–312, May 2000.

[7] P. S. Hsu, M. Van Dyke, Y. Chen, and T. J. Smith, "A cross-cultural study of the effect of a graph-oriented computer-assisted project-based learning environment on middle school students' science knowledge and argumentation skills," *Journal of Computer Assisted Learning*, vol. 32, no. 1, pp. 51-76, February 2016.

[8] V. Sampson, P. Enderle, J. Grooms, and S. Witte, "Writing to learn by learning to write during the school science laboratory: Helping middle and high school students develop argumentative writing skills as they learn core ideas," *Science Education*, vol. 97, no. 5, pp. 643-670, September 2013.

[9] T. D. Sadler and D. L. Zeidler, "Scientific literacy, PISA, and socio-scientific discourse: Assessment for progressive aims of science education," *Journal of Research in Science Teaching*, vol. 46, no. 8, pp. 909-921, October 2009.

[10] Y. C. Chen, S. Park, and B. Hand, "Examining the use of talk and writing for students' development of scientific conceptual knowledge through constructing and critiquing arguments," *Cognition and Instruction*, vol. 34, no. 2, pp. 100-147, March 2016.

[11] Y. C. Chen, B. Hand, and L. Norton-Meier, "Teacher roles of questioning in early elementary science classrooms: A framework promoting student cognitive complexities in argumentation," *Research in Science Education*, vol. 47, no. 2, pp. 373-405, April 2017.

[12] K. L Cho and D. H. Jonassen, "The effects of argumentation scaffolds on argumentation and problem solving," *Educational Technology Research and Development*, vol. 50, no. 3, pp. 5-22, September 2002.

[13] S. Bocconi, A. Chioccariello, G. Dettori, A. Ferrari, K. Engelhardt, P. Kampylis, and Y. Punie, Europe. [Online]. Available: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC104188/jrc104188_computhinkreport.pdf. Accessed on: August. 18, 2020

[14] J. M. Wing, "Computational thinking and thinking about computing," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 366, no. 1881, pp. 3717-3725, July 2008.

[15] K. Brennan and M. Resnick, "New frameworks for studying and assessing the development of computational thinking," in *Proc. AERA*, Vancouver, Canada, 2012, pp. 1-24.

[16] J. M. Wing, "Computational thinking," *Communications of the ACM*, vol. 49, no.3, pp. 33-35, March 2006.

[17] J. Wing, "Computational thinking's influence on research and education for all," *Italian Journal of Educational Technology*, vol. 25, no. 2, pp. 7-14, November 2017.

[18] C. Selby and J. Woollard. England. [Online]. Available: http://eprints.soton.ac.uk/id/eprint/356481,

[19] Ö. Korkmaz, R. Cakir, and M. Y. Özden, "A validity and reliability study of the computational thinking scales (CTS)," *Computers in Human Behavior*, vol. 72, pp. 558-569, July 2017.

[20] Y. C. Chen, "Using the science talk–writing heuristic to build a new era of scientific literacy," *The Reading Teacher*, vol. 73, no. 1, pp. 51-64, July 2019.

[21] R. Driver and B. Bell, "Students' thinking and the learning of science: A constructivist view," *School Science Review*, vol. 67, no. 240, pp. 443-56, March 1986.

[22] J. Bransford, R. Sherwood, N. Vye, and J. Rieser, "Teaching thinking and problem solving: Research foundations," *American Psychologist*, vol. 41, no. 10, p. 1078, 1986.

[23] S. S. Anagün, "Teachers' perceptions about the relationship between 21st century skills and managing constructivist learning environments," *International Journal of Instruction*, vol. 11, no. 4, pp. 825-840, 2018.

[24] W. Bechtel and R. C. Richardson, *Discovering Complexity: DECOMPOSITION and Localisation as Strategies in Scientific Research*, Princeton (NJ): Princeton University Press, 1993, pp. 177-183.

[25] D. Klahr, *Scientific Discovery as Problem Solving, in Exploring Science: The Cognition and Development of Discovery Processes of D. Klahr*, Cambridge, MA: MIT Press, 2000, pp. 21-39.

[26] S. Tobias and T. M. Duffy, *Constructivist Instruction: Success or Failure?* New York, USA: Routledge, 2009, pp. 34-61.

[27] M. Kim, "Understanding children's science identity through classroom interactions," *International Journal of Science Education*, vol. 40, no. 1, pp. 24-45, January 2018.

[28] V. Albe, "When scientific knowledge, daily life experience, epistemological and social considerations intersect: Students' argumentation in group discussions on a socio-scientific issue," *Research in Science Education*, vol. 38, no. 1, pp. 67-90, January 2008.

[29] M. P. Jiménez-Aleixandre, A. Bugallo Rodríguez, and R. A. Duschl, "Doing the lesson or doing science: Argument in high school genetics," *Science Education*, vol. 84, no. 6, pp. 757-792, November 2000.

[30] A. Choi, A. Notebaert, J. Diaz, and B.Hand, "Examining arguments generated by year 5, 7, and 10 students in science classrooms," *Research in Science Education*, vol. 40, no. 2, pp. 149-169, March 2010.

[31] A. Y. Takao and G. J. Kelly, "Assessment of evidence in university students' scientific writing," *Science & Education*, vol. 12, no. 4, 341-363, May 2003.

[32] Y. C. Chen, "Examining the integration of talk and writing for student knowledge construction through argumentation," Ph.D. dissertation, The University of Iowa, Iowa, US, 2011.

[33] K. L. McNeill, "Teachers' use of curriculum to support students in writing scientific arguments to explain phenomena," *Science Education*, vol. 93, no. 2, pp. 233-268, March 2009.

[34] C. Chin and J. Osborne, "Students' questions and discursive interaction: Their impact on argumentation during collaborative group discussions in science," *Journal of research in Science Teaching*, vol. 47, no. 7, pp. 883-908, September 2010.

[35] G. Kanselaar, G. Erkens, J. Andriessen, M. Prangsma, A. Veerman, and J. Jaspers, "Designing argumentation tools for collaborative learning," in *Visualising Argumentation: Software Tools for Collaborative and Educational Sense-Making*, P. A. Kirschner, S. J. Buckingham-Shum, and C. S. Carr, Eds., London, ENG: Springer, London, 2013, pp. 51-73.

[36] C. V. Schwarz *et al.*, "Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners," *Journal of Research in Science Teaching*, vol. 46, no. 6, pp. 632-654, August 2009.

[37] J. M. Zydney and Z. Warner, "Mobile apps for science learning: Review of research," *Computers & Education*, vol. 94, pp. 1-17, 2016.

[38] G. J. Hwang, "Definition, framework and research issues of smart learning environments-a context-aware ubiquitous learning perspective," *Smart Learning Environments*, vol. 1, no. 1, pp. 1-14, 2014.

[39] G. J. Hwang *et al*., "A long-term experiment to investigate the relationships between high school students' perceptions of mobile learning and peer interaction and higher-order thinking tendencies," *Educational Technology Research and Development*, vol. 66, no. 1, pp. 75-93, 2018.

[40] M. Evagorou and J. Dillon, "Argumentation in the teaching of science," in *The Professional Knowledge Base of Science Teaching*, D. Corrigan, J. Dillon, and R. Gunstone, Eds., CH: Springer, 2011, pp. 189-203.

[41] J. B. Henderson *et al*., "Key challenges and future directions for educational research on scientific argumentation," *Journal of Research in Science Teaching*, vol. 55, no. 1, pp. 5-18, Jan 2018.

[42] A. A. Tawfik, V. Law, X. Ge, W. Xing, and K. Kim, "The effect of sustained vs faded scaffolding on students' argumentation in ill-structured problem solving," *Computers in Human Behavior*, vol. 87, pp. 436-449, October 2018.

[43] J. F. Voss, C. R. Wolfe, J. A. Lawrence, and R. A. Engle, "From representation to decision: An analysis of problem solving in international relations," in *Complex Problem Solving: Principles and Mechanisms*, R. J. Sternberg and P. A. Frensch, Eds., New York, NY, USA: Lawrence Erlbaum Associates, Inc, 1991, pp. 119–158.

[44] A. R. Cavagnetto, "Argument to foster scientific literacy: A review of argument interventions in K–12 science contexts," *Review of Educational Research*, vol. 80, no.3, pp. 336-371, September 2010

[45] G. A. M. Saido, S. Siraj, D. Dewitt, and O. S. Al-Amedy, "Development of an instructional model for higher order thinking in science among secondary school students: A fuzzy Delphi approach," *International Journal of Science Education*, vol. 40, no. 8, pp. 847-866, May 2018.

[46] A. Zohar, "Science teacher education and professional development in argumentation," in *Argumentation in Science Education*, S. Erduran and M.P. Jiménez-Aleixandre, Eds., CH: Springer, 2007, pp. 245-268

[47] K. L. Goodson and F. Rohani. (2012). *Higher Order Thinking Skills: Definition, Teaching Strategies, Assessment*. [Online]. Available: http://www.cala.fsu.edu/files/higher_order_thinking_skills.pdf

[48] G. Nuthall, "The way students learn: Acquiring knowledge from an integrated science and social studies unit," *The Elementary School Journal*, vol. 99, no. 4, pp. 303-341, March 1999.

[49] M. G. Voskoglou and S. Buckley, "Problem solving and computational thinking in a learning environment," *Egyptian Computer Science Journal*, vol. 36, no. 4, pp. 28-46, December 2012.

[50] F. Kalelioglu, Y. Gulbahar, and V. Kukul, "A framework for computational thinking based on a systematic research review," *Baltic Journal of Modern Computing*, vol. 4, no. 3, pp. 583-596, May 2016.

[51] S. Papert, "Redefining childhood: The computer presence as an experiment in developmental psychology," *IFIP Congress*, Tokyo, Japan, 1980, pp. 993-998.

[52] M. Romero, A. Lepage, and B. Lille, "Computational thinking development through creative programming in higher education," *International Journal of Educational Technology in Higher Education*, vol. 14, pp. 2-15, December 2017.

[53] E. N. Caeli and A. Yadav, "Unplugged approaches to computational thinking: A historical perspective," *TechTrends*, vol. 64, no. 1, pp. 29-36, 2020.

[54] V. J. Shute, C. Sun, and J. Asbell-Clarke, "Demystifying computational thinking," *Educational Research Review*, vol. 22, pp. 142-158, 2017.

[55] A. Peel, T. D. Sadler, and P. Friedrichsen, "Learning natural selection through computational thinking: Unplugged design of algorithmic explanations," *Journal of Research in Science Teaching*, vol. 56, no. 7, pp. 983-1007, September 2019.

[56] J. T. Shemwell, K. R. Gwarjanski, D. K. Capps, S. Avargil, and J. L. Meyer, "Supporting teachers to attend to generalisation in science classroom argumentation," *International Journal of Science Education*, vol. 37, no. 4, pp. 599-628, March 2015.

[57] D. Weintrop, E. Beheshti, M. Horn, K. Orton, K. Jona, L. Trouille, and U. Wilensky, "Defining computational thinking for mathematics and science classrooms," *Journal of Science Education and Technology*, vol. 25, no. 1, pp. 127-147, February 2016.

[58] M. Román-González, J. C. Pérez-González, and C. Jiménez-Fernández, "Which cognitive abilities underlie computational thinking? Criterion validity of the Computational Thinking Test," *Computers in Human Behavior*, vol. 72, pp. 678-691, July 2017.

[59] X. P. Voon, L. H. Wong, W. Chen, and C. K. Looi, "Principled practical knowledge in bridging practical and reflective experiential learning: case studies of teachers' professional development," *Asia Pacific Education Review*, vol. 20, no. 4, pp. 641-656, December 2019.

[60] International Society for Technology in Education (ISTE), US. [Online]. Available: https://www.iste.org/explore/ISTE-blog/Because-the-world-is-changing%2C-so-are-the-ISTEStandards#:~:text=In%201998%20the%20original%20ISTE,focus%20of%20the%20original%20standards

[61] M. Telenius *et al*., "Argumentation within upper secondary school student groups during virtual science learning: Quality and quantity of spoken argumentation," *Education Sciences*, vol. 10, no. 12, p. 393, 2020.

[62] J. F. Osborne, J. B. Henderson, A. MacPherson, E. Szu, A. Wild, and S. Y. Yao, "The development and validation of a learning progression for argumentation in science," *Journal of Research in Science Teaching*, vol. 53, no. 6, pp. 821-846, August 2016.

[63] M. Billig, *Arguing and Thinking: A Rhetorical Approach to Social Psychology*, Cambridge, England: Cambridge University Press, 1996, pp. 142-157.

[64] A. Weinberger, K. Stegmann, and F. Fischer, "Knowledge convergence in collaborative learning: Concepts and assessment," *Learning and Instruction*, vol. 17, no. 4, pp. 416-426, 2007.

[65] C. A. Chinn, "Learning to argue," in *The Rutgers Invitation Symposium on Education Series. Collaborative Learning, Reasoning, and Technology*, O'Donnell, A.M., Hmelo-Silver, C.E., Erkens, G., Eds.; Lawrence Erlbaum Associates Publishers: Hillsdale, NJ, USA, 2006, pp. 355–383.

[66] G. H. Fletcher and J. J. Lu, "Education-Human computing skills: Rethinking the K-12 experience," *Communications of the ACM*, vol. 52, no. 2, February 2009, pp. 23-25

[67] A. Yadav, J. Good, J. Voogt, and P. Fisser, "Computational thinking as an emerging competence domain," in *Competence-based Vocational and Professional Education: Bridging the Worlds of Work and Education*, M. Mulder, Ed., CH: Springer International Publishing, 2017, pp. 1051-1067.

[68] Organisation for economic co-operation and development [OECD]. (2014). OECD Stat. Extracts. [Online]. Available: http://stats.oecd.org/

[69] F. Ștefănică, S. Abele, F. Walker, and R. Nickolaus, "Modeling, measurement, and development of professional competence in industrial-technical professions," *Competence-based Vocational and Professional Education*, pp. 843-861, Springer, Cham, 2017.

[70] K. L. McNeill and J. Krajcik, "Synergy between teacher practices and curricular scaffolds to support students in using domain-specific and domain-general knowledge in writing arguments to explain phenomena," *The journal of the Learning Sciences*, vol. 18, no. 3, pp. 416-460, July 2009

[71] L. K. Berland and B. J. Reiser, "Classroom communities' adaptations of the practice of scientific argumentation," *Science Education*, vol. 95, no. 2, pp. 191-216, March 2011.

[72] B. J. Reiser, "Scaffolding complex learning: The mechanisms of structuring and problematising student work," *The Journal of the Learning Sciences*, vol. 13, no. 3, pp. 273-304, July 2004.

[73] S. M. Land and C. Zembal-Saul, "Scaffolding reflection and articulation of scientific explanations in a data-rich, project-based learning environment: An investigation of progress portfolio," *Educational Technology Research and Development*, vol. 51, no. 4, pp. 65-84, 2003.

[74] J. R. Hill and M. J. Hannafin, "Cognitive strategies and learning from the World Wide Web," *Educational Technology Research and Development*, vol. 45, no. 4, pp. 37–64, 1997.

[75] B. Loh *et al*., "The progress portfolio: Designing reflective tools for a classroom context," in *Proceedings of CHI 98*, pp. 627–634, Reading, MA: Addison-Wesley, 1998.

[76] S. M. Land, "Cognitive requirements for learning with open-ended learning environments," *Educational Technology Research and Development*, vol. 48, no. 3, pp. 61–78, 2000.

[77] A. Yadav, H. Hong, and C. Stephenson, "Computational thinking for all: pedagogical approaches to embedding 21st century problem solving in K-12 classrooms," *TechTrends*, vol. 60, no. 6, pp. 565-568, November 2016.

[78] M. E. Jordan and R. R., McDaniel, "Managing uncertainty during collaborative problem solving in elementary school teams: The role of peer influence in robotics engineering activity," *Journal of the Learning Sciences*, vol. 23, no. 4, 2014.

[79] J. Piaget, "Intellectual evolution from adolescence to adulthood," *Human Development*, vol. 15, pp. 1–12, 1972.

[80] Y. C. Chen and R. Techawitthayachinda, "Developing deep learning in science classrooms: Tactics to manage epistemic uncertainty during whole-class discussion," J*ournal of Research in Science Teaching*, 2021.

[81] L. Resnick, *Education and Learning to Think*, Washington, DC: National Academy Press, 1987, pp. 24-33.

[82] A. M. Phillips, J. Watkins, and D. Hammer, "Beyond "asking questions": Problematizing as a disciplinary activity," *Journal of Research in Science Teaching*, vol. 55, no. 7, pp. 982-998, September 2018.

[83] P. D. Pearson, E. Moje, and C. Greenleaf, "Literacy and science: Each in the service of the other," *Science*, vol. 328, no. 5977, pp. 459-463, April 2010.

[84] M. P. Jiménez-Aleixandre and S. Erduran, "Designing argumentation learning environments," in *Argumentation in Science Education: Perspectives from Classroom-based Research*, S. Erduran and M. Jimenez-Aleixandre, Eds., New York, NY, USA: Springer, 2007, pp. 91-116, 2008.

[85] T. Panitz. US. [Online]. Available: http://files.eric.ed.gov/fulltext/ED448443.pdf

[86] M. I. Stein, "Creativity and culture," *The Journal of Psychology*, vol. 36, no. 2, pp. 311-322, October 1953.

[87] J. Castek and B. Dwyer, "Think globally, act locally: Teaching climate change through digital inquiry," *The Reading Teacher*, vol. 71, no. 6, pp. 755-761, May 2018.

[88] J. A. J. Toledo, C. A. Collazos *et al.*, "Collaborative strategy with augmented reality for the development of algorithmic thinking," *Iberoamerican Workshop on Human-Computer Interaction*, pp. 70-82, Springer, Cham, 2018.

[89] L. Norton-Meier, B. Hand, L. Hockenberry, and K. Wise, "Questions, claims, and evidence: The important place of argument in children's science writing," New Hampshire, US: Heinemann, 2008, pp. 124-133.

[90] R. H. Ennis, "Critical thinking assessment," Theory into Practice, vol. 32, no. 3, pp. 179-186, Jun 1993.

[91] P. Sengupta, J. S. Kinnebrew, S. Basu, G. Biswas and D. Clark, "Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework," *Education and Information Technologies*, vol. 18, no. 2, pp. 351-380, Jun 2013.

[92] S. Bramwell-Lalor and M. Rainford, "The effects of using concept mapping for improving advanced level biology students' lower-and higher-order cognitive skills," *International Journal of Science Education*, vol. 36, no. 5, pp. 839-864, March 2014.

[93] IEA, Germany. [Online]. Available: http://www.iea.nl/fileadmin/user_upload/Studies/ICILS_2018/IEA_ICILS_2018_Computational_Thinking_Leaflet.pdf

[94] A. Labusch, B. Eickelmann, and M. Vennemann, "Computational thinking processes and their congruence with problem-solving and information processing," in *Computational Thinking Education*, S. C. Kong, and H. Abelson, Eds., SG: Springer, 2019, pp. 65-78.

[95] K. Beecher, *Computational Thinking: A Beginner's Guide to Problem-Solving and Programming*, Swindon, UK: BCS Learning & Development Limited, 2017, pp. 150-171.

[96] C. C. Selby, "Relationships: computational thinking, pedagogy of programming, and bloom's taxonomy," in *Proc WiPSCE*, London, UK, 2015, pp. 80-87.

[97] ACARA. (2012). Australian Curriculum Assessment and Reporting Authority (ACARA). Sydney: Australian Curriculum Assessment and Reporting Authority. [Online]. Available: http://www.australiancurriculum.edu.au/English/Curriculum/F-10

[98] J. Voogt, P. Fisser *et al*., "Computational thinking in compulsory education: Towards an agenda for research and practice," *Education and Information Technologies*, vol. 20, no. 4, pp. 715-728, December 2015.

Xin Pei Voon received her BSc. degree in microbiology from Universiti Putra Malaysia (UPM), Malaysia in 2013. She was a recipient of the high achiever's scholarship from Taylor's University and received her MSc. degree in teaching and learning from Taylor's University, Malaysia, in 2017. From 2017 to 2019, she was a research associate of the learning sciences and innovations research programme at the Centre for Research in Pedagogy and Practice, Office of Education Research, National Institute of Education, Nanyang Technological University (NTU), Singapore. She is a graduate research fellowship recipient and currently pursuing a Ph.D. degree in educational technology at UPM. Her current research focuses on the development of computational thinking among pre-service teachers. Her research interest includes teachers' professional development, computational thinking, science education, learning sciences and AI in education.

Su Luan Wong received her PhD in educational technology from Universiti Putra Malaysia (UPM), Malaysia in 2003. She is a professor and currently the deputy dean of graduate studies and international at the Faculty of Educational Studies, UPM. Her current research interest focuses on interest driven learning. In recognition of her active role as a scholar, she was elected executive committee member for the Asia-Pacific Society for Computers in Education (APSCE) in 2006, a post that she still holds. In 2011, she established a Special Interest Group — Development of Information and Communication Technology in the Asia-Pacific Neighbourhood — under the auspices of APSCE to bridge the research gap between scholars from developing and developed countries. Her hard work and dedication to serve the research community in the Asia-Pacific region has led to a highly coveted association to APSCE as its President for 2016-2017.

Lung-Hsiang Wong received his Ph.D. degree in computer engineering and with a focus on artificial intelligence in education from Nanyang Technological University (NTU), Singapore. He is a Senior Research Scientist and the Co-Director of the Learning Sciences and Innovations Research Programme at the Centre for Research in Pedagogy and Practice, Office of Education Research, National Institute of Education, NTU. His current research interests are in the areas of mobile and seamless learning, computer-assisted language learning and science learning, computer-supported collaborative learning, and teachers' professional development. Drawing upon his vast experience in conducting design-based research and school-based longitudinal intervention studies, he developed his niches in both seamless learning and computer assisted language learning. In particular, he has become a key researcher on mobile seamless learning by leading the synthesis efforts.

Mas Nida Md. Khambari received her Ph.D. in curriculum and instruction (educational communications and technology) from University of Wisconsin Madison, USA in 2014. She is a senior lecturer at the Faculty of Educational Studies, Universiti Putra Malaysia (UPM) and has held several posts such as the Head of the Educational Technology Unit, coordinator of Putra Future Classroom, coordinator of Immersive Learning Hub, and Associate Fellow Member of the Centre of Academic Development and Member of the Innovative Teaching and Learning Practices Task Force of UPM. At the International level, she was appointed a member of the Education Subcommittee Program (2018 – 2020). She has been appointed a member of the Executive Committee (2021-2024) of the prestigious Asia-Pacific Society for Computers in Education. Her research interests include learning technologies, instructional design, gamification, alternative assessments, and innovations in teaching and learning. Her awards and honours include the Vice-Chancellor Fellowship Awards for Teaching Category (UPM) and the Putra InnoCreative Awards for Best InnoCreative Educator in Immersive Learning Experience (UPM).

Sharifah Intan Sharina Syed-Abdullah received her Ph.D. in sustainability education from the University of Edinburgh in 2018. Previously, she received her M.Ed. (science education) from the National University of Malaysia and B.Ed. (Education with Science) from Universiti Malaysia Sabah. She is a senior lecturer at the Faculty of Educational Studies, Universiti Putra Malaysia. Her research interests are mainly in the areas of environmental education, sustainability education, science education, curriculum and instruction, and non-formal learning. Drawing on this interest, she has been involved in the aforementioned areas at the national level.