European Journal of Educational Research
Volume 9, Issue 1, 33 - 50.
ISSN: 2165-8714
http://www.eu-jer.com/

A Proposal for Holistic Assessment of Computational Thinking for Undergraduate: Content Validity

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Received: June 14, 2019 ▪ Revised: September 15, 2019 ▪ Accepted: November 26, 2019

Abstract: Studies have acknowledged computational thinking (CT) as an efficient approach for problem-solving particularly required in digital workplaces. This research aims to identify indicators for a holistic CT assessment instrument for undergraduate students. A three-round fuzzy Delphi study has been conducted to gain comprehensive opinions and consensus from undergraduate lecturers of computer science disciplines and experts from the information technology industry. In round 1, the experts judged a set of predefined indicators describing CT skills and attitudes identified from the literature, while rounds 2 and 3 focused on variables selection. The consensus was achieved on holistic CT, and the indicators are teamwork, communication, spiritual intelligence, generalization, problem-solving, algorithmic thinking, evaluation, abstraction, decomposition, and debugging. Results demonstrate the importance of attitudes in the process of solving a problem and suggest higher education institutions to consider holistic CT in preparing qualified future graduates. Many CT studies focused only on the skills of CT. This study outlines the assessment indicators that consider both CT skills and attitudes, particularly at the undergraduate level.

Keywords: *Computational thinking, assessment, fuzzy Delphi method, undergraduate education.*

To cite this article: Sondakh, D. E, Osman, K., & Zainudin, S. (2020). A proposal for holistic assessment of computational thinking for undergraduate: Content validity. *European Journal of Educational Research, 9*(1), 33-50. https://doi.org/10.12973/eu-jer.9.1.33

Introduction

Today's workforces are now facing the Fourth Industrial Revolution (4th IR) era, wherein computer-based technologies will push innovational changes to global industries. Subsequently, transformative influence on employment, skills, and education is inevitable (Schwab, 2016). Among the skills continuing to grow in demand in this digital age workplaces are analytical thinking and innovation, technology design and programming, critical thinking and analysis, complex problem-solving, and system analysis and evaluation (World Economic Forum, 2018). The aforementioned skills are included in computational thinking (CT). CT enhances analytical abilities (Yevseyeva & Towhidnejad, 2012), transforms the technology user into a technology builder (Barr, Harrison, & Conery, 2011), and new information creator (Li & Wang, 2012). CT, in particular, fosters complex problem-solving ability. Complex problem-solving deals with the capacity to solve novel, ill-defined problems in complex real-world settings (Leopold, Ratcheva, & Zahidi, 2016). CT enables the formulation of solutions for large and complex problems or systems in the real-world (Wing, 2006).

CT is the thinking process in formulating solutions to problems by drawing on the concepts of computer science (Aho, 2012; Wing, 2006). Even if it originated from the computing field, CT addresses the areas far beyond computer science (Kalelioğlu, Gülbahar, & Kukul, 2016; Pulimood, Pearson, & Bates, 2016; Qin, 2009; Ruthmann, Heines, Greher, Laidler, & Ii, 2010). Thinking like a computer scientist is the essence of CT (Grover & Pea, 2013); however, it addresses problems in a broad range of subjects (Qin, 2009). CT does not necessarily involve a computer or merely about programming because the result of CT is a process rather than a product (Roberts, 2016). As emphasized by Wing, one of CT characteristics is 'ideas, not artifact'. CT is the computational concepts people use to approach and solve problems (Wing, 2006).

Works on CT are varied. Several works related to introducing CT have been carried out (Bubno & Takacs, 2017; Fronza, El Ioini, & Corral, 2016; Talib, Yasin, & Mohd, 2017). Some researchers emphasized on creating artifacts for promoting CT (Chang, Tsai, & Chin, 2017; de Lima et al., 2016; Nikaido & Ventura, 2016; Shanmugam, Yassin, & Khalid, 2019).

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Assessing CT abilities is another field of interest in CT studies (Chang et al., 2017; Snow, Rutstein, Bienkowski, & Xu, 2017). Some studies consider teachers' conception of CT (Kert, 2019; Rahayu & Osman, 2018, 2019; Senin & Nasri, 2019). Gender differences are also a notable discussion in CT study (Gunbatar & Karalar, 2018). The present study focuses on CT assessment, specifically for undergraduate students.

Studies have explored CT assessment at the undergraduate level. Gouws et al. (2013) applied the game-based approach. Walden et al. (2013) developed an instrument comprising multiple choice and short answer questions on simple algorithms, sorting, digital information storage, and file structure. However, the instrument is not validated. The aforementioned studies focused on the measurement of skills and did not include attitudes. CT is a cognitive activity (Selby & Woollard, 2013); however, problem-solving with only the cognitive process involved is insufficient. It also requires affective elements, such as attitudes and beliefs about the problems, problem domain, and individual abilities to solve the problem (Jonassen, 2000). CT, in the same way, is not characterized by skills merely, but also by attitudes (Wing, 2006). The attitudes, which are the values, motivations, feelings, and characters relevant to CT (Barr et al., 2011), are important as they enhance ones' problem-solving capability. Attitudes promote the ability to deal with complex and difficult problems (Barr et al., 2011) and enable people to work with others to cope with problems that are too difficult to be solved individually (Missiroli et al., 2017).

In a recent study (Korkmaz et al., 2017), the instrument "Computational Thinking Scale" has been developed to assess undergraduate students' creativity, algorithmic thinking, critical thinking, problem-solving, and cooperation skills, and the scale has been validated. However, this instrument does not cover other essential skills, such as abstraction, decomposition, and generalization. On the contrary, these skills are considered the core of CT. Abstraction is useful in defining patterns, generalizing from specific instances, and parameterizing (Wing, 2011). On top of that, abstraction enables the simplification of large and complex problems (Curzon et al., 2014). Decomposition plays a role in breaking down a problem into smaller sub-problems that are simpler and more manageable (Curzon et al., 2014). Generalization enables the identification of patterns and similarities among problems (Angeli et al., 2016; Mueller, Beckett, Hennessey, & Shodiev, 2017). Subsequently, the solution developed for the problems can be reapplied (generalized) to similar ones.

Taking into consideration that CT comprises a set of skills and attitudes applicable to problem-solving (Wing, 2006), this study proposes the 'holistic Computational Thinking.' The term 'holistic' to describe the inclusion of skills and attitudes in the CT framework. Overall, the study intends to develop Hi-ACT (Holistic Assessment of Computational Thinking), an instrument to assess CT holistically, for Indonesian undergraduate students. Currently, in Indonesia, the efforts to promote CT have been carrying out; even the idea to incorporate CT skill to the educational curriculum has been promoted. Indonesia also joins Bebras International competition, an international initiative aiming to promote CT among students of all ages. Additionally, both Indonesian government and employers require graduates who are qualified in technical (knowledge on specific tasks, logical thinking, critical thinking systematic thinking, innovative thinking, analytical thinking, and mastery of information and technology) and soft skills (integrity, problem-solving, interpersonal skills, communication, teamwork, leadership, and social skills) (Ministry of Research Technology and Higher Education 2015; Gribble, 2014).

Identifying the constructs of the Hi-ACT, including their associate items, is crucial prior to instrument development. This paper reports the investigation of a set of constructs and their associated items for a CT assessment instrument, to answer the question 'what are the underlying constructs and indicators of holistic CT?'.

Holistic Assessment of Computational Thinking (Hi-ACT)

Studies have defined CT as thinking process takes place in formulating solutions to problems (Aho, 2012; Barr et al., 2011; Grover & Pea, 2013; Mueller et al., 2017; Qin, 2009; Roman-Gonzalez, Perez-Gonzelez, & Jimenez-Fernandez, 2016; Wing, 2006). However, what is considered CT cognitive skills is still varying (Barr et al., 2011; Bocconi, Chioccariello, Dettori, Ferrari, & Engelhardt, 2016; Brennan & Resnick, 2012; Grover & Pea, 2013; Mueller et al., 2017; Selby & Woollard, 2013; Wing, 2006). This study underpins the skills to (Selby & Woollard, 2013) and (Bocconi et al., 2016) core CT skills, i.e., abstraction, algorithmic thinking, decomposition, automation, generalization, and debugging. The attitudes were colligated based on the ACM and IEEE 2013 Computing Curricula, including teamwork, communication, problem-solving, flexibility, ambiguity tolerance, and personal attributes (ACM and IEEE Computer Society, 2013) and the Computer Science Teacher Association (CSTA) and the International Society for Technology in Education (ISTE)'s operational definitions of CT attitudes. The attitudes that applicable to CT including confidence in dealing with complexity, persistence in working with difficult problems, tolerance for ambiguity, ability to deal with open-ended problems, and ability to communicate and work with others to achieve a common goal. The first four emphases on behaviors required when solving problems, while the last relates to communication and teamwork (Barr et al., 2011). Therefore, the different designation of the aforementioned attitudes was expressed as problem-solving, teamwork, and communication. In addition, the present study recommends spiritual intelligence as another element of CT attitudes.

CT is relevant to solve problems in a broad range of subjects (Qin, 2009), including art, science, humanities, and social science (Perkovic et al., 2010). In that case, spiritual intelligence is capable as a complement to CT concepts, as spiritual intelligence plays a role in solving problems (Nasel, 2004; Sisk, 2002). According to Sisk & Torrance (2001), as cited by (Nasel, 2004), some abilities of spiritual intelligence such as wisdom, self-awareness, creative reasoning, integrity, compassion and asking 'why' questions are relevant to a much broader range of problems apart from spiritual matters. Arguing that spiritual intelligence is an essential context of a holistic approach to problems related to expert systems, a study by (Kadkhoda & Jahanic, 2012) defined a process to solve artificial intelligence problems based on spiritual intelligence abilities including self-awareness, creative reasoning, integrity and asking 'why' question.

In sum, the Hi-ACT recommends eleven CT concepts: abstraction, algorithmic thinking, automation, decomposition, debugging, evaluation, generalization, problem-solving, teamwork, communication, and spiritual intelligence.

a. **Abstraction** is the ability to reduce problem complexity by removing unnecessary details and create the right model of the problem (Angeli et al., 2016; Wing, 2006). Two constructs were defined for abstraction. First, remove unnecessary detail (AR) which indicating evaluation and, filtering valuable information (Mueller et al., 2017), separate essential information from the redundant one (Atmatzidou & Demetriadis, 2014), and find the appropriate level of detail to define the problem (L'Heureux, Boisvert, Cohen, & Sanghera, 2012). Second, create the right model (AC), which implicates the ability to develop a model of solution based on the details identified earlier (Angeli et al., 2016).

b. **Algorithmic thinking** is the ability to formulate the step-by-step instructions to solve problems. Six constructs were defined to describe algorithmic thinking, i.e., procedural thinking, sequence action, conditional, repetition, parallelism, and logical reasoning. Procedural thinking (ATPr) indicates the identification, selection, and execution of appropriate steps to solve problems (L'Heureux et al., 2012). Sequence action (ATS) represents the ability to create a set of precise and correct steps to solve problems, using explicit wording (Atmatzidou & Demetriadis, 2014; Brennan & Resnick, 2012; Mueller et al., 2017). Conditional (ATC) describes the ability to making a decision based on certain conditions and create options of solutions (Brennan & Resnick, 2012; Korkmaz et al., 2017). Repetition (ATR) describes the using of the same instruction iteratively (Mueller et al., 2017; Shute, Sun, & Clarke, 2017). Parallelism (ATPa) which describes the execution of more than one instructions simultaneously (Brennan & Resnick, 2012). Logical reasoning which represents the ability to do reasoning and inferring conclusion based on existing knowledge (Brennan & Resnick, 2012).

c. **Automation** relates to the use of a machine that operates automatically. In CT, automation indicates the use of a tool to implement the designed solution (Barr et al., 2011).

d. **Decomposition** deals with breaking-down large and complex problem into sub-problems. Two constructs were defined for decomposition. First, divide and conquer (DD) which describes the division of a problem into smaller and easy to manage sub-problems (Atmatzidou & Demetriadis, 2014) Second, modularizing (DM) which describes the ability to reassemble parts of solution into a complete one (Angeli et al., 2016; Mueller et al., 2017).

e. **Debugging** enables the identifying of potential errors in designed solutions (Kazimoglu, Kiernan, Bacon, & MacKinnon, 2012). This skill involves the ability to think of anticipation plan for a problem (Mueller et al., 2017) and recognize the problem when the instructions do not correspond to solutions (Angeli et al., 2016).

f. **Evaluation** is the ability to analyze solution performance, improve, and optimize solutions to problems. Three constructs were defined for evaluation: Performance evaluation (EP), which deals with assessing solutions' completeness, effectiveness, efficiency and usability (Mueller et al., 2017); Iterative refinement (EI), which deals with improving solutions' precision; and Optimizing (EO) which deals with the usage of resources (L'Heureux et al., 2012).

g. **Generalization** is the ability to recognizes parts of solutions applied in previous problems that might be reused or reapplied to similar problems. Three constructs were defined for generalization, i.e., pattern recognition, reuse, and remix. Pattern recognition (GP) describes the identification of patterns and commonalities in problems (Mueller et al., 2017). Reuse (GU) describes the reusing of existing solutions to solve similar problems (Angeli et al., 2016; Atmatzidou & Demetriadis, 2014; Mueller et al., 2017). Remix describes the merging of one's work with others (Brennan & Resnick, 2012; Mueller et al., 2017).

h. **Problem-solving**. In this study, the term 'problem-solving' represents the characters applicable to the process of finding solutions to a problem. Referring to (Microsoft, n.d.; Zakaria, Haron, & Daud, 2004), four constructs were defined for problem-solving, i.e., confidence, persistence, ambiguity handling, and willingness. Confidence (PSC) is indicated by trust in one's abilities, ideas, or plans when dealing with problems. Persistence (PSP) is indicated by perseverance in working on challenging problems. Ambiguity handling (PSA) covers anticipating changes and ambiguous situations, accepting risks, and adaptable with uncertainty. Willingness (PSW) describes the eagerness to solve problems.

i. **Teamwork** is the ability to work with others in a group. Four constructs were defined for teamwork, i.e., cooperation, coordination, participation, and conflict management. Cooperation (TCp) indicates the ability to work with others towards the same goal (Barr et al., 2011; Korkmaz et al., 2017; Orchard, King, Khalili, & Bezzina, 2012). Coordination (TCd) indicates the ability to maintain harmony among team members (Orchard et al., 2012). Participation (TP) indicates the active participation and responsibility of the task assigned (Britton, Simper, Leger, & Stephenson, 2015; Strom & Strom, 2011). Conflict management (TCM) indicates the ability to handle conflict in an effective manner (Barr et al., 2011; Britton et al., 2015).

j. **Communication** skill is centered on the ability to exchange information in verbal and non-verbal means (Britton et al., 2015; Strom & Strom, 2011).

k. **Spiritual intelligence** deals with the application of spiritual abilities to enhance an individual personal character and to facilitate solving problem tasks (Nasel, 2004; Sisk, 2015). The spiritual abilities adopted in this study are self-awareness, integrity, and creativity. Self-awareness (SIS), describes the knowledge of one's strengths, weaknesses, and characters (Amram & Dryer, 2008; Parmar, 2014). Integrity (SII) deals with having a moral principle and living it up in the relationship with others (Amram & Dryer, 2008; Orchard et al., 2012). Creative reasoning (SIC), which indicates the ability to discover distinctive ideas to solve problems (Amram & Dryer, 2008).

Methodology

This study aims to validate Hi-ACT's initial items by conducting a content validity assessment. One way to assess content validity is through evaluation by the expert, using the Delphi method (Boateng, Neilands, Frongillo, Melgar-Quinonez, & Young, 2018). This study employs the fuzzy Delphi method (FDM) to assess Hi-ACT's content validity. This analytical method merges the Delphi technique and fuzzy theory to reach a consensus on a particular issue by using a series of intensive questionnaires to collect data from a group of selected experts (Chang et al., 2011). In this study, FDM was employed to attain consensus on the indicators (constructs and items), of CT skills among a panel of experts. For the items examined in the questionnaire, some were adopted from the existing instrument (Korkmaz et al., 2017), and the unavailable ones were developed based on the concepts found in the literature.

Participant

This study intends to determine the essential CT skills for undergraduate students. CT is rooted in computer science concepts of solving problems (Aho, 2012; Grover & Pea, 2013; Wing, 2006). Therefore, the opinions of a panel of experts who understand the way computer scientists solve a problem were acquired. Academic experts, who were lecturers from computer science disciplines, and practitioner experts who were those with experiences related to information technology (IT) project development or those who are actively engaged in the information technology industry, with at least five years of experience, were recruited. The experts were selected based on their background knowledge and role in the IT industry. According to Rowe and Wright (2001), the panel size must be within the range of 5 to 20 experts. This study employed 20 experts: ten academic experts and ten practitioner experts from the IT industry. Most experts (17) have more than ten years of experience in their fields.

Materials

A number of items related to each aforementioned construct were composed based on the literature. Four main databases were explored, i.e., ACM, IEEE, ScienceDirect, and Google Scholar. The terms 'computational thinking concepts', and 'computational thinking skills' were used to search for items for constructs related to knowledge related to CT. For the remaining constructs, we used the combination of key terms of each construct with the term 'scale' or 'instrument.' A total of 172 items were created (see Appendix). The options for responses used a 7-point Likert-scale (Table 1). The questionnaire was divided into two sections. The first section contains the list of constructs and items. In the second section, experts were asked to define constructs or items they considered relevant yet not address in the current list.

Procedure

This study employed the Fuzzy Delphi Method (FDM) to analyze experts' opinions. FDM is an analytical method that combines Delphi and Fuzzy Theory. Delphi is a qualitative technique commonly used to develop forecasts through group consensus, based on iterative approach (Cheng & Lin, 2002). Experts' opinions in qualitative format, which are subjective, are the major drawback of Delphi as it leads to a result sensitivity to ambiguity. This is caused by the possibility of different interpretations of experts' opinions (Damigos & Anyfantis, 2011). In order to tackle the issue, fuzzy numbers from Fuzzy set theory are applied to interpret experts' responses (Cheng & Lin, 2002). The application of FDM was adapted from the procedures described by (Chang et al., 2011).

Step 1: Collect opinions from the experts. Experts provide their responses in a linguistic scale, which incorporates a Likert-scale with Triangular Fuzzy Numbers (TFN). The TFN comprises three fuzzy numbers m_1, m_2, m_3, which respectively are the minimum value, medium value, and maximum value, between the range of 0 and 1. The sevenpoint linguistic scale and the TFN employed in this study are shown in Table 1. Each response on Likert-scale will be converted into fuzzy numbers.

Table 1. Linguistic Scale

Likert Scale	Linguistic Scale	TFN		
		m_1	m_2	m_3
1	Very irrelevant	0.0	0.0	0.2
2	Irrelevant	0.0	0.1	0.3
3	Slightly irrelevant	0.1	0.3	0.5
4	Fairly relevant	0.3	0.5	0.7
5	Slightly relevant	0.5	0.7	0.9
6	Relevant	0.7	0.9	1.0
7	Very relevant	0.9	1.0	1.0

Step 2: Set up TFN. Calculate the average responses for every fuzzy number. Then, calculate the construct threshold value (?-construct), which indicates the consensus level among the experts. For each expert, the difference between the average fuzzy number and expert's TFN was computed, resulting in the threshold value for each item. The following equation was applied:

$$d(\bar{M},\bar{m}) = \sqrt{\frac{1}{3}(M_1 - m_1)^2 + (M_2 - m_2)^2 + (M_3 - m_3)^2}$$

Furthermore, compute the group consensus percentage. The threshold value and group percentage determine the consensus level among experts. The consensus is considered achieved when the threshold value is less than or equal to 0.2, and the group percentage value of more than 75% (Chang et al., 2011). When these conditions are met, proceed to the defuzzification process. Otherwise, another round of survey is required, and computations in Step 2 and 3 are repeated.

Step 3: Compute defuzzification value (DV). Defuzzification process converts the fuzzy number into a crisp real number, using the following equation:

$$DV = \frac{1}{3} * (m_1 + m_2 + m_3)$$

Then the items are ranked based on the resulting DV. The DV is also used to screen the items by setting the alpha-cut level (Hsu, Lee, & Kreng, 2010). The commonly used alpha-cut level is 0.5 (Saido, Siraj, DeWitt, & Al-Amedy, 2018). If the DV of an item is less than 0.5, then the item is deleted.

Findings / Results

In the present study, three rounds of FDM were conducted to validate constructs and items of the measurement instrument to assess CT skills. The instrument was designed commensurate with the Indonesian context. In round one, a list of predefined constructs and items derived from the literature was presented to the experts. The experts were to determine their importance using linguistic scales. Additionally, experts were asked to define constructs or items they considered relevant yet not address in the current list. Then, the data were analyzed as per the steps in FDM. As the results, of the 172 items, 98 items achieved the experts' consensus. Of the 74 that did not achieve experts' consensus, some items were eliminated or modified based on experts' suggestions. Eight items were discarded: "Confident to solve most hard problem" (PSC3), "Can only do problems everyone else can do" (PSC11), "Most problems are too hard for me to solve" (PSC12), "I give up on problems right away" (PSP7), "Give up when don't get the right answer right away" (PSP8), "There are some problems I will just not try" (PSW4), "I don't like to try problems that are hard to understand" (PSW5), and "The goals that team members agree upon are equally divided among the team" (TCd1). Two items were modified. First, PSA2 "Uses intelligence in dealing with ambiguous situations and guides others to cope with ambiguous situations effectively" was split into "Uses intelligence in dealing with ambiguous situations" (PSA2) and "guides others to cope with ambiguous situations effectively" (PSA10). Second, COM7 "Ensure consistency between words, tone, facial expression, and body language" was splint into "Ensure consistency between words and tone" (COM7) and "Ensure consistency between facial expression and body language" (COM8). Experts also recommended three additional items. One item for 'Conditional' construct: "Identify all of possibilities for the final result" (ATC4). Two items for 'Repetition' construct: "Identify all possibilities of procedures that can be executed more than once" and "Decide, based on certain conditions, when to execute a procedure and when to stop." Hence, a total of 71 items were included in the second-round questionnaire. Of the 71 items in the second round, 43 achieved the consensus, and 28 did not. Finally, the last round was carried out for the remaining 28 items, wherein 14 items achieved the consensus. Tables 2 to 11 summarize the FDM results. The item threshold values were calculated between 0.05 and 0.22. Furthermore, the percentage of group consensus ranges between 46% and 100%. These values indicate that some items did not achieve the required acceptance criteria and should be removed.

From the abstraction construct (Table 2), three items with less than 75% group percentage were removed: AR7, AR8, and AC4 at 54%, 54%, and 46%, respectively. From the algorithmic thinking construct (Table 3), the unachieved group consensus was for item numbers ATC4 and ATR2 at 57% and 60%, respectively. The automation construct only has one item, "use tool to implement sequence of instructions of a solution," which got a group consensus of 62%, a threshold value of 0.22, and average fuzzy numbers of 0.7. Based on these results, the construct and its item should be removed. Similarly, one item of decomposition (Table 4), DD5 at 62%, should be removed. Others that need to be removed because of low group percentage were item numbers DE1 and DE3 of debugging at 54% and 69%, respectively (Table 5). The results for problem-solving construct (Table 8) also suggest removing the five following items for low group percentage: PSC2, PSC6, PSC10, PSA2, and PSA9 at 69%, 54%, 54%, 57%, and 57%, respectively. The results for evaluation, generalization, teamwork, communication, and spiritual intelligence constructs reveal that all the items achieved the required acceptance criteria (Tables 6, 7, 9, 10, and 11).

Table 2. FDM Results for Abstraction

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Remove irrelevant detail							
AR1	Reducing complexity by removing unnecessary detail	0.16	80%	0.66	0.83	0.93	0.81
AR2	Evaluate what is valuable information and what is not	0.09	93%	0.79	0.93	0.98	0.9
AR3	Filtering information when developing solutions	0.07	100%	0.73	0.9	0.98	0.87
AR4	Separate the important from the redundant information	0.18	87%	0.71	0.85	0.91	0.82
AR5	Add or remove details to clarify a problem	0.12	93%	0.73	0.88	0.96	0.86
AR6	Find the appropriate level of detail to define a problem	0.16	80%	0.63	0.81	0.92	0.79
AR7	Ignoring detail that we don't need helps in concentrating on those that we need	0.17	54%	0.53	0.72	0.87	0.71
AR8	Unnecessary to keep all specific details to formulate solution	0.22	54%	0.36	0.54	0.72	0.54
Choosing the right representation							
AC1	Understand that a model depicts general idea of the problem	0.11	93%	0.71	0.88	0.96	0.85
AC2	Create a model to solve problem	0.13	86%	0.66	0.84	0.94	0.81
AC3	Choosing a way to represent an artifact, allow it to be manipulated in useful ways	0.15	85%	0.65	0.82	0.93	0.8
AC4	Excluding unnecessary details from the model	0.18	46%	0.58	0.75	0.88	0.74

Table 3. FDM Results for Algorithmic Thinking

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Sequence actions							
ATS1	Formulate instructions to achieve the desired effect	0.12	93%	0.75	0.9	0.97	0.87
ATS2	Create a set of precise steps to solve a problem	0.18	87%	0.69	0.83	0.92	0.81
ATS3	Elaborate particular activity or task as a series of individual steps or instructions	0.11	93%	0.67	0.85	0.96	0.83
ATS4	Explicitly wording of the steps to solve problem	0.09	100%	0.72	0.88	0.98	0.86
ATS5	Put instructions in the correct sequence	0.16	87%	0.73	0.87	0.94	0.85
Procedural thinking							
ATPr1	Select and execute appropriate steps to solve problem	0.09	93%	0.82	0.95	0.98	0.92
ATPr2	Identify the steps required to solve a problem	0.07	93%	0.81	0.95	0.99	0.92
ATPr3	Identify the sequence of steps including possible decisions and branching	0.13	93%	0.74	0.89	0.96	0.86
ATPr4	Understands normal and exceptional behaviours of a solution	0.13	93%	0.74	0.89	0.95	0.86
Conditional							
ATC1	Make decisions based on certain conditions	0.14	93%	0.77	0.9	0.93	0.87
ATC2	Think of possibility of different procedures for a problem	0.17	86%	0.69	0.84	0.92	0.82
ATC3	Produce many options while thinking of the possible solution to a problem	0.17	86%	0.66	0.82	0.91	0.8
ATC4	Identify all of possibilities for the final result	0.16	57%	0.63	0.8	0.91	0.78

Table 4. Continued

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Repetition							
ATR1	Implement the same design plan for a specified number of times	0.11	100%	0.67	0.85	0.96	0.83
ATR2	Adapt the plan in response to new or different information	0.18	60%	0.64	0.64	0.89	0.72
ATR3	Repeat design processes to refine solutions until the ideal result is achieved	0.17	87%	0.68	0.83	0.91	0.81
ATR4	Identify all possibilities of procedures that can be executed more than once	0.15	86%	0.64	0.81	0.93	0.79
ATR5	Decide, based on certain conditions, when to execute a procedure and when to stop	0.05	100%	0.73	0.91	0.99	0.88
Parallelism							
ATPa1	Running different sequences of instructions at the same time	0.13	85%	0.62	0.81	0.93	0.79
ATPa2	Dividing up resources and task in such a way to be processed in parallel	0.09	100%	0.73	0.89	0.98	0.87
Logical reasoning							
ATL1	Explain why something happens	0.14	87%	0.75	0.89	0.95	0.86
ATL2	Infer a conclusion based on existing knowledge	0.15	93%	0.66	0.83	0.92	0.8
ATL3	Explain how a conclusion is drawn	0.19	86%	0.68	0.82	0.9	0.8
ATL4	Can provide a reason for one own thinking	0.17	93%	0.68	0.83	0.92	0.81
ATL5	Using existing knowledge to make reliable predictions	0.15	87%	0.61	0.79	0.91	0.77
ATL6	Elaborate logical connections between cause and effect	0.11	92%	0.7	0.87	0.96	0.84

Table 5. FDM Results for Decomposition

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Divide and conquer							
DD1	Breaking apart problem into smaller subproblems makes it easier to solve	0.16	93%	0.65	0.81	0.91	0.79
DD2	Breaking down a problem into simpler versions enables the same problem to be solved in the same way	0.08	100%	0.75	0.91	0.98	0.88
DD3	Apply the order of mathematical operations properly	0.15	79%	0.52	0.71	0.87	0.7
DD4	Do classification	0.15	86%	0.64	0.81	0.93	0.79
DD5	Write an outline	0.16	62%	0.58	0.77	0.9	0.75
Modularizing							
DM1	Be able to combine smaller parts to produce something larger	0.18	85%	0.66	0.82	0.9	0.79
DM2	Develop a solution by assembling the smaller parts	0.15	92%	0.68	0.84	0.93	0.82

Table 6. FDM Results for Debugging

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Debugging							
DE1	Solve the bug before developing strategies to deal with problems	0.2	54%	0.6	0.76	0.88	0.75
DE2	Think of anticipation plan for a problem	0.13	92%	0.7	0.86	0.95	0.84
DE3	Comfortable using trial and error method	0.22	69%	0.5	0.68	0.82	0.67
DE4	Recognize problem when procedures do not correspond to solutions	0.09	93%	0.69	0.86	0.96	0.84

Table 7. FDM Results for Evaluation

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Performance evaluation							
EP1	Determine whether the procedures in a solution is complete to solve the problem	0.14	92%	0.67	0.84	0.94	0.82
EP2	Assessing whether the solution is suitable for answering the problem	0.15	93%	0.66	0.83	0.93	0.81
EP3	Assessing whether the solution does the right thing	0.07	93%	0.76	0.92	0.99	0.89
EP4	Comparing the performance of different procedures that solve the same problem	0.14	79%	0.61	0.81	0.93	0.78
EP5	Assessing whether the solution is easy for people to use	0.15	87%	0.61	0.79	0.91	0.77
Iterative refinement							
EI1	Refine the solution to improve its precision	0.16	79%	0.58	0.76	0.9	0.75
EI2	Evaluates solution against the success criteria	0.11	86%	0.66	0.84	0.95	0.82
EI3	Adjusts the design and implementation of a solution when necessary	0.17	79%	0.59	0.77	0.89	0.75
Optimizing							
EO1	Analyze the solution for efficient use of resources	0.12	93%	0.67	0.84	0.95	0.82
EO2	Develops a solution that can utilize the available resources	0.17	79%	0.63	0.81	0.91	0.78
EO3	Adapts the solution to optimize resources utilization	0.12	93%	0.64	0.82	0.94	0.8
EO4	After the problem solved, analyze what went right and what went wrong is necessary	0.1	100%	0.75	0.9	0.98	0.88

Table 8. FDM Results for Generalization

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Reuse							
GU1	Applying an existing solution in a given problem in order to cover more possibilities	0.14	92%	0.64	0.81	0.93	0.79
GU2	Use sequence of instructions previously employed to solve a new problem	0.12	87%	0.7	0.87	0.95	0.84
GU3	Transfer ideas and solutions from one problem area to another	0.13	87%	0.73	0.88	0.95	0.85
GU4	Build on other people's work	0.16	87%	0.71	0.86	0.94	0.84

Table 9. Continued

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Remix							
GM1	Embed other's work into one's own in a meaningful way	0.15	80%	0.73	0.87	0.94	0.85
GM2	Efficient in researching relevant information	0.17	93%	0.71	0.85	0.91	0.82
GM3	Constructively builds on contributions of others and integrates own work with work of others	0.12	93%	0.75	0.9	0.97	0.87
GM4	Combines and builds on the ideas of others	0.15	87%	0.74	0.88	0.95	0.86
Pattern recognition							
GP1	Identify patterns, similarities, and connections between prior and current problems	0.08	87%	0.83	0.95	0.99	0.92
GP2	Solve similar problems with the same set of steps or principles	0.08	93%	0.75	0.91	0.98	0.88

Table 10. FDM Results for Problem-Solving

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Confidence							
PSC1	Am a good problem solver	0.07	93%	0.78	0.93	0.99	0.9
PSC2	I'm better than others at solving problems	0.19	69%	0.53	0.71	0.85	0.7
PSC4	Confident to solve most problems	0.12	93%	0.71	0.87	0.96	0.85
PSC5	Given enough time, I believe I can solve most problems that confront me	0.09	87%	0.79	0.93	0.99	0.9
PSC6	When faced with a novel situation, I am confident that I can handle problems that may arise	0.16	54%	0.62	0.8	0.92	0.78
PSC7	Can solve new and difficult problems	0.09	100%	0.74	0.9	0.98	0.87
PSC8	Have a systematic method for comparing alternatives and making decisions	0.1	80%	0.77	0.91	0.98	0.89
PSC9	When I make plans to solve a problem, I am almost certain that I can make them work	0.08	100%	0.73	0.89	0.98	0.87
PSC10	My ideas about how to solve problems are as good as others	0.14	54%	0.53	0.72	0.87	0.71
Persistent							
PSP1	Work a long time on a problem	0.12	100%	0.69	0.85	0.96	0.83
PSP2	Keep working on a problem until I get the right answer	0.15	87%	0.69	0.85	0.94	0.83
PSP3	Keeps trying when a task becomes difficult	0.14	93%	0.71	0.87	0.95	0.84
PSP4	When a solution to a problem was unsuccessful, I will examine why it didn't work	0.09	100%	0.73	0.89	0.98	0.87
PSP5	When I'm confronted with a complex problem, I develop a strategy to collect information so that I can define exactly what the problem is	0.17	92%	0.69	0.69	0.91	0.76
PSP6	When my first effort to solve a problem fail, I still have certainty about my ability to handle the situation	0.15	92%	0.68	0.85	0.94	0.82

Table 11. Continued

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Ambiguity handling							
PSA1	Anticipates impact of change and directs self and others in smoothly shifting gears	0.11	93%	0.7	0.87	0.96	0.84
PSA2	Uses intelligence in dealing with ambiguous situations	0.16	57%	0.63	0.8	0.91	0.78
PSA3	Rises to challenge, accepting risk and uncertainty as normal	0.13	87%	0.73	0.88	0.95	0.85
PSA4	Remains calm and focused during time of change	0.1	87%	0.77	0.91	0.97	0.88
PSA5	Willing and open to change	0.12	80%	0.78	0.91	0.97	0.89
PSA6	Adaptable with the unknown	0.13	93%	0.75	0.89	0.96	0.87
PSA7	I have no problems with demonstrating the solution of a problem in my mind	0.12	93%	0.66	0.84	0.95	0.82
PSA8	I understand where I should use the variables such as X and Y in the solution of a problem	0.19	57%	0.64	0.79	0.89	0.77
PSA9	Be able to apply the solution I plan respectively	0.12	93%	0.7	0.86	0.96	0.84
PSA10	Guides others to cope with ambiguous situations effectively	0.14	86%	0.63	0.81	0.93	0.79
Willingness							
PSW1	I like to try to solve problems	0.09	93%	0.81	0.94	0.98	0.91
PSW2	It is fun to try to solve problems	0.09	86%	0.79	0.93	0.99	0.9
PSW3	I will try almost any problem	0.16	86%	0.69	0.84	0.93	0.82

Table 12. FDM Results for Teamwork

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Cooperation							
TCp1	Enjoy working with others (working together)	0.1	100%	0.75	0.91	0.98	0.88
TCp2	Share the power with other	0.16	93%	0.68	0.83	0.91	0.81
TCp3	Understand that there are shared knowledge and skills between team members	0.07	93%	0.83	0.96	0.99	0.93
TCp4	Create a cooperative atmosphere among the members when addressing problems	0.09	93%	0.82	0.95	0.98	0.92
TCp5	Listen to and consider other members' opinions	0.05	100%	0.85	0.97	1	0.94
TCp6	Willing to ask others for help	0.07	100%	0.73	0.9	0.99	0.87
TCp7	Trust other team members	0.17	86%	0.66	0.82	0.92	0.8
TCp8	Setting aside differences when work with others to achieve a common goal	0.08	100%	0.76	0.91	0.99	0.89
TCp9	I like experiencing cooperative learning together with my group friends	0.12	87%	0.77	0.91	0.96	0.88
TCp10	In cooperative learning, I think I attain more success	0.1	93%	0.77	0.91	0.97	0.88
TCp11	I like solving problems related to group project together with my friends in cooperative learning	0.14	87%	0.77	0.9	0.95	0.87
TCp12	More ideas occur in cooperative learning	0.09	87%	0.81	0.94	0.99	0.91
Coordination							
TCd2	Working together harmoniously	0.09	93%	0.81	0.94	0.98	0.91
TCd3	Communicates actively and constructively	0.08	93%	0.85	0.85	0.98	0.89
TCd4	Acknowledges the contribution of others	0.15	93%	0.79	0.9	0.93	0.87

Table 13. Continued

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Participation							
TP1	Stays focused on the task during group work	0.08	93%	0.81	0.95	0.99	0.92
TP2	Fulfills individual role assigned by the group	0.08	93%	0.81	0.95	0.99	0.92
TP3	Participates actively and accepts a fair share of group work	0.08	93%	0.81	0.95	0.99	0.92
TP4	Works skillfully on assigned tasks and completes them on time	0.12	93%	0.77	0.91	0.96	0.88
TP5	Shares responsibilities for the team's success or failure	0.1	93%	0.81	0.93	0.97	0.9
Conflict management							
TCM1	Responds to and manages direct/indirect conflict constructively and effectively	0.07	93%	0.83	0.96	0.99	0.93
TCM2	Fully accept each other's strengths and weakness	0.09	87%	0.79	0.93	0.99	0.9
TCM3	Try to achieve harmony by avoiding conflict	0.19	87%	0.66	0.81	0.91	0.79
TCM4	Takes criticism in a friendly way	0.09	93%	0.77	0.92	0.98	0.89
TCM5	Avoids using put-downs or blaming others	0.1	93%	0.78	0.92	0.97	0.89
TCM6	Accepts compromise to deal with conflict	0.12	87%	0.75	0.9	0.96	0.87

Table 14. FDM Results for Communication

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Communication							
COM1	Shares feelings, ideas, or opinions	0.08	93%	0.81	0.95	0.99	0.92
COM2	Speaks clearly with acceptable vocabulary	0.15	93%	0.76	0.89	0.93	0.86
COM3	Use a variety of communication means (written message, e-mail, phone, informal discussion, etc.)	0.1	87%	0.81	0.93	0.97	0.9
COM4	Limits length of comments so others can talk	0.09	93%	0.74	0.9	0.97	0.87
COM5	Listens to everyone and respects their views	0.08	93%	0.79	0.94	0.99	0.91
COM6	Contributes appropriately in healthy debate	0.09	93%	0.77	0.92	0.98	0.89
COM7	Ensure consistency between words and tone	0.13	86%	0.67	0.84	0.94	0.82
COM8	Ensure consistency between facial expression and body language	0.11	93%	0.69	0.86	0.96	0.84

Table 15. FDM Results for Spiritual Intelligence

Construct/Item		Threshold Value	Consensus (%)	Average Fuzzy Number			DV
Self-awareness							
SIS1	Aware of one's abilities and weakness	0.12	80%	0.78	0.91	0.97	0.89
SIS2	Live with self-respect	0.14	87%	0.75	0.89	0.95	0.86
SIS3	I am satisfied as I am	0.12	93%	0.69	0.85	0.95	0.83
SIS4	Do any work with self-confidence	0.2	87%	0.68	0.83	0.89	0.8
SIS5	I can decide my goal	0.13	93%	0.73	0.88	0.96	0.86
SIS6	Look for and try to discover my blind spots	0.09	100%	0.69	0.86	0.97	0.84
SIS7	In negotiating, I try to see things from the other person's perspective even when I disagree	0.13	85%	0.7	0.86	0.95	0.84
SIS8	During an activity or conversation, I monitor and notice my thoughts and emotions	0.15	87%	0.66	0.83	0.93	0.81
SIS9	My actions are aligned with my soul-my essential true nature	0.1	100%	0.71	0.88	0.97	0.85
SIS10	I am aware of my inner truth-what I know inside to be true	0.1	93%	0.71	0.88	0.97	0.85
Integrity							
SII1	I'm proud of my country's culture	0.13	93%	0.74	0.89	0.96	0.86
SII2	Character is the real strength	0.08	87%	0.83	0.95	0.99	0.92
SII3	Aware of one's own values and beliefs	0.07	93%	0.82	0.95	0.99	0.92
SII4	Keep the promises given to others	0.1	80%	0.81	0.93	0.98	0.91
SII5	One's actions are aligned with my values	0.11	87%	0.79	0.79	0.99	0.86
SII6	I accept myself with all my problems and limitations	0.09	87%	0.79	0.93	0.99	0.9
SII7	I know how to be myself when interacting with others	0.13	93%	0.66	0.81	0.9	0.79
SII8	Help and support each other	0.06	93%	0.85	0.97	0.99	0.94
SII9	Respect and trust each other	0.07	93%	0.83	0.96	0.99	0.93
SII10	Be open and honest with each other	0.1	87%	0.81	0.93	0.97	0.9
SII11	Put consciousness in a positive direction	0.09	87%	0.78	0.93	0.99	0.9
SII12	Lives one's values in relationships with others	0.1	80%	0.77	0.91	0.98	0.89
SII13	Act with honesty and truthfulness	0.2	87%	0.73	0.85	0.9	0.83
SII14	Keep working diligently even when no one is watching	0.08	87%	0.83	0.95	0.99	0.92
Creative reasoning							
SIC1	To solve problems, I draw on my ability to hold, accept and go beyond paradoxes	0.16	93%	0.71	0.85	0.92	0.83
SIC2	I can hold as true and integrate seemingly conflicting or contradictory points of view	0.11	93%	0.74	0.89	0.97	0.87
SIC3	I find it challenging to find out what the truth is	0.13	93%	0.7	0.86	0.96	0.84
SIC4	I can think of an answer to a problem, even though initially, apparently no solution	0.13	92%	0.67	0.84	0.95	0.82
SIC5	Offer new ways of looking at problem	0.14	93%	0.74	0.88	0.95	0.86
SIC6	Find unusual way to solve a problem	0.17	80%	0.69	0.84	0.93	0.82
SIC7	Display curiosity about many things	0.16	80%	0.7	0.85	0.93	0.83
SIC8	Willing to change one's mind and try something else	0.14	87%	0.74	0.89	0.95	0.86
SIC9	Willing to admit when made a wrong decision	0.11	93%	0.74	0.89	0.97	0.87
SIC10	Can improve the original idea	0.13	93%	0.69	0.86	0.96	0.84
SIC11	Can express ideas well	0.09	93%	0.77	0.92	0.98	0.89

Discussion and Conclusion

This study proposes holistic CT, which refers to an approach to complex problem solving that comprises both skills and attitudes. A three-round FDM with experts from the computer science discipline and information technology-based industry was conducted to validate that this set of constructs represents the knowledge and attitudes identified from the current literature. Each construct has items describing skills related to the construct. The findings revealed ten components of CT skills and attitudes (Figure 1). Teamwork ranks the highest among the components proposed in this study, followed by communication, spiritual intelligence, generalization, problem-solving, algorithmic thinking, evaluation, abstraction, decomposition, and debugging. This result demonstrates the importance of attitudes in the process of solving problems. Furthermore, the importance of each item was calculated from the experts' responses, and the results prompted the following discussion.

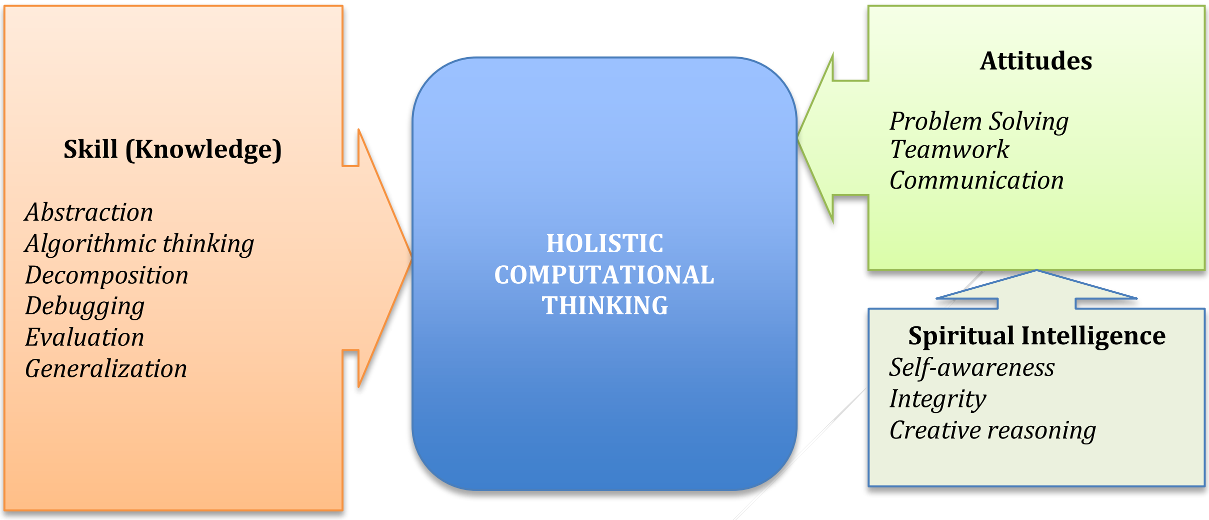

Figure 1. Hi-ACT Conceptual Framework

First, the results demonstrate that most of the items (92%) achieved the required acceptance criteria, indicating the experts' agreement that the proposed constructs were included in holistic CT, except for automation. The automation construct proposed in this study has one item, "Use tools to implement the sequence of instructions of a solution," which was identified from the literature. In the first round, experts did not provide new items. After the third round, the consensus criteria for the only item of Automation were not achieved. Thus, the item was discarded. The Automation construct was also discarded. This exclusion reflects that CT does not necessarily involve a computer to implement a solution plan. The use of computer programs to automate the execution of a set of instructions was highlighted by (Bocconi et al., 2016; Lee et al., 2011). The authors argued that instructing a computer to execute a set of repetitive tasks is labor-saving, fast, and efficient compared to human processing power. However, according to (Wing, 2008), the 'computer' could be a 'metal' machine and could also be a human, because humans do computation and information processing as 'metal' computers do. Therefore, this finding supports the thought that involving a computer (hardware) in CT is not mandatory.

Second, the core concept of abstraction is the process of filtering out unnecessary details. The experts agree that removing unnecessary details can reduce a problem's complexity. By contrast, an agreement was not reached on "Unnecessary to keep specific detail" and "Excluding unnecessary detail from the model." Therefore, abstraction deals with selecting the unnecessary details from the valuable and necessary ones in the context of the present study but not to completely remove them. One expert argued that the details that were initially considered unnecessary might be useful (for the same problem) in different circumstances.

Third, the experts' responses reveal that teamwork ranks the highest among the eleven holistic CT constructs. Therefore, working well with others is critical when dealing with a complex problem in the workplace. Communication, spiritual intelligence, generalization, problem-solving, algorithmic thinking, evaluation, abstraction, decomposition, and debugging follow teamwork. According to the result, elements of attitude rank higher than those of knowledge. This result supports previous studies' (Gribble, 2014; Saputra, 2014) claim that Indonesian workplaces require integrity, teamwork, communication, and problem-solving skills, among others. Such skills should be considered in preparing graduates to succeed in a rapidly changing field (ACM and IEEE Computer Society, 2013).

Finally, one fundamental assumption of this study is that spiritual intelligence is applicable as part of problem-solving skills included in CT attitudes. Kadkhoda and Jahanic (2012) argued that spiritual intelligence is an essential context of a holistic approach to solving a problem for it has the abilities and competencies for every personal and social problem without limitation. The attitudes that reflect spiritual intelligence, such as self-awareness, creative reasoning, integrity, and asking "why" questions are beneficial in challenging situations for simplifying or solving problems. As Table 11 indicates, spiritual intelligence is acknowledged as part of CT elements. Integrity, which ranks the highest among spiritual intelligence's sub-constructs, implies that solving complex problems calls for values that prompt one to be helpful, supportive, respectful, and trusting of others; honest, and diligent. Such values are mainly required in teamwork because integrity maintains the relationship among team members.

In conclusion, the findings of this study are important, given the fact that most previous CT studies focused on cognitive skills. This study contributes to an extension of CT literature by providing comprehensive concepts of CT. It cogitates on a set of essential skills and attitudes significant to CT as a strategy to solve complex problems. In particular, it comes up with a set of indicators that should be beneficial to measure CT competency of undergraduate students.

Given the importance of proficiency in information technologies and complex problem-solving in the digital workplaces, CT is a must for students nowadays. Undergraduate students are encouraged to gain an understanding of CT in order to enrich their abilities to solve complex problems in the real world and to acquire valuable skills to become relevant in the digital workplaces. Educators are recommended to incorporate CT skills and attitudes in their teaching materials for improving complex problem-solving abilities among students. It is also crucial for the educators, particularly those from non-computer science disciplines, to understand CT. Thus, the findings of this study could be in use during programs to introduce educators to CT. Finally, higher education institutions today are prompted to consider holistic CT to prepare qualified future graduates.

The holistic CT concepts proposed in this study were established in the Indonesian context is acknowledged as a limitation of this study. Despite that fact, the holistic CT indicators were defined based on the prominent literature on CT that provides perspectives from international working groups (e.g., the CSTA & ISTE's project on CT and the ACM & IEEE joint task force on CS curricula). The findings of this study, therefore, could be applied on a broader scope. Further study design for diversified countries is needed. Lastly, a study that engages students from various disciplines could be worthwhile in further examining the constructs and items' validity and reliability proposed in this study.

Acknowledgement

This research is funded by the Universitas Klabat and the Ministry of Education, Malaysia under Translational Research Grant Scheme TRGS/1/2018/UKM/01/6/1.

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