An Assessment of the Challenges Affecting Students' Conceptual Understanding of Algorithmic Thinking: The Case of Senior 3 Students in a Rwandan School

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Abstract
This article reports the current state of Senior 3 students' algorithmic thinking (hereafter, "AT") in Kigali, Rwanda. AT is one of the important abilities in computer science education (hereafter, "CSE"), and has great significance for ICT nation toward the Vision 2050. In Rwanda, the programming in CSE has been made compulsory; however, there has been no research on definition of AT skills and on the status of Rwandan students. AT skills require structurization of repeated events (i.e., iteration) toward efficiency. As the case study, 44 students were chosen by convenient sampling and assessed by an unplugged assessment. Then, four of them were interviewed to grasp their understanding more conceptually. Resultantly the majority had basic AT skills. Interestingly, some students were able to grasp repetitive phenomena within the iteration but were not able to represent it using iterative structure. We propose the necessity of teaching how to construct iteration in CSE.

***Keywords**: Computer science education, Conceptual understanding, Algorithmic thinking (AT) skills*

Introduction

The emergence of computers in the 20th century made a tremendous impact on the processing of information. Currently, society is knowledge-based and replete with knowledge and information. Therefore, we must acquire the ability to process information and to utilize computers effectively as a basic skill (National Research Council [NRC], 1999; United Nations Educational, Scientific and Cultural Organization [UNESCO], 2002). Thus, programming has become widespread and compulsory in basic education. Countries that have made it from the primary education level include Russia in 2009, Hungary in 2012, the United Kingdom in 2014, and Australia and Finland in 2016 (Ministry of Education, Culture, Sports, Science and Technology -Japan., 2015). Rwanda had also set since 2016 (Rwanda Ministry of Education [RME], 2016).

In order to process or to access information for any purpose, we must input a command to the computer to process that information. This information processing that is carried out inside computers is compared to a human brain and is called algorithmic thinking (hereafter, "AT"). The term AT is commonly recognized as one of the most important abilities in computer science (hereafter, "CS") and/or programming education (Futschek, 2006; Knuth, 1985; Tucker et al., 2003). Programming in education recently has had two major trends, that is, *from vocational training to technology education for all* and *from skills education to problem-solving skills development* (Matsuda, 2017). Naturally, there are some benefits of the practical use of computers in programming. For example, students enjoy the perks of technology and programming, thereby deriving a positive educational experience in addition programming practice motivates them to learn and to gain confidence in the subject (Bocconi et al., 2016; Computer Science Teachers Association [CSTA]., 2016). However, there is a difference between *being able to do* something with a simple kit of learning materials and *understanding* the underlying CS concepts (Futschek, 2006). Conceptual understanding in students remains a challenge regardless of programming practice. Even if programming languages are developed for education, like Scratch, they do not help with conceptual understanding and learning major concepts such as iteration (CSTA, 2016; Grover & Basu, 2017). Here, iteration means the repetition of instructions a specified number of times or until a condition is met (Sulov, 2016).

Developing countries require improvement of both information and communications technology (ICT) tools and network environment, and quality of CS education (hereafter, "CSE"). It is often expected if schools have ICT tools, innovative learning will take place naturally (Rubagiza et al., 2011). However, in many developing countries, such tools are limited in quantity and accessibility and, therefore, the tools and environment aspect of ICT tends to be emphasized more often in those countries. Under the Vision 2020 (Republic of Rwanda, 2012) and Vision 2050 (Republic of Rwanda, 2020), Rwanda is no exception. On the other hand, the current research takes emphasis on the quality aspect of programming in CSE because it requires a specific mode of thinking within programming activity. This specific mode of thinking does not remain only at ICT skills acquisition but rather conceptual understanding of principles of algorithms. Additionally, the number of distributed computers is not sufficient relative to the number of students in each school. Thus, there is a need to identify more fundamentally what AT is and how to enhance students' AT skills conceptually effectively with limited means.

Literature Review and Objective

Algorithmic Thinking

According to UNESCO (2002), to play an active role in a knowledge-based society, the objective of programming education, which "should be able to solve routine everyday problems in an algorithmic form" (p. 121) requires the acquisition of AT. The term *algorithmics* was coined along with computer and defined as the study of how algorithms (programs) are constructed and executed (Knuth, 1985). AT becomes necessary when algorithms are constructed to solve similar problems repeatedly and efficiently by saving thinking time (Csizmadia et al., 2015). The core concept of AT is the structurization of repeated events (i.e., iteration) and orientation toward efficiency. Recently, computational thinking (hereafter, "CT") is widely accepted as a 21st century skill that all children should master (Wing, 2006). Denning (2009) argued that what was known as AT in the 1950s and 1960s was renamed CT. Meanwhile, Bocconi et al. (2016) stated that the only difference between CT and AT is the involvement of computer practices.

Rwanda is one of the countries to make programming in CSE compulsory. In fact, to "develop CT and logical reasoning through computer programming" is one of the goals at the ordinary level (Rwanda Education Board [REB], 2015). Although the term *AT* is not explicit, structured programming and understanding of iterative structures are regarded as basic knowledge in the curricula (Kamoce et al., 2017; Mwesigye et al., 2017; REB, 2015). Hence, it is important to clarify what kind of ideas should be used to grow specific procedures and to realize it as iteration. Therefore, the term *AT* is intentionally used in this study rather than *CT*.

Iteration Concepts in AT

Structurization of repeated events can be called an iteration that is a necessary mechanism embedded within commands, such as “loop,” and “do while.” Iteration expresses the repetition of sequential instructions a specified number of times or until a condition is met (Sulov, 2016). To construct an iteration, it is necessary to distinguish between processes that are repeated and those that are not. This enables students to understand the part which repeats in each cycle and to understand how and when such iteration terminates (Grover & Basu, 2017). Here, Knuth (1985) identified the characteristics of AT as economy of operations, dynamic notion of the state of process, and finiteness. The iterative structure can never be expressed without particular intention since sequential repetition is more natural for students and can provide the effect as an iteration. Therefore, an economy of operations is a major factor which causes creation of an iteration. For example, if an operation would be repeated 100 times, the program in sequential format and thus writing the same algorithms 100 times become very long. Based on this understanding, we regard iterative structure as *pattern cognition* and *patterning*. According to Mulligan and Mitchelmore (2009), a mathematical pattern is a predictable regularity with numeric, spatial, or logical relationships. Pattern recognition has stages and individual student responses tended to be at almost the same developmental stage.

The difficulty in learning iteration concepts often has been observed across countries (see CSTA, 2016; Futschek, 2006; Grover & Basu, 2017), and also was identified as providing universal difficulties. In Rwanda, Vernon (2020) mentioned that words alone are not enough to understand and to explain the process of iteration and changes in each state. This is because schools in Rwanda rely primarily on oral and written language, and there are few opportunities to illustrate such diagrams even in programming education. Specifically, it is hypothesized that conceptual understanding of iteration and thus the representation of the iteration process might be a major issue in Rwanda.

Scratch programming, which originates from Logo programming, requires more overt instruction. In fact, the Rwandan curricula (Kamoce et al., 2017; Mwesigye et al., 2017; REB, 2015) for programming looks almost like an instruction manual on how to undertake programming. Previous studies (CSTA, 2016; Futschek, 2006; Grover & Basu, 2017), however, have shown that students cannot acquire advance thinking such as AT without pedagogical intervention.

Patterns to Represent Iteration Concepts in AT

Marr (1982) proposed that the information process is divided into three levels—(i) computational theory; (ii) algorithmic or data representation; and (iii) hardware implementation—and showed that each level of thinking is interconnected but relatively independent. In general, programming education is approached from the third level, and so computer operation skills and syntactic difficulty of programming language are taken up as issues before reaching the second level (see Futschek, 2006). However, the actual computer operation skills of Rwandan senior 3 (hereafter, "S3") students are quite low. This can be associated with some basic facts that only 3.9% of households own computers, and the computer literacy rate among the population aged between 15 and 24 years is 15.2% (National Institute of Statistics of Rwanda, 2021). Moreover, under ICT in education policy (RME, 2016), computer equipment has been distributed to all schools, but their practical use is still limited.

With the above understanding this study focuses on the second level of the information process with Rwandan S3 as research participants. Here, unplugged material (Bell et al., 1998) without involvement of computer facility is applied for this purpose because focus is on conceptual understanding of iteration process. The typical task for this purpose is understanding the route corresponding to a map in everyday language, and one of Bell et al.'s (1998) proposed unplugged materials. It seems similar to Logo programming, which is the origin of Scratch. Both of these are required to control an object with language by recognizing space and predicting the state of the object (i.e., *Turtle in the case of Logo*) while accounting for time. Moreover, Pittalis et al. (2020) stated that diagrammatic representations are effective in expressing patterns and/or rules linguistically.

Rationale of the Study

From the above under the Vision 2020 and 2050, Rwanda has promoted ICT skills toward a knowledge-based society. And the CSE include programming is important in the education policy. In developing countries, especially in Rwanda under such situation, it is engaged with improvement of both ICT environment and at the same time CSE quality. AT is the necessary skills in the CSE as in the 2-(1) section but the difficulty of learning iteration concepts has often been noted across countries as in the 2-(2) section. Under this condition, no researchers have undertaken the study on Rwandan students. We expected that clarifying the current state at the end of basic education would contribute to the design of comprehensive CSE in the future.

Research Objective

The objective of this study was to develop an assessment test in order to identify the current state of S3's AT skills conceptually in Rwanda. Here, current states refer both to the stages of structurization and characteristics of patterns. S3 is in the final stage within the 9 years of free compulsory education in Rwanda. Research questions are

- RQ (1) What is definition and components of AT
- RQ (2) What are the current states of AT particularly iteration concepts in Rwandan S3 students

Clarification of current states of students' AT skills can provide suggestions for quality improvement of CSE and they are related to curriculum development and pedagogies.

Research Methodology

Research Local and Subjects

No studies in this topic are done in Rwanda and so we need to explore ways of identifying the states of students' AT skills. In terms of explorable study, this article is discussed deeply on small sample as a case study. During the COVID-19 pandemic, it was difficult to go to another country and even district from own residence. For the convenience of the research collaborator who works in the capital city, Kigali, the research subjects were from a day public school in Kigali. In Kigali, most schools are day schools. Day schools provide fewer opportunities to practice programming than boarding schools although both kinds of students require having AT until the completion of the ordinary level (REB, 2015). Thus, a day school was chosen to discover students' current states of AT skills. In order to select sampling population, we employed the convenience sampling in assesment test and nested sampling in interview phase (Onwuegbuzie et al., 2007). The convenience sampling is a type of non-probability sampling that involves the sample being drawn from that part of the population that is close to hand. This type of sampling is most useful for pilot testing. The nested sampling in interview stage was used to those who represented the iteration concepts in the assessment test In short, 44 students took the assessment test and out of these, four students were selected for interviews.

Research process

We employed unplugged materials as an assessment of students' AT. However, it was not possible to find a validated framework due to the scarcity of previous studies. Therefore, in this study, we applied a formative evaluation process to develop an assessment tool (Putra, 2021). This process consisted of a review by local experts, two-time user evaluations by 66 students who were also selected by convenience sampling, and a confirmation of the validity. They were no duplicates for respective participants, 44 students in the implementation phase. Students' AT was captured quantitatively by the developed assessment test, was complemented qualitatively by the interviews.

Distribution of roles was as follows. The first author developed mainly a draft assessment test and conducted the research online, whereas the second author accommodated the survey on the site. The third and fourth authors participated in the development and revision of the framework and interpreted the students' results.

Table 1

Time Flow of Formative Evaluation

	Self-evaluation	Expert evaluation	User evaluation	User evaluation	Implementation
Date	From April to May, 2021	From May to June, 2021	July 7th, 2021	July 15th, 2021	October 20th, 2021
Participants	First author	Second, third and fourth authors, and local schoolteachers	First pilot assessment test on 12 students	Second pilot assessment test on 54 students	Assessment test on 44 students, and interviews with 4 of them

Outline of the Assessment Tasks

Regarding the RQ (1), the definition of AT is intended to solve a problem efficiently, and its components are identified as conceptual understanding of iteration and orientation of solution, based on the previous research.

Thus, assessment tasks were set. Q1 represents a conceptual understanding of algorithms in everyday language and/or illustrative representations. We conducted whole research in English because of the school language in S3. It aims to find not only patterns, but specifically patterns in the route (process) to reach the destination and to represent them as a control structure. Questions in the second set, Q2, inquired about their intention about problem solving to use more efficient way rather than repeated sequential representation.

Table 2

Outline of the Assessment Tasks

Q1: Structurization		**Question Type**
1-1	Mapping following instructions	Selecting an option (from four alternatives)
1-2	Illustrate following instructions	Drawing the moving route following indicated processes
1-3	Express and illustrate own instructions	Free writing based on the Q1-1 and Q1-2
Q2: Orientation of Solution		**Question Type**
2-1	Your preferred strategy	Selecting an option (from two alternatives)
2-2	Fast strategy for you	Selecting an option (from two alternatives)
2-3	Accurate strategy for you	Selecting an option (from two alternatives)
2-4	Explanation on each advantage	Free writing

Please refer to Appendix 1 for the whole assessment tool.

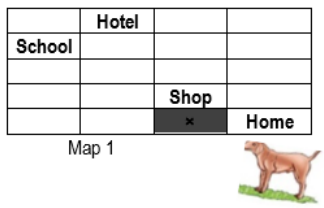
For example, in Q1-1 (Figure 1), students were asked to choose the appropriate process from options A, B, C, or D to reach school from home, the initial state in this case. The multiple-choice question was used here to identify categories of students' thinking through typical wrong answers as a choice. The correct answer is C, but if students chose another option, we interpreted their answer as indicating some difficulty in manipulating and controlling objects through language. In Q2, there are two strategies: Strategy-A for counting them in groups of 10s, and strategy-B for counting them one by one. Students have to choose a strategy and provide a reason why they chosen the strategy, such as speed or accuracy. Through this question, we expect to find students' tendency of using preferred reasoning.

Figure 1

Task of Q1-1: A part of the Assessment Test

(1) Choose an appropriate process among A, B, C, and D so that the dog arrives at the school.

A: Dog takes the move [3 cells up, 3 cells to right]
B: Dog repeats the move [1 cell up, 1 cell to left] 4 times
C: Dog repeats the move [1 cell up, 1 cell to left] 3 times
D: Dog takes the move [2 cells up, 2 cells to left, 1 cell up]



Evaluation Method

The rubric for the assessment test was developed based on the PASA framework of Pattern and Structure Assessment (Mulligan & Mitchelmore, 2009). Originally, PASA had four stages, namely, the pre-structural stage

(PRS), emergent stage (ES), partial structural stage (PS), and structural stage (S). However, in this study, the initial stage (IS) was added before the PRS, which shapes cases like no response or no understanding of task content. Each task has five stages, including IS. Appendix 2 shows the rubric on how to categorize and to evaluate stages of students' responses. The four interviewees were selected based on their responses which are used iteration concept and repeated the same process in the test. Interviews took place in school, and each participant was interviewed only one time formally. Interviews conducted by first author through online and second author in the field and transcribed the recorded interview protocol by first author. The interviews followed three steps: (a) ask students to read aloud the task, (b) confirm their understanding of the meaning of the task, and (c) ask students to answer the task (Newman, 1977). RQ (2) was analyzed by this kind of mixed method.

Results

Tasks on Structurization

In Q1-1, Options A, B, C, and D were selected by 13, 1, 13, and 13 students, respectively. Because the question is assessed in terms of the selected option and their description such as an arrow and a line on the map (see Appendix 2: Rubric), there is no direct correspondence between the selection of an option and the measurement stage of Q1-1 on Table 3. C was the correct answer. However, the same number of students selected options A and D. With respect to Option A, students had misunderstood direction (Williams et al., 1993). This mistake commonly occurs due to lack of language mastery and can be found both in transition from linguistic representation to positional relation (Q1-1 and Q1-2), as well as from positional relation in the map to linguistic representation (Q1-3). With regard to option D, students might have mistakenly recognized arrival as reaching one square before the destination. Some students consistently represented the same type of answers both in Q1-2 and Q1-3. They chose Option D with confidence. In other cases, the selected choice and illustration on the map did not match. Because Q1-2 and Q1-3 also included a description from students, we further assessed them using the framework and interview data. Q1-2 asked the students to draw the indicated processes 1 to 4 on the map. There were a variety of responses. To show structural understanding for each stage, some examples are shown in Figure 2. The PRS response mimics the route without following the processes and shows uncertain understanding of the problem setting. The ES and PS responses show going down and right three times each, but do not have a consistent pattern of iteration. The S response is correct because the object can get home from school using the indicated steps.

Table 3

Distribution of Measurement Stages on Q1-1, Q1-2, and Q1-3

	Q1-1	Q1-2	Q1-3
IS	5%	18%	18%
PSR	32%	9%	21%
ES	34%	18%	11%
PS	9%	16%	14%
S	20%	39%	36%

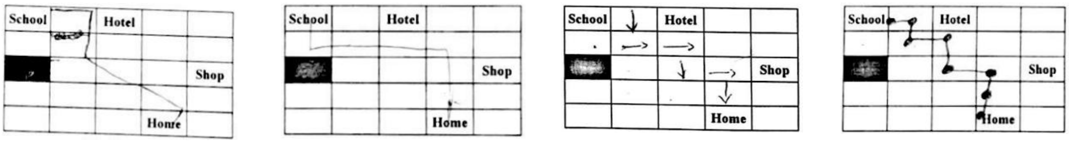
Total	100%	100%	100%

Source: Field data, 2021

Figure 2

Typical Students' Responses at Four Structural Stages on Q1-2

PRS ES PS S



Source: Field data, 2021.

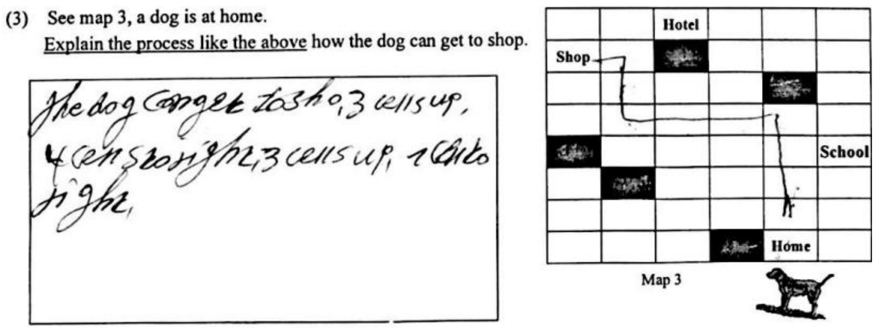
Task Q1-3 required students to create an original process in which the object would get to its destination. The students were expected to mimic the iterative structure introduced in the previous tasks, but only 23% of them did so, including those who wrote the same process repeatedly. This shows that students prefer a sequential strategy. Analysis of three tasks in Q1 identified three difficulties in AT, namely, (i) lack of accuracy, (ii) mismatch between linguistic and description (illustrative representations); and (iii) difficulty of iterative structural representation. Each of these difficulties is discussed in the following sections.

Lack of Accuracy

Figure 3 illustrates a response from one of the interviewees. Her cell counting is unstable for the number of steps. Sometimes she includes the current cell, and sometimes she starts from the next cell. If the way of counting cells and/or the recognition of the current location are not consistent, this can be judged as a misconception. Additionally, she demonstrates the left and right misconceptions (Williams et al., 1993). However, she shows the basic ability to operate objects using language. In algorithmic form, the programming requires a precise representation because such small mistakes in linguistic representation results in a completely different route or does not work as a computer program. Thus, she can be judged as lacking in programming ability (ES) although she demonstrates a large ability of algorithm representation.

Figure 3

Student's Response Concerning the Lack of Accuracy on Q1-3



Linguistic expression: "The dog can get to shop, 3 cells up, 4 cells to right, 3 cells up, 1 cell to right."

Source: Field data, 2021.

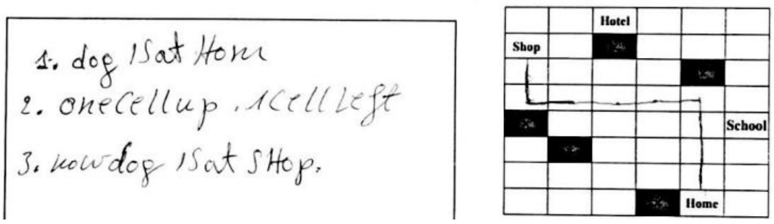
Mismatch between Linguistic and Illustrative Representations

During the interview stage, we confirmed how the dog moves from the home to the shop on the map. His response is different from the four indicated processes. From the observation, it seemed that he did not follow the four processes but used his own thoughts. After finishing the illustration of Q1-2 for the first time, he was asked to draw the route following the four processes again, but he could not redraw it correctly. This was because he thought that the problem was already solved once the dog arrived home from school. Resultantly, he was evaluated as ES.

Next, for Q1-3, he was asked to draw the route on the map first, and then to explain the rationale behind the illustrated route in words. Although he understood the problem setting of a dog navigating from home to the shop well, his drawing and linguistic explanation were different (Figure 4). During the interview, however, he confidently stated that both were the same. Furthermore, he was asked to explain the illustration on the map orally rather than in writing. The oral explanation was the same as the written representation: "one cell up, one cell left." He was evaluated as PRS because it was difficult to correspond the linguistic and the illustrative representation.

Figure 4

Student's Response at Interview Survey on Q1-3



Linguistic expression: "(1) dog is at home; (2) one cell up, 1 cell left; (3) now dog is at shop"

Source: Field data, 2021.

Structurization of Iteration

Here, the responses that described the iteration concept and repeated the same process were analyzed. In Case 1 of Figure 5, a student used an iterative structure, but when he repeated the process of "2 cells up, 2 cells left" (he also misunderstood left and right) three times, the object passed through the shop. However, as the object can get to the shop, it may be said that he correctly used iteration at this stage. Hence, he was evaluated as S.

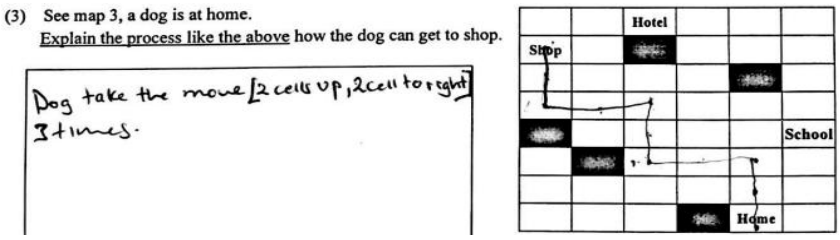
Additionally, the most popular response in Q1-3 is Case 2 of Figure 5, which showed "2 cells up, 2 cells left, 2 cells up, 2 cells left, 1 cell up", which was also evaluated as S. The same process appeared twice but is expressed not in an iterative structured method. For this problem, there was no need to iteratively construct the answer and it was not so difficult to write the same processes repeatedly. Therefore, students preferred to use sequential representation rather than iteration.

Students who wrote the same processes repeatedly might be able to rewrite them as iteration, if they felt that the iterative structure was necessary. In the interviews, we investigated whether the students would be able to create repeated processes in terms of iterative structure.

Figure 5

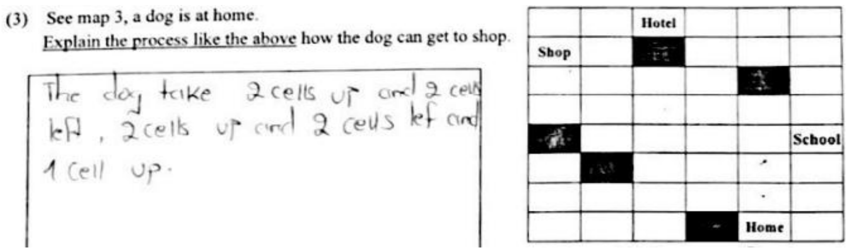
Responses Using Repetition and Iteration on Q1-3

Case 1:



Linguistic expression: “Dog take the move [2 cells up, 2 cell to right] 3 times.”

Case 2:



Linguistic expression: “The dog takes 2 cells up and 2 cells left, 2 cells up and 2 cells left and 1cell up.”

Source: Field data, 2021.

We selected a girl’s interview (see Table 4). After confirming her understanding of Q1-3, we asked her to draw on the map and to describe her process in writing and then orally. She declared that she would mimic the process of Q1-2. However, her response did not use an iteration. She could understand and graphically represent the process with the iteration structure in Q1-2, but when she was asked to express it in writing and orally in Q1-3, she only repeated the same process as sequential, not iterative structure. She wrote and spoke about the process one by one while solving the problem; thus, it could be assumed that she had an idea of inductive style. After her first response of Q1-3, she was asked to describe the process using an iterative structure in Q1-3. She declared that she would use the iteration as in Q1-2’s instruction. However, what was written was the same process as the first one. Even though she could understand repetition and iteration, it was difficult for her to express it in writing and orally.

Table 4

The part of Interview Protocol (S: student, R: researcher)

9:56	S	Question is it is it is talking about to show the process like above (*means Q1-2*) to show the dog and and get to shop.
10:12	R	okay. So can you write the dog's process to get to shop
10:22	S	Yeah. First dog is at home. Un Ah the the in the question.. they say explain the process like above. I'm I'm going to like above
10:31	S	I'm going to use the process above. I'm going to use process number 2 (*means the part of indicated process of Q1-2*). one cell up two cell up cells and two cell up two cell up two cells on the left and the one cell up
11:03	R	Excellent. Please write by word
11:07	S	Yeah. Process number 1, dog …two cell, two cell left down…two cell up…cell up (*She is speaking small alone)*
12:42	R	Okay, please read your process.
12:45	S	Process number 1, dog is at home. Process number 2, dog will take move two cell up, two cell to left, another cell up, two cell left. Process number 3, dog will take another move to.. one cell up. And, dog is at shop.
13:11	R	Excellent. You really did well
13:19	R	I ask you additional task. Please explain another process using repeat concept.
13:32	R	Please see the question 2. says that "cat repeats the move one cell to right one cell down three times".
13:42	S	Un.. Yeah
13:44	R	Can you utilize this repeat concept? Repeat two times or three times with same process.
13:54	S	Yes. I'm gonna, I'm gonna use this second process of number 2.
14:02	R	Okay, can you write down your another process using repeat concept
14:05	S	*(The student is in writting)*
15:39	R	Okay, please read aloud another process.
15:45	S	Process number 1, dog is at home. Two uunn.. Process two cell, two cell up, two cell left, two cells up, two cell to left and one cell up
16:06	R	What is the difference between before and this process? What is the difference of your two processes?
16:24	S	Difference is…. there is no difference
16:29	R	Are there same?
16:35	S	because because I.. I use the same processes

Source: Field data, 2021.

Orientation of Solution

Consequently, (see Table 5), students tend to prefer using the grouping strategy (way- A) in the case of the time aspect. In the case of accuracy, they slightly favored the counting-all strategy (way- B). Approximately 36.3% of the students who chose way-A stated that counting by grouping had advantages such as speed and accuracy, and hence, they preferred to use it. Meanwhile, 36.3% of the students perceived that grouping had the advantage of speed, but not accuracy. They might be under the impression that counting one by one would give more accurate answers. Furthermore, the other 9% of the students recognized that the counting-all strategy has the advantage of accuracy but is slower. Because they preferred counting-all, their solutions emphasized accuracy rather than speed.

Table 5

Distribution of Students' Response Combination Q2-1, Q2-2, and Q2-3

Q2-1 preference	Q2-2 speed	Q2-3 accuracy	Percentage
A	A	A	36.3%
A	A	B	36.3%
A	B	A	2.2%
A	B	B	2.2%
B	A	B	9.0%
Another combination such as BBB, BBA, BAA.			0.0%
No answer			14.0%

Source: Field data, 2021.

Discussion

This research reveals the following results: First, S3 students in Rwanda are expected to have the basic ability of AT; to "think in terms of sequences and rules as a way of solving problems and understanding situations" (Csizmadia et al., 2015, p. 7), to capture the dynamic changes of objects and to express and to control the structure of events in language. Second, although they were able to capture the elements of structure, they found it challenging to structure it as a control structure from the quantitative view of results Q1-1 to Q1-3. There were many challenges in the linguistic representation, such as mismatch between the linguistic and illustrative representations, and lack of accuracy. Specifically, it was found that expressing iteration is difficult according to the qualitative analysis of students' responses of the assessment test and interview protocol. Third, it was found that more than 70% of S3 students prioritized the speed at which they arrived at their solution. Although this result might depend on the task setting on counting concrete objects, it suggests that students are likely to use the iteration concept if they recognize that iteration can speed up processing. In Rwandan curricula, the iteration concept, including repetition, was mentioned only in terms of the economy of the creation. Hence, we hope that the iteration solution will be emphasized and mentioned in terms of speed in the CSE curricula.

This research was conducted by applying a case study method to fill the gap left by a dearth of previous studies. Because Rwanda has immediately set programming as being compulsory from primary level and prioritized the development of computer environments in all schools to aim at creating an ICT nation, it is imperative to accumulate case studies to find a solution to the misconceptions identified in this research. Furthermore, we claim that we can validate the tool rationally by following the AT definition based on the previous studies as well as by taking a formative evaluation process with local experts to ensure internal validity. Under the restriction of the pandemic, it was difficult to conduct the assessment widely, and the generalization of this research is still pending. In order to improve an external validity, it is required to implement this assessment with students who are from other schools as well as other districts in Rwanda to collect rich data.

Conclusion and Recommendation

Rwandan students are expected to learn and to utilize programming languages for their future. This study revealed that even S3 students still struggle to represent algorithm even in everyday language. Improving English ability is not a target of CSE. However, it is crucial for educators to be aware of the issues when introducing programming because students need to refine how to present their ideas about procedures with a formal language to others (including to a computer).

The curriculum must support students in their developmental thinking, rather than only forcing them to think naturally in an algorithmic way through the programming practice and technical skill acquisition as well. Thus, it is necessary to specify what kind of ideas should be used to target procedures and knowing how to structure repeated events as iteration in language. The establishment of such in-depth thinking and conceptual understanding of iteration will contribute to the acquisition of skills that can cope with day-to-day technological changes.

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Appendix 1. Assessment Test

The repeat concept helps you avoid writing the same process several times.
If you wish to utilize this concept, necessary find out the structure of a term in the pattern.

Question 1: Structurization

Map 1 presents the locations of a dog and spots in the town. Black cells are not possible to pass through because of the construction. In the beginning, the dog is at home. If the dog moves 1 cell up and 1 cell to left, it will arrive at the shop.

(1) Choose an appropriate process among A, B, C, and D so that the dog arrives at the school.

A: Dog takes the move [3 cells up, 3 cells to right]
B: Dog repeats the move [1 cell up, 1 cell to left] 4 times
C: Dog repeats the move [1 cell up, 1 cell to left] 3 times
D: Dog takes the move [2 cells up, 2 cells to left, 1 cell up]

	Hotel		
School			
		Shop	
		×	Home

Map 1

(2) Draw the moving path of the cat on Map 2 following 4 processes.

1: Cat is at school
2: Cat repeats the move [1 cell to right, 1 cell down] 3 times
3: Cat takes the move [1 cell down]
4: Cat is at home.

School		Hotel		
×				Shop
			Home	

Map 2

(3) See Map 3, the dog is at home.
Explain the process like the above how the dog can get to shop.

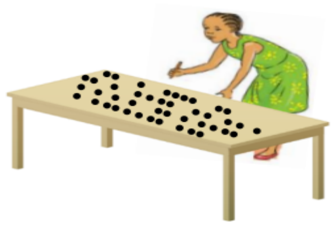
		Hotel			
Shop		×			
				×	
×					School
	×				
			×	Home	

Map 3

Question 2: Orientation of Solution

In this question, you have to answer your opinion.
There are 50 circles at a random line on the table.
When a girl counts aloud all circles, she comes up with 2 optional ways of counting (A or B).

Way-A	The girl makes a set of 10 circles and repeats it until all the circles are organized. She reads aloud the numbers by 10s, until all sets are pointed (this means reading aloud by 10, 20, 30, 40, 50).
Way-B	The girl repeats to count up aloud each circle until she counts the last one.



Answer your opinion, any answers will be correct.

(1) Which way (A or B) do you prefer to use when counting lots of circles?	Answer is
(2) Which way (A or B) can achieve counting 50 circles faster?	Answer is
(3) Which way (A or B) can accurately achieve counting 50 circles?	Answer is

(4) You can write your opinion into one or both boxes below.
(If A has benefits) Explain in your word the benefits of making a set of 10s.
(If B has benefits) Explain in your word the benefits of counting all.

Appendix 2. Rubric

Q1s	IS	PRS	ES	PS	S
1	No response	Incorrect. Select A, or if there is a description on the map, it is not a track from home to school, or the illustration ignores the squares.	Incorrect. Select B or D or illustrate the process as B or D on the map. It seems to have a misconception of arrival; case B goes through but overs the school; case D stops one square before the school.	Partially correct answer. Select C, but the voluntary written illustration does not follow the instructions of C. Therefore, the answer is doubtful whether it can be drawn according to the instructions.	Correct answer. Select C and/or illustrate the same process of C on the map. Correct the understanding of the process of the dog going to school.
2	No response or understanding of the task. The illustration does not connect the school to home (the start is not from school, or the end is not home).	Incorrect. The cat goes home from school, but students do not understand or forget the pre-condition of the task. The illustration goes through the black cell or ignoring the squares, e.g., moving diagonally.	Incorrect. The illustration connects the school and home with understanding of the pre-condition. However, it incorrectly follows the specified process. It seems difficult to follow it or create his/her own route.	Partially correct answer. The illustration almost followed a specified process. However, it is unclear whether the route is not repetitive and whether the algorithm was followed strictly.	Correct answer. The specified process is illustrated with clear iterative process. It is possible to follow the algorithm precisely.
3	No response or no understanding of the task. The student's description does not allow the route (the start is not from home, or the end is not the shop). It seems difficult to operate an object by language.	Incorrect. Although the description seems to go to shop from home (Student operates by language), it exceeds or fails to reach the destination. Or there is no description but the illustration on the map shows correctly. (Difficult to indicate by language but able to illustrate).	Incorrect due to some misconceptions. The description allows the dog to go to the shop from home, but the illustration varies from reader to reader because it ignores the cells (it is unclear if student is able to match linguistic and illustrative representations).	Partially correct answer. The description allows the dog to go to shop from home. The student can correspond the description and illustration. However, there are some misconceptions about the cell counting and/or arrival.	Correct answer. The description allows the dog to go to shop from home clearly.