

A multimodal approach to identifying affective states in Computational Thinking practices

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Abstract: Computational thinking (CT) presents a common challenge: the limitations of assessment instruments. This article seeks to discuss how the multimodal approach (through the identification of students' affective states) can contribute to the assessment of the development of CT skills. As a method, it is considered the experiment of activities in pairs, with the participation of 40 high school students, analyzed in the tactic of plugged computing. During data collection, the following instruments were used: pre-test and post-test, video capture and open questionnaire. We separated into groups of “Have Gained” and “No Gained” for better characterization of affective states through the EZ-MMLA Toolkit tool, which results in student engagement in carrying out activities. Therefore, this study is a subsidy for evaluation frameworks in future work.

Keywords: Assessment of Computational Thinking, Affective States, Multimodal, Plugged Computing

Uma abordagem *multimodal* para a identificação de estados afetivos em práticas de pensamento computacional

Resumo: O pensamento computacional (PC) apresenta um desafio comum: as limitações dos instrumentos de avaliação. Este artigo busca discutir como a abordagem multimodal (através da identificação dos estados afetivos dos estudantes) pode contribuir para a avaliação do desenvolvimento das habilidades de PC. Como método, considera-se o experimento de atividades em duplas, com a participação de 40 estudantes do ensino médio, analisados na tática de computação plugada. Durante a coleta foram utilizados os seguintes instrumentos: pré-teste e pós-teste, captura de vídeo e questionário aberto. Separamos em grupos de “Teve Ganho” e “Não Teve Ganho” para melhor caracterização dos estados afetivos por meio da ferramenta *EZ-MMLA Toolkit*, a qual nos resulta um engajamento dos estudantes na realização das atividades. Portanto, este estudo é um subsídio para *frameworks* de avaliação em trabalhos futuros.

Palavras-Chave: Avaliação de Pensamento Computacional, Estados Afetivos, *Multimodal*, Computação Plugada

1 Introduction

The first conceptualizations of Computational Thinking (CT) date back to the 1960s, when the nomenclatures “theories of computation” and “procedural thinking” were used [Grover e Pea 2013]; however, it is a methodology for solving problems based on the fundamentals and techniques of Computer Science [Avila *et al.* 2017]. Given this, there is a significant amount of research on CT skills, as addressing assessment involves several scenarios discussed in the scientific community of Computing, especially about teaching programming and robotics in the educational environment [Araujo, Andrade, e Serey Guerrero 2016].

Given the Norms on Computing in Basic Education - Complement to the BNCC [BNCC 2017], which defines the competences and skills of CT, educational environments have been adopting evaluative activities with the four pillars: “Abstraction, Decomposition, Pattern Recognition and Algorithm” [BBC 2021; França 2020]. Simultaneously, discussions of

computational thinking assessments feature little valid, structured, and credible research, as well as the use of multiple assessment system approaches, which are formative and summative, for targeted and open-ended activity assignments and research on CT concepts to be used [Grover e Pea 2013].

Thus, multiple tools are used for CT assessment, such as open and closed questionnaires, *Dr. Scratch*¹, physical blocks, and code analysis, which are the most common in mappings and systematic reviews [Rodriguez *et al.* 2017]. However, the activities that integrate the teaching of CT have limitations regarding the instruments and forms of evaluation since the approaches that consider the affective aspects are still incipient because they directly influence learning since they vary in forms and contexts of the curricula and practices with the contents worked by the teachers in cooperation with the students [Mueller *et al.* 2017].

Through the existing possibilities in the literature, Multimodal was investigated in high school through the capture of elements often unnoticed in the learning processes, such as emotion and eye movements, among other human senses that are important when one wants to evaluate the assimilation of content by students [Blikstein 2013].

Given the potential of Multimodal in educational scenarios, it becomes unique in complementing and enriching traditional measures in learning, providing high-frequency data on behavior, cognition, and affective states of students [Hassan, Leong and Schneider 2021] to assess CT. Therefore, this article seeks to answer the following question: how can the multimodal approach, through the identification of affective states of students, contribute to the assessment of the development of CT skills?

This article is structured in three parts: in section 2, support is sought in the literature on computational thinking strategies in teaching and learning, developed for students within an educational environment, besides the relationship between affectivity and learning. Next, section 3 presents the proposed method for the development of the research, experiment, and data collection instruments with an approach to statistical inference techniques. Section 4 explains the results achieved. Section 5 conveys discussions on the research, and section 6 presents the final considerations of the study, its contributions, and limitations and points out some directions for future research.

2 Theoretical Foundations

The theoretical basis of this research brings together thinkers who mix the affective state with student learning, besides the conception and evaluation of computational thinking with the multimodal approach.

2.1 The relationship between affectivity and learning

Emotions, according to Kostulshi [Kostulski 2004], are superior psychological functions, therefore, culturally shaped and subject to development, transformation, or new appearances. Interestingly, there is work with emotions in educational environments to support and contribute to the teaching, learning, and assessment of students.

According to Fonseca [Fonseca 2016], emotions have accompanied the human species since its evolution and, obviously, through the development of children and adolescents, constituting a fundamental part of human learning. Faced with the emotional state that the student presents at the time of the activity, the teacher can build a profile of the students regarding their performances.

Wallon's theory comprehensively expresses affectivity as a functional set that emerges from the organic and acquires a social form in the relationship with the other, and that is a fundamental dimension in the integral formation of the individual, being an essential milestone in the pedagogical thought in the development of the learning [Burin 2019].

From a pedagogical point of view, when affective reactions occur automatically or untimely, it does not help to exercise the teacher's profession with quality, which is to teach,

¹ Available at: <http://www.drscratch.org>.

having as a correspondent the effective learning of students, nor do they help students to learn what they need [Luckesi 2014].

2.2 CT Skills

Computational Thinking cannot be presented in a single concept. This term is defined according to the teaching strategy of each institution [Barr and Stephenson 2011; Lee *et al.* 2011]. Because of this, the definition of Santana [Santana, Chavez and Bittencourt 2021] is adopted, as it meets the research as a whole by emphasizing that the CT: “[...] *It is an approach to problem-solving involving several skills, such as abstraction, decomposition, and pattern recognition. Computer science is closely related to computer science, so when using the term "problem-solving" includes formulating problems and expressing solutions that can be computed (p. 9).*

Given the four CT skills, the Computational Thinking Test (CTT) by Román González [González 2015] was adopted, which has 28 questions and is well regarded and validated by the Scientific Community in research with CT. The CTT considers that the objectives are identified with the ability to train and solve problems. However, 20 (twenty) questions that deal with computational contents (*sequence, repetition, and conditional*) were chosen.

Each question addresses skills such as Abstraction (one of the *computational thinking* skills), which ignores details and focuses on general characteristics for better problem-solving [França 2020]. In the CTT, 09 (nine) questions² involve *abstraction*: Q1, Q2, Q3, Q7, Q11, Q12, Q13, Q14, and Q15. The Algorithm skill is a finite sequence of procedures that allows for solving a given problem [Barr e Stephenson 2011]. In the CTT, 20 (twenty) questions involve *algorithm*: Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12, Q13, Q14, Q15, Q16, Q17, Q18, Q19, and Q20. Decomposition is a skill that divides a complex problem into smaller parts to facilitate its management and understanding [França 2020]. In the CTT, 09 (nine) questions involve *decomposition*: Q4, Q5, Q6, Q7, Q10, Q11, Q12, Q13, and Q15. Pattern Recognition skill is the ability to perceive similarities or differences that help make predictions and lead to “shortcuts” or “access” to the heart of a problem, often being the basis for algorithmic design and problem-solving [González 2015]. In the CTT, 13 (thirteen) questions involve *pattern recognition*: Q4, Q5, Q6, Q8, Q9, Q10, Q11, Q12, Q14, Q15, Q17, Q18, and Q20.

2.3 Assessment of Computational Thinking

There are limitations in the literature to implementing CT in the classroom, such as methods and instruments and non-standard tests in educational environments. In 2011, the National Research Council of the United States, in the Workshop on “*Pedagogical Aspects of Computational Thinking*,” elaborated the first report on the forms of evaluation. The document mentions three fundamental reasons to evaluate CT skills: i) *to analyze the curriculum and teaching materials*, ii) *the individual performance*, and iii) *to train and support trainers* [National Research Council, 2011].

Given this scenario, studies by Araújo [Araujo, Andrade and Serey Guerrero 2016] list the most common instruments in evaluations: open and closed questionnaires, surveys, logbooks, interviews, and visual and coded programming language. Few instruments are managed separately. There is always more than one instrument in the validation of skills. However, none of these instruments collect behavioral aspects in the CT evaluation process, only the student's development of CT skills.

2.4 Multimodal Learning Analysis

In this scenario, the MMLA can be an approach used to enhance CT pedagogical practices, thus being able to support methods through data capture associated with this process. Given this, Blikstein [Blikstein 2013] emphasizes the importance of using MMLA to prepare offline and online assessments.

² The capital letter “Q” will be used, followed by the numeral to identify the question mentioned.

Worsley [Worsley *et al.* 2016] presents a definition for MMLA at the intersection of three ideas: “*multimodal learning, multimodal data, and computer-supported analysis.*” At its core, the MMLA utilizes and triangulates ways of non-traditional and traditional data to characterize and (or) model student learning in complex learning environments.

According to Hassan [Hassan, Leong and Schneider 2021], the potential of the MMLA in educational environments is unique, complementing and enriching traditional learning measures, providing high-frequency data on students' behavior, cognition, and affection, given the expansion of some techniques that include activity recordings with computers, wearable cameras, wearable sensors, biosensors (for example, skin conductivity, heart rate, and electroencephalogram (EEG)), gesture detection, infrared imaging, and eye tracking.

3 Experimental Study Design

The configuration of this experiment sought to investigate, propose, and validate a Multimodal interaction model, specifically for the detection of affective states during computational thinking activities in learning with high school students and the learning potential that each student developed as a result of the encounters from exploring the pluggable computing approach.

3.1 Context and Participants

To conduct this study was necessary registration on Plataforma Brasil³, which consisted of sending documents used in the data collection and approval of the Consolidated Opinion by the Research Ethics Committee (in Portuguese, Comissão de Ética e Pesquisa, CEP). After CEP approval, the experiment was conducted in an institution of the state public education network in Recife. Forty high school students participated - from the 1st, 2nd, and 3rd years. They were invited by the school coordination, given the incentive to the promotion of teaching computing in secondary education provided for in the National Common Curricular Base (in Portuguese, Base Nacional Comum Curricular, BNCC) [BNCC 2017]. Although they are from high school, Table 1 shows the absolute and relative frequency of each stage of schooling.

Table 1. Number of Students per Grade/Year

Grade/Year	Absolute Frequency	Relative Frequency (%)
1º	28	70
2º	9	23
3º	3	07
Total	40	100

The 1st year students had no prior experience with computing content; however, the 2nd and 3rd year students already had some experience. The age range of these students varied between 14 and 18 years old, with the majority being 15 years and six months old.

3.2 Research characterization

The planning of the meeting was proposed for 01 (one) shift, for 3 (three) hours, in the morning and the afternoon, during regular classes, with a pair of students for each meeting. In this way, the approach with plugged computing was referenced. At this meeting, the following computation contents were explained: *sequence*, *repetition*, and *conditional*, each one from the perspective of the levels of cognition “*use*,” “*modify*,” and “*create*” [Lee *et al.* 2011] during the resolution of the exercises after the content, to the capture of data occur in support of the *Multimodal* approach. Although the meetings were face-to-face, the *StreamYard*⁴ platform was adopted to conduct the challenges and thus capture the students' faces, record the audio via

³ Available at: <https://plataformabrasil.saude.gov.br>.

⁴ Available at: <https://streamyard.com>.

webcam, and develop the construction of digital blocks on the *Scratch*⁵ platform. The same procedure was adopted for each pair.

The CTT by Román González [Román González 2016], presented in section 2.2, was used as a pre-test and post-test, as this study seeks to present instruments that collaborate in the assessment of CT. Regarding the computing content explored in the meeting, each pair of students performed all the activities in *sequence*, as it was expected that the students would understand and express a series of steps logically. Regarding *repetition*, the activities required students to perceive and apply mechanisms that optimized the execution of a series of steps. On *conditional*, the activities explored the ability to make decisions based on certain conditions. Throughout the moment, data were captured and analyzed to answer the question defined in this investigation. The capture instruments are diversified, with pre-test and post-test, video recordings, and open questionnaires.

3.3 Experiment Setup

The construction of the experiment was a milestone for understanding the research, as it shows relevant information for the investigation, which sought to foster learning regarding the teaching scenario each student developed at the time of the workshop.

Figure 1 demonstrates the experiment configuration to guide the execution of activities and evaluative tests by the moment of the demonstrated content, in addition to the Multimodal approach.

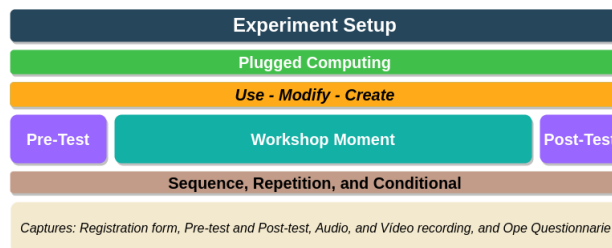


Figure 1: Experiment Setup

The Scratch platform was chosen since plugged computing activities are more common in visual programming environments [França 2020].

3.4 Data collection

The first activity of the workshop took place through the Registration Form via a Google Forms⁶ link. The form contains the Term of Free and Informed Assent - a document requested by the CEP. In the course, the students received the link to the pre-test. The workshop schedule and its steps were explained after they accessed the questionnaires and filled them out.

Figure 2 illustrates the reason for choosing the visual programming tool (*Scratch*), in which students could register on the platform and then receive small handling tips on the website.

For the capture of affective states, the faces, voices, and computer screens were recorded at the time of activity on the platform. For better identification in the workshop, student 01 was chosen to receive a code ready to perform the role of “executor,” who read the digital blocks used to build the code; and student 02 played the role of “assistant,” who kept clicking, dragging, and fitting the digital blocks in the Scratch platform. The procedure was performed in reverse in the second challenge. There were 2 (two) challenges.

⁵ Available at: <https://scratch.mit.edu>.

⁶ Available at: <https://forms.gle/BxYVR72Q3X6zt3LV7>.



Figure 2: Plugged Computing Scenario

3.5 Analysis of Collected Data

The analysis began with the data collected from the pre-test and post-test, which happened individually. The database was organized in a csv⁷ spreadsheet, and from there, the import to the R⁸ Programming Language was conducted, which significantly presents the statistical calculations and construction of graphs of the collected data.

Two groups were constructed in the research, the group that “*Had Gains*” and the group that “*Had No Gains*.” The raw score ranged from 0 to 20, an inference from the number of questions. This note was converted to a scale from 0 to 100 (zero to one hundred) for better reading and interpretation. Thus, the post-test score was subtracted from the pre-test score as follows: $= post_test - pre_test$. This operation was performed with all students individually. Students above 0 (zero) were classified as belonging to the “*Had Gain*” group, and those below or equal to zero were classified as belonging to the “*Had No Gain*” group. Descriptive statistics techniques were adopted to identify possible statistically significant differences between the different contexts and approach for CT enhancement used in this experiment.

After separating the groups, the *EZ-MMLA Toolkit*⁹ was used to process the database, and from the captured facial features, the affective states of each student would be identified. It is expected to demonstrate how an approach based on MMLA can contribute to the challenge of assessing CT and advancing research in the area.

4 Results

This section describes the results obtained with the identification of the performance reached by the students in the accomplishment of the activities in the experiment that culminates with the approach of the Multimodal tool.

4.1 Categorization

Given the result of the pre-test and post-test, the boxplot graph (Figure 3) shows the difference in the performance scores of the students, with 22 (twenty-two) students in the “*Had No Gains*” group and 18 (eighteen) in the “*Had Gain*” group.

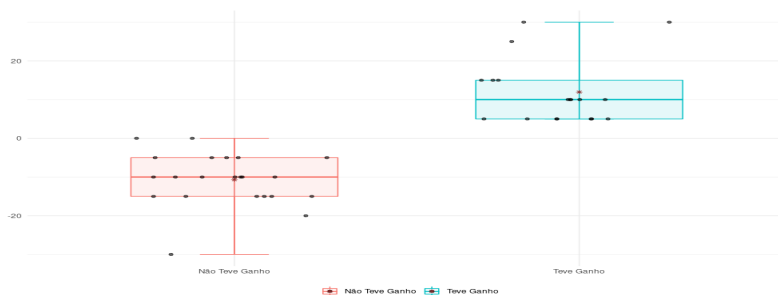


Figure 3: Difference in the scores of the students in pre-test and post-test

⁷ It is a format used to store data that can be imported and exported in programs such as Microsoft Excel, Google Sheets, Apple Numbers, OpenOffice Calc, and other applications.

⁸ Available at: <https://www.rstudio.com>.

⁹ Available at: <https://mmla.gse.harvard.edu>.

The plotted graph shows the difference in pre-test and post-test scores. Through this difference, it is possible to identify the groups that “Had Gains” and “Had Not Gains.” It is inferred that this result was due to the fatigue of the students, which was visible at the end of the workshop, and the construction noise in the area outside the research room. Many had the dedication to fill in the correct alternatives very carefully, and others completed the filling in less time to finish the post-test and leave the class.

4.2 Plugged Computing Scenario

The *Scratch* platform has become fundamental in the construction of collaborative activities. It is an instrument of interaction with students in carrying out the challenges proposed in the scenario of plugged computing. The stages of presentation, handling, interaction, and carrying out activities contributed to changes in their affective states. Figure 4 shows the groups “Had Gain” and “Had No Gain” during the performance of the plugged computing approach, focusing on the affective state of highest impact during the performance of activities with the students.

After processing the videos through the EZ-MMLA tool, the database was generated to obtain the affective states of each student while carrying out the activities (Figure 4). The affective states are generated in English. However, it was necessary to rename the affective states after translation into Portuguese (happy/feliz, nervous/nervoso, surprised/surpreso, and fearful/temeroso) to suit the research scenario, which meets the profile of each participating student.

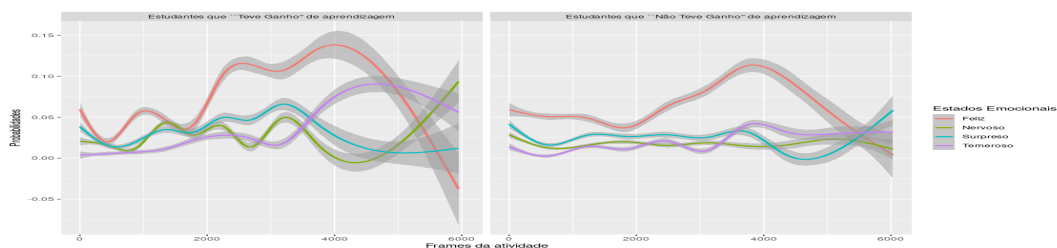


Figure 4: Affective states of the students in the Plugged Computing Scenario

The affective states are related to each individual. Although the groups “*Had Gain*” and “*Had No Gain*” are connected to the performance of the pre-test and post-test, there is a significant oscillation in the group “*Had Gain*” at all times of activities compared to the group “*Had No Gain*.” The activity consisted of building digital blocks that the “*executor*” mentioned, and the “*assistant*” conducted the fittings in Scratch — throughout the duration, the students reacted according to the construction and completion of the challenges. Thus, it is possible to interpret the students' engagement in carrying out the activities through the levels of alteration of each emotional state, especially the “*happy*” emotional state with the highest oscillation. Therefore, it is clear that there was positive satisfaction from the students in performing the challenges that involved computational thinking during the workshop.

4.3 Open Questionnaire

The aim of the *open questionnaire* was that students could express their opinions and feelings about the workshop. The procedure was to invite the student in front of the computer screen, which showed 03 (three) guiding questions within the research objectives. The students read the questions aloud and then answered as best they wished, looking at the laptop's webcam so that video capture could occur for analysis of the answers.

To the first question ([01] *What was your favorite part of today's workshop?*), the responses show that there is an emphasis on performing commands (programming) in Scratch and that the students learned new things (something different from the classroom); while performing the pre-test and post-test, they remember the PacMan, which made it the favorite moment of the workshop.

In the second question ([02] *Describe what it would be like to conduct the activities in collaboration (in pairs) and without (alone)*), they explained that carrying out the activities in pairs was very enriching, easier, integrative, funny, friendly, and quite productive. These same collaborators claimed that an individual activity would not have the same result as in pairs, as it would be more difficult, tedious, boring, and time-consuming. There were also some claims that they did not notice the difference in conducting the activity in pairs or individually.

In the third question, ([03] *Can you tell us a little more about what this workshop means to you?*), the students pointed out that there was a new experience in their lives, in addition to an enriching new learning experience that contributed to new knowledge about computing, of which they didn't know. According to their responses, the workshop helped to open doors about the professional areas they intend to pursue. Some claimed never to have programmed on the Scratch platform, and now that they had the opportunity, they will continue studying at home. In addition to computer learning that they did not know because it was very new and interesting. However, there were still participants who claimed not to know how to answer the question and did not even express any meaning.

Among the limitations, it is possible to point out the initial rejection of the students to answer the open questionnaire through recording. After talking and explaining the activity, they agreed to do it. It is inferred that the rejection occurred because the students were not comfortable responding or did not like being recorded directly or for another personal reason. However, all students responded, some with long answers and some with short answers.

The audio was not captured during the speech capture of some students due to a technical problem with the microphone. But based on their facial expressions during the recording, the workshop was used satisfactorily.

5 Discussions

Given the research question, it is evident that the incorporation of the Multimodal approach to contribute to the assessment of CT skills occurred in an integrative way through the union of capture profiles: pre-test and post-test, evaluative cards, *EZ-MMLA Toolkit*, audio transcription, and open questionnaire. It is understood that the situation may cause the participant embarrassment in conducting the workshop and filling out the forms requested in the meetings. Therefore, this could be resolved through dialogue with the participant for clarification and collaboration in solving the incident. From the first moment until the end of the workshop, the participant had complete freedom in not wanting to participate in any moment of the stages.

It was also considered that the storage of the collected data may be a risk, as it can be hacked, so the data are treated confidentially and secretly and stored on an External HD of one of the researchers without access to an internet connection. The following dimensions are preserved and respected: psychic, moral, intellectual, social, cultural, and physical, as pointed out in the research methodology for using questionnaires during the workshop, video questionnaires, and data analysis on the subject evaluation of *computational thinking*. However, students benefit by learning computing content in the teaching scenario and using the visual programming language platform (Scratch) in an introductory way in professional life in the computing area.

Although the results occurred in a state public school, the ways in which the workshop occurred could be the same for other education networks (municipal, federal, and private). When faced with the results, the teacher of Basic Education acknowledges that the affective states of the students require balance in conducting the activities, especially in the evaluative activities, in addition to the scenario collaborating in the concentration of that student. The context in which the workshop was held required different materials and tools. For example, in the connected computing scenario, students use a computer/notebook with a webcam as the central tool for use on the platform” and other links worked on within the workshop. The limitations were the inaccuracy of the tools to detect emotional states. Although they are useful tools with a good level of accuracy, in addition to the characteristics of the environment that can

interfere with the acceptability of emotional states, such as: low ambient light, webcam quality, among others not identified. The non-sharing of the students' projects, that is, there was no access for discussion about carrying out the activities.

Each adopted tool contributes significantly to the results in isolation. However, when there is a framework of more evaluative instruments, the evaluation of *computational thinking* skills has more promising results through learning plugged computing. Therefore, the difference in this research is the conjunction of these tools in the evaluation of *computational thinking*.

6 Final Considerations

Computing teaching has gained notoriety in educational environments due to its concepts, methodologies, and evaluation. Despite this, gaps in the assessment are still common in the Scientific Community, but they are promising, given the methodologies that operate in teaching computing in the classroom. This study aimed to investigate how the Multimodal approach through affective states can contribute to assessing the development of computational thinking skills in learning scenarios of plugged computing.

To answer the research question, the methodology adopted through the experiment configuration allowed the pluggable computing approach to obtain better evaluation frameworks regarding the types of captures. Therefore, based on experience, the use of *StreamYard* is recommended, as it covers the entire process of recording students' faces and computer screens with possibilities for all sorts of activities. At the same time, the position of the webcam allows for a good capture of the students' faces, for greater accuracy of the affective states when processing in the *EZ-MMLA Toolkit*, and is reliable when identifying their engagement in carrying out the challenges, as well as the use of a headset makes the words articulated by the students more understandable during the capture of the voice (audio) for a good transcription of the audios. The open questionnaire requires questions that lead students to explain their opinions about the workshop, but making a self-reflection journal presents more pertinent and significant contributions to the research.

It was sought to list more than one instrument that corroborates with studies and presents tools to evaluate computational thinking, as well as the possibility of new instruments for the evaluation, especially of the affective states, as it contributes a lot to the proper performance of the students. Therefore, this article serves as a subsidy for the area of evaluation of computational thinking with the use of Multimodal, and in this way, it enhances evaluation frameworks in future works that relate computational thinking skills with Multimodal.

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