A Digital Application to Assist Basic Education Teachers in the Interdisciplinary Development of Computational Thinking Skills on the Math Discipline in Brazilian Learning Context

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Abstract: Computational Thinking (CT) has skills that can be explored in Math questions and can improve student's capability of solving problems. Approaches have been proposed in the literature to support teachers in elaborating, sharing, and searching Math questions that stimulated CT skills. However, the wide dissemination of these approaches has problems to put in practice by teachers. To fill this gap, in this paper, we present a digital application that aims to help the teachers to work in CT skills through activities of creation, cataloging, and utilization of Math questions. The validation of the application propose here was conducted with undergraduate students in Math, who reported that the solution is easy to use and supports and helps teachers put in practice creating, cataloging, and utilizing Math questions to stimulate CT skills. Also, the application able the searching and sharing Math questions between teachers easily.

1 INTRODUCTION

Computational Thinking (CT) has become an approach to stimulating the problem-solving capacity that has been widely discussed by the community (Angeli and Giannakos 2020). This approach consists of developing essential Computer Science skills to design solutions to problems more efficiently and effectively (Wing, 2006). The skills stimulated by the CT are described by Barr and Stephenson (2011) as indispensable, since primary education, for the development of problem-solving capacity in students. Two aspects are commonly considered in several studies identified in the literature to stimulate these skills: i) using specific disciplines to stimulate CT skills (e.g., Programming, Robotics, and Game Development) (Rodriguez *et al.*., 2019); ii) second using the dynamics of the disciplines of the primary teaching cycle (e.g., Math, Science, and Reading) to stimulate CT skills by interdisciplinary approaches (Del *et al.*., 2020).

Researchers have evaluated the positive impacts that approaches conceived from these two perspectives have brought into the classroom in several countries. These efforts are changing the way traditional schools work, transforming school life so that students can develop necessary skills for any individual in this new era marked by digital transformations (Korkmaz, 2018). This scenario has been consolidated in Brazil since the National Common Curricular Base (*Base Nacional Comum Curricular* - BNCC). This document establishes new guidelines for teaching in the country. In teaching Computer Science in schools, it is possible to highlight, according to the definitions presented in the BNCC, the general competence "Digital Culture". This general competence defines the CT as a piece of essential knowledge for all students, which should be stimulated interdisciplinary, since the initial years at school, together, for example, with the Math discipline.

When considering the CT's incentive in conjunction with Math's discipline, following the BNCC guidelines, it is possible to see some efforts that aim to propose interdisciplinary approaches in this sense (Palts and Pedaste, 2020). However, computer-based approaches are considerably more common, such as those based on computer programming, educational robotics, and game development. These approaches have shown significant positive results, but some there are still significant obstacles to the widespread dis-

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semination of these practices, such as the lack of adequate infrastructure in schools and teachers' need to acquire specific CS knowledge.

Our research group conducted previous research, focused on the interdisciplinary approaches to stimulating CT skills without specific CS knowledge, the different perspectives of conformity that Math questions present with the CT skills were evaluated. Based on these studies, an approach was proposed to enabling the CT skills to be incorporated into Math questions with the aim that the practice of these new model questions in the classroom improves the problem-solving ability of primary school students (Costa *et al.*, 2017). The approach was conceived from three essential activities: creation, cataloging, and use of Math questions that stimulate the CT skills; and was validated from a quasi-experiment, and the results showed that the questions created, cataloged, and used, according to the proposal, better stimulate students regarding the problem-solving capacity.

Although the approach was promising, it is possible to identify some difficulties around the essential activities proposed (creation, cataloging, and use). One of them concerns the impossibility of conducting cataloging CT skills in Math questions for any questions. The other is related to the inefficiency in using the questions produced since the question creators only have access to what they conceive, making it difficult for other teachers to share and reuse the questions created and cataloged.

Because of the difficulties encountered in the studies conducted previously, the following research question was formulated to guide the study presented in this article: "How to support and make the process of creating, cataloging and using Math questions, that stimulate computational thinking skills, more easily, efficient and collaborative?"

This work's objective was to develop a digital application that aims to provide a set of resources that help teachers develop CT skills in combination with Math questions in response to the research question. The application was designed to support the activities of creation, cataloging, and use of questions, providing strategies for these activities to be carried out collaboratively - making it easier to share what is produced and evaluated by teachers within the application.

The application proposed in this paper was evaluated by carrying out an extracurricular course with undergraduate students in Math at the Federal University of Campina Grande (UFCG). At the end of the course, participants answered a questionnaire about their experience with the application. The questionnaire's responses indicate that the application efficiently assists the interdisciplinary activities proposed in the literature (creation, cataloging, and use). Also, the participants highlighted high satisfaction with the *feedback* generated by automatic question classifier incorporated into the application, using Machine Learning and Natural Language Processing techniques, for the questions produced during the course.

The remaining of this paper are organized as follows: related works are presented in Section 2; the results in our previous work are presented in Section 3; the research methodology is presented in Section 4; the application design and implementation are presented in Section 5; in Section 6, we present and discuss the results of the application validation; and Section 7 is dedicated to conclusions and future work.

2 RELATED WORK

The literature highlights some other solutions, based on digital applications, online tools, and games, to stimulate the CT skills in the Math discipline and develop the ability to solve problems in an interdisciplinary way. In Melo *et al*. (2018) and Souza *et al.*. (2018), two gameS models are presented to stimulate the CT in Math. Both work with logic-based strategies for problem-solving and incorporate CT skills that involve the abstraction of information and algorithms' construction.

Barcellos et al. (2016), with the objective of training teachers on the possibilities of inserting the CT in the Math discipline, propose a training course using the Moodle[1] platform, where participants are introduced to activities that use Scratch[2] as a strategy for incorporating CT into the Math discipline.

The approach proposed by Costa (2014) aims to train students in Youth and Adult Education so that they develop the CT through the mobile application called ForEJA, where strategies are based on exercises. However, these exercises are not focused on Math.

As it is possible to observe, the literature does not present, according to the initial exploratory search carried out, works directly related to the proposal presented here. However, the works identified show similarity with the application proposed in this paper, which introduces CT to stimulate the ability to solve problems in an interdisciplinary way. However, the application proposed here differs from the other solutions due to the range of CT skills addressed and to the fact that it is applied to Math questions without

[1]https://moodle.org/

[2]https://scratch.mit.edu/

the need for strategies linked to specific CS subjects, which require specific CS knowledge by teachers, and adequate infrastructure, by schools, so that they can be put into practice. Moreover, the application incorporates intelligent approaches to creating, cataloging, and collaboratively using questions.

3 AN APPROACH TO STIMULATING COMPUTATIONAL THINKING IN MATH DISCIPLINE

The literature presents several approaches to stimulate CT in the context of education. However, their wide dissemination is hampered due to the absence of adequate infrastructure on the part of schools and teachers' training to have the specific knowledge in Computer Science to conduct the proposed activities in the classroom. In order to overcome these difficulties, our research group presented an interdisciplinary approach that aims to stimulate CT skills without the need for specific disciplines of Computer Science (Costa *et al.*, 2017).

The approach consisted in the adequacy of Math questions to stimulate a more significant number of CT skills. In this sense, three activities were proposed concerning the creation, cataloging, and use of the question: creation activity refers to a step-by-step that guides teachers on the creation and insertion of CT skills in Math questions used in the classroom; cataloging activity consists of guidelines for carrying out the majority evaluation of the CT skills, based on manual analyzes, conducted by three experts individually, for cataloging the CT skills in the questions created; and use activity concerns the guidelines regarding the use of the questions conceived with the execution of the previous activities, in the classroom, by the teachers.

To conduct the question creation activity, the authors proposed a set of steps to guide how to incorporate the nine CT skills proposed by Barr and Stephenson (2011). From these step by step, it was possible to produce new questions with greater compliance to CT skills (questions with more skills associated with their statement).

To identify the differences present in the questions produced from the proposed step-by-step and questions traditionally used in the classroom, the authors conducted a majority evaluation of the questions' skills. The process was based on individual expert evaluations, where, at the end of these evaluations, each skill was cataloged if at least two evaluators had identified it. For example, given a question, the nine skills were evaluated individually by experts. If the skill "data collection" was identified by two of these specialists, it was cataloged in the question. The same procedure was performed for the other CT skills used in the study. To support the evaluation process, experts used the definitions presented by Barr and Stephenson (2011), which guide the practical application of CT skills in Math.

To validate the impact of the proposed approach on the problem-solving capacity of students was conducted a quasi-experiment (Costa *et al.*, 2017). This study divided two classes of the eighth year of Brazilian primary education into two groups (experimental and control). For each group, different question models were used. The experimental group was used questions produced from the proposed step-by-step (a more significant number of CT skills identified in the primary evaluation and cataloging by specialists), and for the control group was used legal questions put into practice by classroom teachers (smaller number of skills identified in the majority evaluation and cataloging by specialists).

After practices with proposed Math questions over two weeks, the authors used a questionnaire containing questions from the PISA (Program for International Student Assessment), an exam that aims to assess students' math literacy worldwide and solve problems final performance analysis tool. The results showed that Math questions, in greater compliance with the CT skills, improved the problem-solving capacity in primary education students. The significance (95%) of the results was measured using hypothesis tests. The authors highlighted that the performances obtained by the experimental group were significantly higher than the performances obtained by the control group.

The proposed approach was promising, but it is not viable to manually catalog the CT skills in a more significant number of Math questions. Also, there was a mechanism that allowed sharing and reuse, by other teachers, of the questions that have already been created and cataloged. This paper presents a digital application design that supports teachers collaboratively in conducting the essential activities proposed in the literature to stimulate the CT and math discipline to support the proposed methodology in literature and overcome the difficulties mentioned.

4 METHODOLOGY

The methodology followed to conduce this work was breaking into three steps:

- Understanding the approach to stimulating the CT skills by Math questions to extract the functionalities to the concept the application;
- Application implementation based on the functionalities extract on the previous step;
- Validation of the application with Math undergraduates' students.

The main functionalities extracted on the first step are: i) allowing users to create Math questions, which stimulate CT skills, and add them to an online repository to facilitate access to these questions in a decentralized manner; ii) enabling the cataloging of CT skills, in each of the questions created in the application, to be conducted collaboratively to circumvent the difficulties encountered with the manual cataloging of large amounts of questions; iii) making it possible to use questions from a mechanism for locating and generating personalized exercise lists.

Based on these functionalities was conducted in the second step, the application presented here was conceived from three modules that reflect creating, cataloging, and using Math questions that stimulate CT skills. Finally, we conducted the validation process, where we set up questionnaires to characterize the participants and collect their impressions regarding the application proposed here.

5 THE APPLICATION DESIGN AND IMPLEMENTATION

The application[3] has three main modules that reflect the functionalities. The creation module allows questions to be created. At the end of the creation process, the application provides a *feedback* preliminary about the skills present in the elaborated question through an automatic classifier. The cataloging module, in turn, allows a newly produced question to be evaluated and, in case of acceptance, to be published for use with the skills cataloged by majority analysis. The search and use module allow, through Information Retrieval mechanisms, the questions to be in the repository and used to compose lists of exercises, which can be printed from the application.

In the application, two types of actors are considered: the ordinary user and the administrator. The first type can take on two leading roles: i) creator, who takes on the role in creating questions; ii) the evaluator responsible for analyzing and identifying the skills in a newly created question submitted to cataloging. The administrator, in turn, is a user specialization responsible for consulting the three evaluations conducted in the majority evaluation process and, according to the opinion of the evaluating users, accepting or rejecting the insertion of the questions created in the collaborative application repository so that they can be used. Figure 1 presents an overview of the modules integrated into the application and the features developed to meet the requirements.

[3]http://compensar-testes.herokuapp.com/

5.1 Creation

In the creation module, the user initially defines whether the question is objective or subjective and enters the reference source of the question (e.g., author, National High School Exam, PISA, among others). After defining the initial information, the user can insert the question's statement through a text editor incorporated into the application. This editor allows the question to be formatted according to the author's need, inserting images, mathematical expressions (Latex format), among several other text formatting options (e.g., bold, italic, and underlined). After defining the statement, the user then proceeds to a new screen where it is possible to select the contents addressed in the question (e.g., equations, trigonometry, and geometry). Finally, it can insert the answer alternatives in a template, for objective questions, or a correction mirror, for subjective questions.

After completing the question elaboration, the application automatically presents a preliminary *feedback* of the skills present in the produced question and initially stores it in the creator's personal repository. The *feedback* is provided from the automatic classification by models based on Machine Learning. These models can analyze the textual content of the questions' statements and predict the CT skills present in the analyzed questions. For training, validation, and testing of the models, Natural Language Processing techniques were applied and, as a labeled database, previously cataloged questions were used, whose CT skills were identified following the procedures for majority analysis and cataloging presented in the literature (Costa *et al.*, 2017). The models incorporated into the application, according to the results reported in the literature, had an average accuracy of 92.46 % for the nine CT skills that were part of the experiments - which indicates a relevant predictive ability (Costa *et al.*, 2019).

5.2 Cataloguing

The question cataloging module allows the identification of the presence of the CT skills and, according to the majority evaluation, the acceptance or rejection

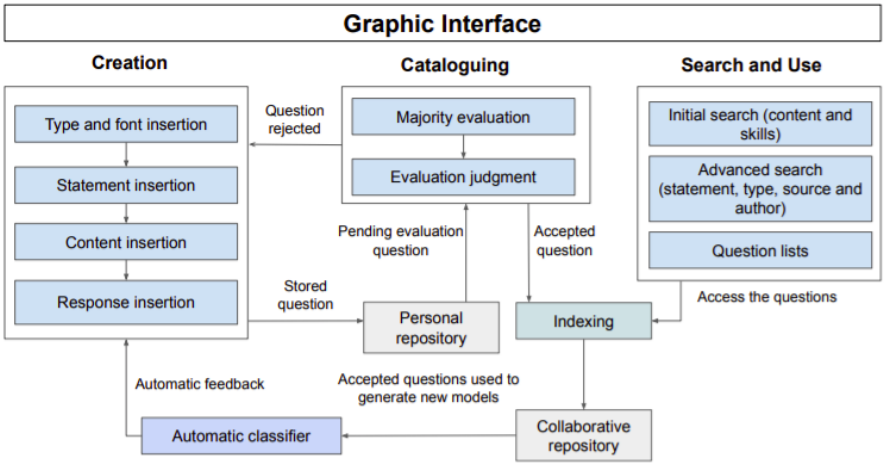

Figure 1: Overview of the application.

of the questions produced. This model controls the questions that are inserted in the application. After creating a question, the author can then submit it to the evaluation process to publish it definitively in the application. For that, the question needs evaluations from its creator and two more evaluating users, totaling three evaluations so that, later, it is possible to apply the majority criterion.

During the evaluation, it is possible to select the identified skills. In the option "Tell us more," the user can highlight the part of the question's statement that refers to the identified skill. Also, it is possible to inform the confidence level of the evaluation and general observations about the consistency of the assessed questions. Specifically, for evaluators other than the question's creator, other information is required, such as suggestions for improvement or minor modifications - such as spelling errors.

At the end of the individual evaluations, each evaluator provides the final publication opinion and indicates whether the question can be published, whether it needs minor modifications or rejected, and returned to the creator to apply the necessary corrections. The final opinion is for the system administrator to be able to accept or reject the question produced.

The administrator then judges whether to accept or reject the question produced based on all the identifications of the skills, proposals for improvement, and the evaluators' final opinion. He/she can make the proposed small changes, accept the publication, or reject it if the changes are substantial. In case of rejection, the question is returned to the creator with the proposed observations to apply them and, if he/she wishes, resubmit the question for a new round of evaluations.

In case of acceptance, the question is registered in the application's collaborative repository, and the skills are mapped according to the majority evaluation. In this process, for each skill evaluated, if at least two evaluators have identified it, it is cataloged in the question (it will appear in the searches that the question has that skill). The questions accepted for publication are no longer modifiable by the creator and serve as input for the automatic classifier, which provides preliminary *feedback*, to continue learning and increasing its predictive capacity, making the automatic opinion more assertive and satisfying for users. This approach aims to reduce or even eliminate the need to conduct majority evaluations when the *feedback* more accurate.

5.3 Search and Use

In the search and use module, so that it is possible to locate the questions accepted and stored in the collaborative repository, their statements are stored in the database using the text indexing property of Mongodb[4] (*Text Index*). This strategy was incorporated into the application in order to make the search process for questions more efficient. Indexing uses approximation techniques (*stemming*), which analyzes the words searched for to reduce them to a root word and allow the results to include variations of the rooted word.

The order of return for textual searches is defined using the *score*, a score assigned to each document after a search has been carried out. The indexing algorithm classifies the documents best suited to the search performed in the application with a higher score. This score defines the order of the questions that will be displayed on the search screen. Therefore, documents with the highest score will take prece-

[4]https://docs.mongodb.com/

dence in sorting. The entire process of (*stemming*) is also considered for the skills present in the questions evaluated.

Search options are presented based on information related to the content and CT skills to make it possible to locate the questions stored in the application, allowing a quick option to return the questions. Also, advanced searches are allowed, which use the other information present in the questions (excerpts of text in the statement, type, source, and author).

The question lists were created to facilitate the use of the questions produced in the application, thus allowing users to group questions based on their search criteria. From this functionality, it is possible to create lists with different contents, filter the insertion of skills and make changes according to the need. Also, the application has a feature that allows the printing of the question lists and their answer sheets containing the correct alternatives for the objective questions or the correction mirror for the subjective ones.

6 VALIDATION OF THE APPLICATION PROPOSED

The application validation process was carried out based on an extracurricular course for undergraduate degree students in Math at the Federal University of Campina Grande (UFCG) in August 2019. The total of participants was 24 (9 female and 15 male). The course was structured in two moments with a total duration of 8 hours: the first moment had the objective of training the participants so that they could carry out the activities of creating, cataloging, and using Math questions that stimulate the CT skills without the support of the digital application, that is, all activities were conducted by the participants just using paper and pen; and the second moment, the participants were introduced to the resources implemented in the application to support the activities of creating, cataloging and collaboratively using the questions. At this time, the same activities conducted manually were performed with the help of the application's features.

During the first stage of the course, held on August 29, 2019, some concepts were presented, including Computational Thinking (CT), Common Curricular National Base (BNCC), and Interdisciplinary Applications of CT in Math. Following that, students were introduced to the interdisciplinary approach described in Section 3 of this paper, which involves the process of creating, cataloging, and using Math questions that stimulate CT skills manually, using paper and pen.

In the second stage, held on August 31, 2019, after students had performed some activities related to creating, cataloging, and using Math questions, the application was introduced. Students were instructed to carry out the activities during the practice using the application and available modules. The first module used was the search module and then the question creation module. In the end, impressions were collected about the feasibility of using the application and how well it supported the activities proposed in the literature that encompasses stimulating the CT through the creation, cataloging, and use of Math questions.

At the end of the course, participants answered a questionnaire on aspects related to the usability of the application and the *feedback* generated by the automatic question classifier according to the following questions: i) "Is the process of producing Math questions that stimulate CT skills easy to perform?"; ii) "The *feedback* generated by the application about the CT skills being stimulated in the question of elaborated Math is satisfactory?"; iii) "Is the process of searching for questions considering a certain content in Math and CT skills easy to perform?".

The results of the questionnaire will be shown below. The participants' level of satisfaction was high, and the indication is that the system is straightforward to use and provides adequate support to the activities proposed (Figure 2). It is worth highlighting the indication of low ease regarding the creation module by one of the participants. However, in the open question asked at the end of the form, the participant indicated that the application could assist CT in math through questions and to stimulate the problem-solving capacity in primary education students to whom the exercises will be presented. Also, another participant highlighted the need to improve the question editor, as it does not allow the direct insertion of tables.

Regarding the automatic feedback for PC skills generated by the classifier (Figure 3), the level of satisfaction of the participants was high and, when consulting the open responses, it was possible to verify that not all the CT skills incorporated by them to the questions were automatically identified. This behavior was already expected since the classifier learns as more information is provided to them.

The questionnaire indicated that the search tools were more effective and easy to use the components to insert information about CT skills and general Math questions information when compared with the manual process (Figure 4).

In general, it was possible to notice that the students showed a great interest in the interdisciplinary proposal presented. This conclusion was possible from an open question at the end of the evaluation

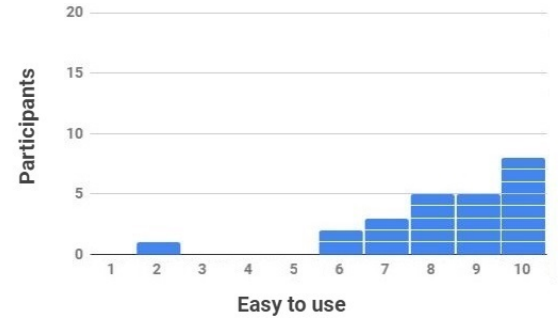

Figure 2: Distribution of ease of use indications and support for the teacher of the creation module.

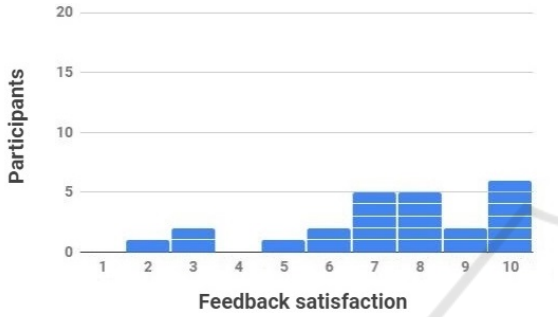

Figure 3: Distribution of satisfaction indications with *feedback* automatic.

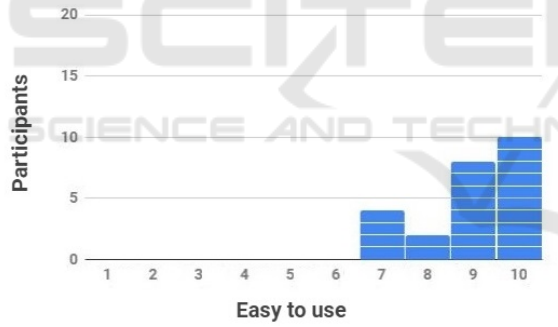

Figure 4: Distribution of ease of use indications and support for the search module teacher.

questionnaire. Some reports of the participants: "*At first I thought the course would be theoretical and boring and when we started the course I was quite surprised. The didactic, the receptivity we were given, allowed for a very dynamic conversation and course. In addition, the idAlsoll this is very good and interesting, particularly I had never thought about the questions in this way, analyzing each skill to be applied.*"; "*This training in my view is an ambitious proposal, which will contribute a lot as a tool to help teachers and create a more specific monitoring for each of the students.*"; "*I found the experience very valid, it helps to understand better to understand better exercises and problems into the classroom, covering different important skills for teaching*.".

Finally, it was possible to identify that, since the participants have little knowledge about the interdisciplinary practices that consider the CT in Math, the application allowed their interest in the theme. These findings could be identified from the open responses to the questionnaire: "*Yes. I found the application to be a handy and interesting platform, even for students. It may act as a stimulus for students to study and resolve questions.*"; "*Yes. Since the contextualization of constructed questions will also allow for better interaction between different disciplines.*"; "*Yes. Being within the scope of work of the skills interconnected with the mathematical, logical thinking, the application made it much easier to conduct the activities done manually.*".

Finally, it is worth noting that the cataloging module and the list generation functionality were not yet presented in the application at the course time. Therefore, it is necessary to validate them in future courses. Also, the application showed signs that it could support the activities proposed in the literature that concern creation, cataloging, and use.

The application can provide collaborative and efficient strategies, considering that the whole process, in principle, was centered on a single individual responsible for creating and cataloging the questions it produced. Another benefit of the application proposed was making the use of CT as a joint approach with Math accessible to more people, particularly to teachers interested in applying the methodology in the classroom.

The preliminary results are encouraging, and it is possible to implement the proposed improvements shortly and make the tool available for community use. Also, by making the application available for more professionals, it will be possible to gather more information to assist the application's validation in all its dimensions, such as performance, usability, reliability, security, availability, maintenance, and technologies involved.

7 CONCLUSIONS AND FUTURE WORK

The CT is considered a strategy to develop the problem-solving capacity and can be developed in an interdisciplinary way with the Math discipline, as we proposed in previous work and strengthened by the BNCC. To support this proposal, we presented in this paper an application that provides functionalities to stimulate the CT's skills from the creation, cataloging, and use of Math questions to help teachers in the classroom.

The results of the application validation on the usability of the question creation and search modules and the satisfaction generated by automatic *feedback* skill showed that it reaches its objective of supporting the interdisciplinary practice of stimulating the CT through Math questions, providing an application to help teachers to create, cataloging and use. Also, the application proved to be an option of great importance regarding stimulating the CT in an interdisciplinary way to the discipline of Math, reducing the need for specific knowledge of approaches linked to the disciplines of Computer Science by the teachers, and adequate infrastructure by schools.

As future work is intended to carry out new courses to validate the application modules regarding the majority evaluation and generation of exercise lists, as they were not yet integrated into the solution when the course described in this paper was performed. Also, new questionnaires and interview approaches can be used to identify participants' real sentiments to collect more significant results about the application characteristics.

In our preliminary validation process, we selected undergraduates students of Math. This selection allows preliminary insights into the application. Therefore, it is necessary to consider teachers actually in the classroom in new extracurricular courses for more significant results about the application efficiency to help the creating, cataloging, and using Math questions and CT skills.

With the consolidation of the application, it will be possible to formalize strategies for using questions. Their CT skills make it easier for the teacher to identify the students' specific difficulties. In this sense, the teacher will be able to build lists of personalized exercises to develop the skills with which the students presented difficulties. Suppose the student had difficulties abstracting important characteristics of problems. In that case, the teacher could consult the application in search of Math questions that specifically stimulate the "information abstraction" skill so that they can be used to develop the student.

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