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Pisa 2021: Knowledge of Computational Logic in the Mathematics Exam

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ABSTRACT

Background: the model question that will be present in the PISA 2021 exam, with the insertion of knowledge related to programming logic in the test that re-analyses mathematical literacy, may not effectively assess the students' potential mathematical knowledge, as students are led to solving the question by using the data presented in its statement. **Objectives**: to analyse a model question that will be present in the new form of evaluation of PISA 2021 regarding the insertion of integrated programming logic with the different literacies. **Design**: we assume a qualitative study, with exploratory and explanatory research, when it incorporates elements of two investigative designs: bibliographic and documentary research. **Setting and Participants**: the study was developed based on model questions from PISA 2021 provided by the OECD. **Data collection and analysis**: the question of PISA 2021 is organised with increasing difficulty and the analysis observes how we understand that the result of questions of a programming logic nature in the Mathematics assessment is moving towards the insertion of a new literacy in the assessed role: Digital Literacy. **Results:** we highlighted three levels of knowledge of programming logic, with emphasis on the imperative paradigm, used for the design of resolution: recognition of patterns, structures of logical controls and representation by variables. **Conclusions**: we conclude the students need to be able to assess and use the information critically if they want to turn it into knowledge, recognising patterns and inferring a critical position as to its consequences, aspects that cover what we understand as Digital Literacy.

Keywords: PISA 2021; Question; Programming Logic

Pisa 2021: conhecimentos de lógica de programação no exame de Matemática

RESUMO

Contexto: o modelo de questão que estará presente no exame PISA 2021, com a inserção de conhecimentos referentes a lógica de programação na prova que volta a avaliar as diversas literacias, com ênfase na literacia matemática, pode não avaliar efetivamente o potencial conhecimento matemático dos alunos, pois os alunos são conduzidos a resolver os questão utilizando

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os dados apresentados no seu enunciado. **Objetivos:** analisar um modelo de questão que estará presente na nova forma de avaliação do PISA 2021 quanto a inserção da lógica de programação integrada com as diferentes literacias**. Design**: assumimos um viés qualitativo, com caráter de pesquisa exploratória e pesquisa explicativa, quando incorpora elementos de dois delineamentos investigativos: a pesquisa bibliográfica e a pesquisa documental. **Ambiente e Participantes**: o estudo foi desenvolvido com base em questões modelos do PISA 2021 fornecidas pela OECD. **Coleta e análise de dados:** a questão do PISA 2021 se organiza com um crescente de dificuldade e a análise observa como entendemos que o advindo de questões de cunho de lógica de programação na avaliação de Matemática está se encaminhando para a inserção de uma nova literacia no rol avaliado: a Literacia Digital. **Resultados**: destacamos três conhecimentos de lógica de programação, com ênfase no paradigma imperativo, utilizados para o design de resolução: reconhecimento de padrões, estruturas de controles lógicos e representação por variáveis. **Conclusões**: entendemos que, frente ao apresentado neste estudo, os alunos precisam ser capazes de avaliar e usar a informação criticamente se quiserem transformá-la em conhecimento; reconhecendo padrões e inferindo uma posição crítica quanto suas consequências, aspectos que abrangem o que entendemos ser uma Literacia Digital.

Palavras-Chave: PISA 2021; Questão; Lógica de Programação.

INTRODUCTION

The topic evaluation is frequently discussed in research around the world, especially those on large-scale such as the Program for International Student Assessment -PISA (Fernandez-Cano, 2016; Villani & Oliveira, 2018). A large-scale evaluation is understood as a large-scale assessment, in the context of our reflection, those using standardised instruments that promote a comparison of the level of knowledge and the competencies of students or adults in different countries of the world.

Research such as by OECD (2015) indicates that the results of tests performed on computers to measure the difference between socioeconomic groups' in their ability to use ICT tools for learning to exercise digital literacy is explained by the difference observed in more traditional academic skills (Science Literacy, Mathematical Literacy and Reading Literacy). Therefore, to reduce inequalities in skills and have students benefit from digital tools, official reports point out that it is necessary to improve equity in the quality of education first.

With access to computers and the Internet, students can search for information and acquire new knowledge beyond what is made available through teachers and printed materials. The technologies also enable students to learn new ways of practising skills that will be useful in the future, such as maintaining a personal web page or publishing online, programming computers, preparing a multimedia presentation individually or collaboratively.

According to OECD (2018), the massive daily presence of technologies also renders imperative the development of Digital Literacy, which is understood as the individual's critical use of Digital Technologies in a way that positioning and conscious and critical behaviours take place. Thus, Digital Literacy is much more related to intellectual capacities that are reflected through different technological skills, than to the mere handling of digital equipment.

Therefore, considering that technology is continually developing, this requires its users to update their knowledge and skills often. The technologies also invite education to rethink the content and methods of teaching and learning. With this in mind, skills and knowledge focused on thinking and computational logic have entered assessment tools such as PISA, which aims to think about and reflect the dynamics of the classroom.

PISA is an applied assessment that uses in its formulation the Response Theory, a predictive method that relates observable variables and hypothetical unobservable traits, also called aptitudes, which are responsible for the appearance of observable variables (Brasil, 2019). It follows the logistic model of three parameters, which infers the probability of correctness to a question being influenced by its difficulty (parameter b), its power of discrimination (parameter a) and the chance, in probabilistic terms, that it is correctly adjusted at random (parameter c).

With:

$$P(\theta) = c_i + (1 - c_i)\frac{e^{Da(\theta - b_i)}}{1 + e^{Da(\theta - b_i)}}$$

In this model, we have that c_i the probability of question i is randomly correct in a student's resolution, in which $P(\theta)$ is the probability of correctness of the question, θ is the latent variable measured of question i, and (Euler number), *bi* is the difficulty index of question i and *D* is a constant of value 1.7 (Brazil, 2019).

As state of the art, we point out Sápiras (2017), Wahlströn (2017), and Spielmann and Ciani (2009), who conducted research that indicates the correlation of teaching programming languages with mathematics teaching and the analysis of previous questions of external assessment.

The Theoretical Framework will address some relevant knowledge such as the way of knowledge organisation, taken by the OECD, in three Literacies (Science Literacy, Mathematical Literacy and Reading Literacy) and what they are; and how we understand that the result of computational issues in the evaluation of Mathematics is moving towards the insertion of a new literacy in the list assessed: Digital Literacy. We also describe some theoretical knowledge related to Programming Logic, with emphasis on the imperative paradigm of Programming.

Our methodology is qualitative, consisting of social research centred on individuals (Goldenberg, 2005), with exploratory and explanatory research when it incorporates elements of two investigative designs: bibliographic and documentary research (Gil, 2011). By analysing and reflecting on the report presented by the OECD (2018) on the PISA 2021 assessment, this research will focus on Mathematical Literacy, but addressing the knowledge of Programming Logic.

STATE OF THE ART

Several studies have already been conducted indicating the correlation of Programming Languages with Mathematics Teaching and Learning (Sápiras, 2017; Wahlström, 2017).

Sápiras (2017) aimed to investigate the relationship between Digital Literacy and Mathematics through the construction of electronic games, based on a qualitative methodology. The main results were evidence of simulation skills, appropriation, collective intelligence, multitasking, transmedia navigation, and distributed cognition, related to mathematical aspects such as cartesian plane, set of integers, numerical line, variables, percentage, and mathematical signs.

Wahlström (2017) produced an application that offered students and teachers a tool to start programming through a graphical programming language. With this language combined with a three-dimensional graphical mechanism, students could start programming with graphic feedback combined with learning the properties of some forms and more advanced mathematical functions.

Spielmann and Ciani (2009) developed a work of analysis of issues of PISA external assessment with questions between the years 2000 and 2009 that aimed to carry out an epistemological reflection, seeking to verify if there was some chain of knowledge production in the proposal of PISA and its questions about aspects related to mathematical knowledge.

In the analysis of the questions, the authors identified the pragmatic chain, finding that the way some statements are conveyed, we cannot effectively assess the students' potential mathematical knowledge, as students are led to solving the question by using the data presented in its statement.

We highlight that the first two papers analyse the knowledge related to Programming with Mathematical Literacy, but not in External Evaluation Questions and the work of Spielmann and Ciani (2009) analyses external issues, but not concerning the knowledge of Computational Logic, as proposed in this article.

This article will discuss the new issues related to Programming Logic that will compose the Pisa 2021 assessment worldwide. As all the tests will have issues with this topic, and as not all federations that take the test assume them in their curriculum, we believe that it is essential to reflect formally so that parents, teachers, and researchers are informed of what they must expect in the following edition of the test, which is considered one of the major assessments in the world.

THEORETICAL BACKGROUND

Azevedo (2011) and the Organization for Economic Co-operation and Development (OECD, 2016) state that there are different forms of literacy, which is defined as the capacity of each individual to use information regardless of age or attendance (or not) in a school system. Azevedo (2001, p.01) also points out that the connection of literacy with a “[...] well-being society and economic development are nowadays a stimulus sufficiently attractive for literacy education to be conceived, in developed societies or in the process of developing [...]”.

According to OECDE (2016), there are different types of literacy, three of which are the most discussed in the academic environment and research in the field: Science Literacy, Mathematical Literacy and Reading Literacy. Such literacies are assessed in the Program for International Student Assessment (PISA), organised by the OECDE, in which Brazil underperformed in 2015 and 2018 (Brasil, 2015, 2019).

The OECDE (2016, p.52) defines Science Literacy as a student’s “ ability to engage with science-related issues, and with the ideas of science, as a reflective citizen.” According to the text, the person who has Scientific Literacy is willing to participate in debates about science and technology, since they can express themselves scientifically about phenomena, interpreting, investigating and evaluating data and evidence. For this, three forms of knowledge are necessary: content, methodological procedures and reasons and ideas used by scientists to justify them, which must lead to individuals’ change in attitude, considering what they can do with this knowledge and how they can creatively apply scientific knowledge in real-life situations, often allied to the use of technologies (Broietti, Dos Santos Nora, & Costa, 2019).

In the last assessment applied in Brazil, in 2018, 55% of Brazilian students had the lowest scores at the basic level in Science. No student reached the maximum level in Science Literacy, and 21% of students were unable to exercise citizenship using their knowledge (Brazil, 2019).

Mathematical Literacy, addressed in PISA, is defined by the OECDE (2014) as the individual’s ability to formulate, interpret and use mathematics in various situations and contexts. For this, it is necessary to reason mathematically, to know facts, procedures, and mathematical concepts to describe, explain and predict phenomena. Mathematical Literacy helps the individual recognise the role of mathematics in one’s social context and helps to take positions for judgments in coherent decision-making, in order to extend from knowledge and apply them in new and unknown situations.

The OECDE (2014) also focuses on Mathematical Literacy, in the use of tools and software that according to it [...] that have become ubiquitous in 21st-century workplaces.” (p.37), such as rulers, calculators, spreadsheets, currency converters, and dynamic geometry software. Thus, uniting the theoretical and practical knowledge of mathematics.

In the last assessment applied in Brazil, in 2018, 68.1% of students did not reach the basic level in Mathematics, considered by the OECD the minimum necessary for them to exercise their citizenship fully. 41% of Brazilian students are unable to solve simple and routine issues, and only 0.1% reached the maximum level of mathematical literacy (Brazil, 2019).

Another form of Literacy discussed and evaluated is Reading Literacy which, according to OECDE (2010, p. 37), is the ability to " understand, use, reflect on and engage with written texts, in order to achieve one's goals, to develop one's knowledge and potential, and to participate in society." In this perspective, Reading Literacy involves the construction of the meaning, large and small, literal, and implicit, of the text; by reflecting on these, the individual relates what one is reading with one's thoughts and experiences. One can seek to reach new meanings or make judgments about the text itself, based on external references. The author also points out that this form of literacy is not limited only to printed material, reaching digital nuances such as computers, tablet, and portable phones.

Reading Literacy adheres to interactive texts, such as exchanges in blog comment sections or email responses; in multiple texts, displayed at the same time on a screen or linked via hypertext; and expandable texts, where a summary can be linked to more detailed information if the user chooses to access them.

In the last assessment applied in Brazil, in 2018, the main domain was reading, the result of which was that 50% of students do not reach the basic level in reading, considered by the OECD as the minimum to exercise their citizenship, so these people are at the lowest level of the assessment. Only 0.2% of the students reached the maximum level of Reading Literacy (Brasil, 2019).

Following the premise presented in the description of literacy, technology is perceived as an integral part of an individual when reaching more developed stages of knowledge. In OECDE (2015), it analyses how students use computers, the interaction between information and technologies, the importance of reflecting on information found online and the implications of digital technologies in educational policies and practices.

This last topic is highlighted within this report; the authors discuss skills that aim to design digital solutions, adapting or creating computer algorithms to meet their needs (programming). For them, these capabilities are based on advanced reasoning and problem-solving skills and require a good command of symbolic and formal language, which are often based on math-related skills. In this way, digital skills are critical to be worked on, as for the first time, today's parents and teachers have little, if any, experience with the tools that children are going to use every day in their adult lives. This chapter discusses the implications for education policy of the need to equip students with the fundamental skills required to participate fully in hyper-connected, digitised societies (OECD, 2015).

Among the skills mentioned in the report, there are: knowing how to collect and use information from the Internet critically, managing the reliability of the information, extracting inferences, navigating digital content, and solving problems. We also infer that the report produced by the OECD does not mention Digital Literacy, but describes the skills related to the use of digital technologies and their use critically and constructively, which is in line with the definitions of Digital Literacy brought by Rosado and Bélisle (2006) and Jenkins *et al*. (2009).

Both authors approach Digital Literacy as a process that is under development, since the technology itself is constantly changing, and is a process experienced by the individual. Also, despite pointing out different skills regarding the Digital Literacy process, we understand that they can be related.

We also recall that since 2012, the assessment has been applied directly to the computer. Simulations gain prominence in questions that require the student to read, interpret and generate data in interactions made on the computer.

Part of Brazil's poor performance in this last assessment has been attributed not only to learning difficulties, but to the low Digital Literacy of these students, since many had difficulties in critically using the tools. Data also indicate that countries with better evaluation performance were also those where computer use is widely disseminated (Almeida, 2019).

Starting in 2021, PISA's mathematical assessment will incorporate questions that verify computational thinking as a logical computational and problem-solving approach in students. The test will also provide the opportunity to report their knowledge of broader concepts and skills in the area of technology, in an optional questionnaire that will address the skills of creating a computer program, identifying the source of an error in a software, or solving a problem and representing a solution as a series of logical steps in an algorithm (Schleicher & Partovi, 2018).

Thus, we saw that literacies are already widely used internationally as guiding students' learning, so we understand that there is a need for research in Digital Literacy in the Brazilian academic scope, as the environment and the way the individual experiences and uses technologies are part of the process of Digital Literacy training.

As an initial way of approximating these principles, we see the insertion of programming logic in external assessment exams such as PISA. While countries like England and New Zealand have already inserted studies of technologies such as Computer Education in their curricula (De Paula, Valente, & Burn, 2014; Valente, 2016), many other countries were still crawling on this journey.

Sebesta (2018) presents the increased ability to express ideas as one of the reasons to study concepts with programming. It further describes that programming logic may be related to several areas of application, such as (i) Scientific Applications, (ii) Business Applications, (iii) Artificial Intelligence, and (iv) WEB Applications.

Programming logic, according to Carboni (2015), is how to represent instructions that make up a program to be executed by a computer in current language. The reasoning of the individual who develops the structure can influence the computational logic the computer executes when solving problems and configuring systems. A way to structure this logical representation is in the form of an algorithm.

The algorithm can be considered a sequence of finite procedures, which, when performed for a certain period, can reach its goal. This sequence of procedures are well-defined and finite statements and commands, it is like a path or formula to solve a problem. Algorithms are implemented through low- or high-level programming languages. Computer hardware runs programs written in low-level language. The higher the level of the language, the more humans can understand it. There are several high-level languages available in the market, and according to TIOBE [https://www.tiobe.com/tiobe-index/], in March 2020, the five most used programming languages were Java, C, Python, C++ and C#. The process of transforming a program written in a high-level language to a low-level language is known as compilation. This process involves several stages, the most traditional, according to Sebesta (2018) lexical analysis, syntactic analysis, semantic analysis, intermediate code generation, code optimisation, and code generation in the target language (this is often the machine language).

According to Carboni (2015), instructions written in a programming language are called programs. However, to Sebesta (2018), programming languages can be categorised into different paradigms, of which the paradigms (i) imperative, (ii) functional, (iii) logical and (iv) object-oriented paradigms were highlighted. The concepts presented in this article are based on the imperative paradigm, in which a program is a sequence of instructions or commands, having variables and control structures.

Programs, according to the imperative paradigm, require commands for the input and output of data and control structures of what is developed in it. Among the main control structures, we highlight the (i) simple sequences, that is, a set of instructions that will be executed in the order in which they were written; the (ii) conditional control structures, used to divert the flow of the program to different parts depending on the realisation of information as false or true and (iii) repetition structures, used to repeat part of a program for a number of times until a logical condition is met.

The IF conditional structure is one of the most flexible structures, and can happen in several ways, depending on whether the condition is satisfied or not during the program; and the fact that each diversion of the flow may or may not have other commands before the completion of the structure. Under the condition of the IF structure, we can continue to use all relational operators for comparisons and also logical operators can still be used (AND, OR, DENIAL, OR EXCLUSIVE) (Sebesta, 2018). The XYZ table shows through a true table, the functioning of logical operators for two logical inputs (1 and 2) that have logical values (true and false). The logical AND returns true when both entries are true; if any of them is false, the result will be false. The OR returns true if any of the entries is true. The denial reverses the input logic, that is, if the input is true, the result is false, and vice versa. The OR EXCLUSIVE returns true only when one entry is true, if both entries are true the result is false. In programming languages, the conditional control IF structure is usually composed of auxiliary diversion commands such as IF THEN ELSE, which diverts the flow of statements when another logical condition is true, and IF THEN diverting the flow of statements when no logical condition is true.

Table 1
Table truth for logical operators AND, OR, DENIAL, and OR EXCLUSIVE. (Sebesta, 2018)

Logical input 1	Logical input 2	AND	OR	DENIAL (for logical input 1)	OR EXCLUSIVE
True	True	True	True	False	False
True	False	False	True	False	True
False	True	False	True	True	True
False	False	False	False	True	False

In the imperative paradigm, the repeating control structures are divided into WHILE, REPEAT, and STOP. To determine which structure is most appropriate for each program sequence, we must be aware of the number of times the program passage needs to be executed, called counted loops), or the condition for it to happen, called conditional loops.

To use the counted loops, we must know in advance how many times the set of instructions will be repeated and, in turn, we need the help of a counter that will assist in the loop of the structure. The use of a counter variable makes it possible to repeat the structure until the counter has reached the limits stipulated in the condition of the structure, so it stops executing the statements following the program flow (Carboni, 2015).

In this structure, the counter is the variable which content is changed by its own added value or subtracted from a constant that can be used to accumulate the number of times the program executes the loop statements, and the counter must be started with a value determined initially.

For conditional loops, in repetition structures, WHILE can be used as a variable conditioned to the satisfaction of a programming structure or also the user response that will control the number of times the action will be repeated (Carboni, 2015).

In the REPEAT structure, the instructions provided to the program are executed at least once, when possible, a number of times are determined, leading it to comply with all procedures determined by the structure and then tests the variable that controls the necessity of the loop.

In the STOP repeating structure, a variable is required to control the loop count in the structure itself. In this structure there is a moderation of instructions, because the structure itself is responsible for starting, incrementing and closing the variable that it controls; it is most indicated when we know the number of times the instruction set will be retained (Sebesta, 2018).

METHODOLOGY

This is qualitative research that consists of a social study centred on individuals who are inserted in a milieu where the researcher is part of and plays an active role. Thus, the research is not inflexible but feasible with changes, allowing the observer to reflect on its records, separate the relevant details, notes, and later organise and use strict methods to validate their notes (Goldenberg, 2005).

We believe it is necessary to highlight more specific aspects that define our investigation. Gil (2011) points out that an investigation assumes a character of exploratory and explanatory research, when it incorporates elements of two investigative designs: bibliographic and documentary research.

According to Gil (2011), exploratory research focuses on developing, clarifying, and modifying concepts and ideas, through a formulation of specific problems or searchable hypotheses. They usually involve bibliographic and documentary surveys, non-standard interviews, or case studies, and rarely use quantitative data collection research techniques or standardised analysis techniques. Gil also indicates that explanatory research focuses on identifying the factors that determine or contribute to the occurrence of facts, to reflect on the elements that involve the reason in different situations.

Among the research designs highlighted, we understand the bibliographic research from Gil's (2011) perspective, as one that uses as corpus the theoretical materials already elaborated, such as books, journals, articles, and, in the content of our research, institutional reports. We emphasise that although research uses a stage in its development of investigative research, there are studies that are developed exclusively with these materials, and, thus, is defined as bibliographic research.

Another of our investigative designs was documentary-based, which we understand as the constitution of analyses of documents and materials that have not had an analytical treatment yet, or that could be remade with the different approaches of an investigation (Gil, 2011). As the main characteristic, according to Gil (2011), they present the analysis of a large number of materials and that were indicated for analysis, such as official documents, reports, letters, and contracts.

We carried out the analysis focusing on the issue available in the report provided by the OECD (OECD, 2018) - which explains how the PISA 2021 test will be-, which will focus again on Mathematical Literacy. In our documentary bibliographic investigation, we realised that knowledge of computational logic would be contemplated.

To achieve our goal, we developed a qualitative analysis through the categorisation and triangulation of data from different levels, defined according to the objectives proposed. Hence, we proposed to describe and interpret the set of documents, texts or transcriptions through systematic descriptions, aiming at the interpretation and understanding of the assigned meanings (Chizzotti, 2003), and it was up to the researcher to mediate the meanings between what was explicit and what emerged by the identification, systematisation and organisation of the significant patterns(Alves-Mazzotti & Gewandsznajder, 2002).

The data were analysed inductively, seeking to identify dimensions, categories, tendencies, patterns, and relationships, proposing, from this, explanations for the phenomena observed (Alves-Mazzotti & Gewandsznajder, 2002; Chizzotti, 2003), which were connected and/or allowed us to answer/explain the objectives outlined in this article.

THE PISA ISSUE

According to the OECD (2018), as technology plays a growing role in students' lives, the development of mathematical literacy must be connected synergistically and reciprocally with the development of computational thinking. Computational thinking, for Wing (2014), is understood as a thought process that involves the formulation of problems and the design of their solutions in a way that can be executed by a computer, a human being or a combination of both. Its association with mathematics implies how specific mathematical topics interact with specific computing topics and how mathematical reasoning complements computational thinking.

The PISA questions are organised to represent a growing difficulty in a contextualised way. In Figure 1, we see the first part of the computational logic question. In the introduction, it shows different tile shapes and floor pattern resulting from the use of each of them.

The question under discussion indicates mathematical objects that are not abstract, but that can be found in real-world situations to be modelled by mathematics. In this context, the mathematical structure can guide modelling, and students can also impose structure on non-mathematical objects to make them the subjects of mathematical analysis.

The subject of tiles can be seen with a geometric pattern that can be analysed in different hypotheses of transformations and translational, rotational, or reflexive symmetries, while the pattern can extend infinitely through space.

Figure 1
Introduction to the subject (OECD, 2018)

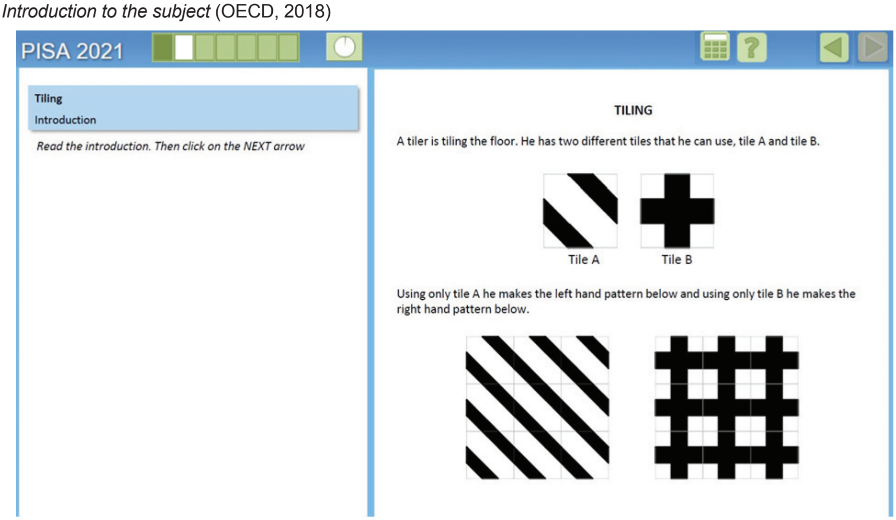


Figure 2 shows the first part of one of the five questions that will be proposed, in which the student needs to analyse the pattern provided by the question and drag the tiles with the mouse (since the tests are applied online) to complete the floor, reproducing the pattern given.

Recognising and reproducing patterns is one of the initial stages of computational logic analysis, in which the student seeks to systematise the information offered and reproduce it continuously and logically. For the OECD (2018), the development of computational logical aspects can enable a relevant approach to involve students with ideas of group theory, using a combination of practical and computational tools. Thus, while mathematics education evolves into available cognitive tools and possible ways to help students explore concepts of this discipline, the thoughtful use of computational tools with Digital Literacy can deepen learning of mathematics content by creating effective learning conditions.

We highlight that the basic recognition of patterns already composed the external assessment of PISA in previous versions, especially when focused on Mathematical Literacy (OECD, 2014). However, we perceived the strong relationship built from it with the knowledge of Computational Logic, as brought by Sebesta (2018).

For cognitive tools to succeed, students must approach learning actively and consciously. They must understand and execute their personal intentions to learn, think and regulate these learning processes.

Jonassen (2007) states that the development of students' self-regulation skills has been the goal of many educational reforms. Instead of working passively in the classroom, students should be able to determine their objectives, prepare to learn, engage in learning activities, monitor what is learned and how they can do better, organise learning activities in the light of this monitoring, and maintain the interest and goal for learning. In this sense, technology is a partner in the process experienced. Nevertheless, it depends on the students and their willingness and interest to learn.

Figure 2

Recognising and reproducing patterns. (OECD, 2018)

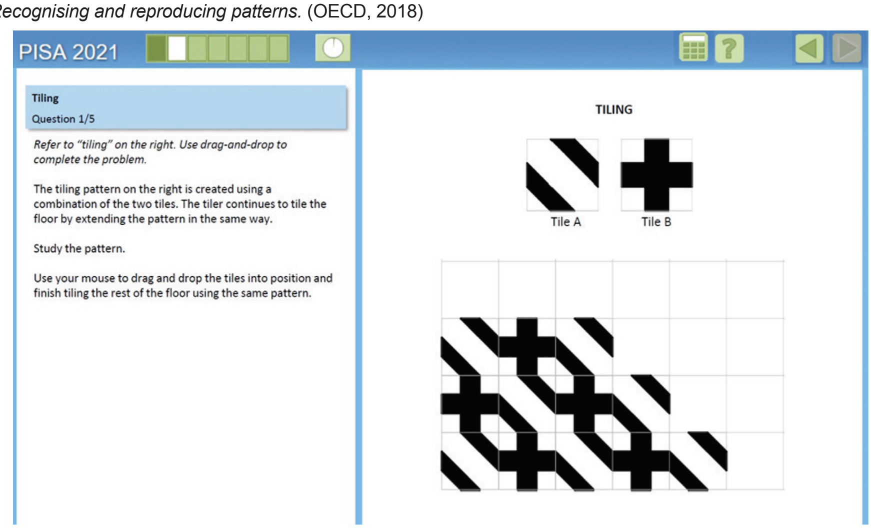
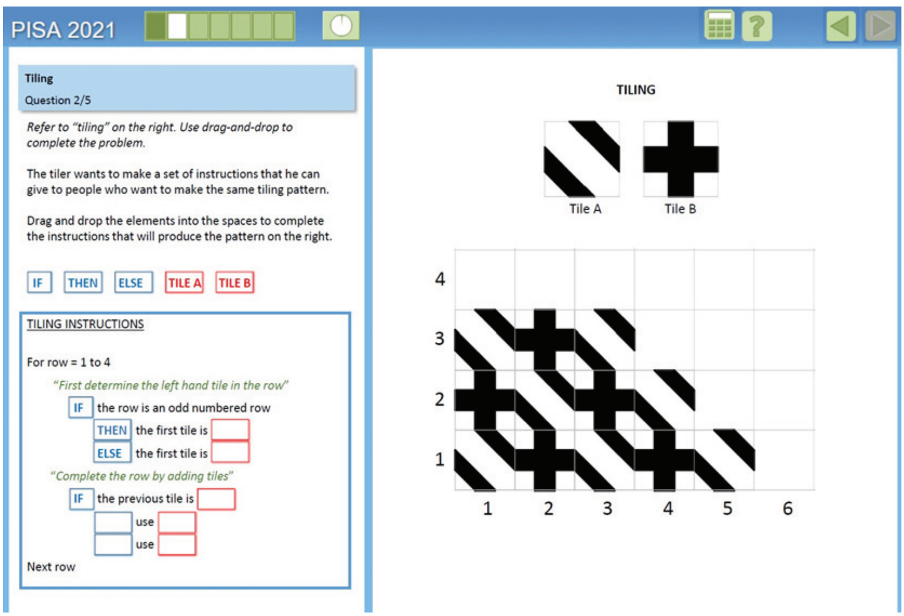


Figure 3 depicts the second part, where the student needs to fill in the blank spaces using a block programming language to construct a computational logic that represents the base presented in the problem. This reproduction uses logical control structures for the formation of a block algorithm, with emphasis on the use of conditionals and repetitions (Sebesta, 2018). In the first conditional, we observe the use of the IF command to ask which tile should be used when the line is odd, and the IF THEN for when the line number is even. In this condition, the IF and IF THEN commands are also used. The repeat control structure STOP is also used, iterating between 1 and 4. (Carboni, 2015).

Figure 3

Reproduction by logical control structures. (OECD, 2018)



We observed in this part of the issue that students need to solve a problem and represent its solution as a series of logical steps in an algorithm (Schleicher & Partovi, 2018). In this sense, computational thinking tools can provide students with a context in which they can re-signify abstract constructions while exploring mathematics concepts dynamically (Wing, 2014), besides expressing ideas and new ways of interacting with concepts using technologies and new representational tools.

This part of the question is similar to that used in the Scratch programming language, a free software frequently used in the classroom for the teaching of Programming Logic concepts in an accessible way that shows a correlation to Mathematics already shown in several studies (Sápiras, 2017; Sápiras, Dalla Vecchia, & Maltempi, 2015).

In Figure 04, the third part of the question, the student needs to choose the rule that represents the algebraic generalisation of the training law to obtain the highlighted pattern, while solving the problem in one's condition logic following the mathematical modelling of the situation.

For OECD (2018), mathematical modelling is the simplification of reality, in order to anticipate characteristics inherent to a phenomenon while approaching or ignoring other characteristics. Mathematical models are formulated in mathematical language and can use algebraic, geometric, or even arithmetic generalisation.

Figure 4

Law of formation. (OECD, 2018)

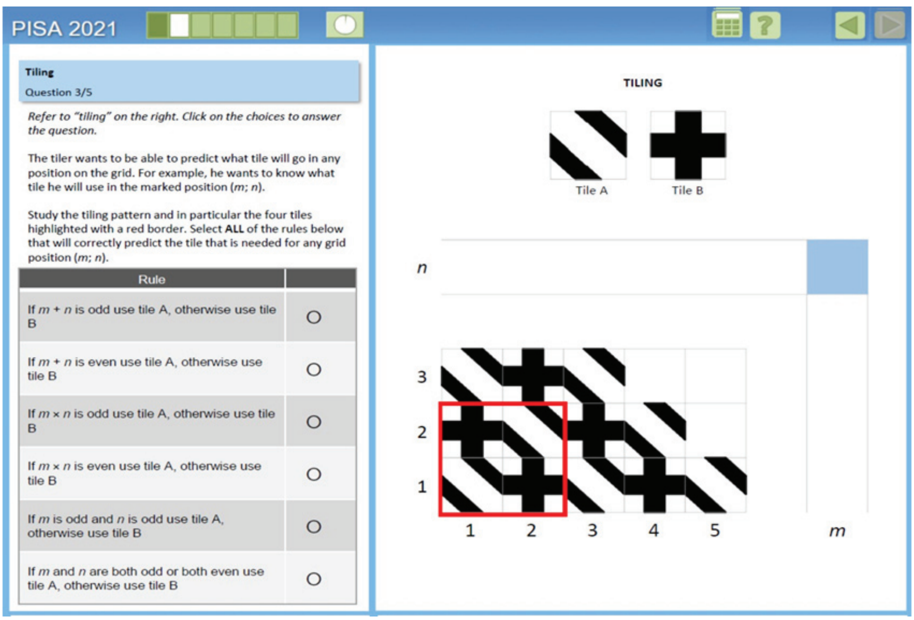


Figure 5 shows some more relevant information about the problem, by bringing a discussion of different ways of describing patterns, such as the algebraic generalisations. The figure shows the two forms of representation, concretely and replacing each type of tile with a different letter.

In this context, the essence of mathematical abstraction is to be an independent system in which mathematical objects come from their meaning from within the system to which they belong. The abstraction involves deliberately meeting the structural similarities between logical and mathematical objects and build relationships between these objects based on these similarities.

In this part of the question, there is no student interaction; only new information that will be relevant to the final two parts of the question is presented.

Figure 5

Discussion of the question. (OECD, 2018)

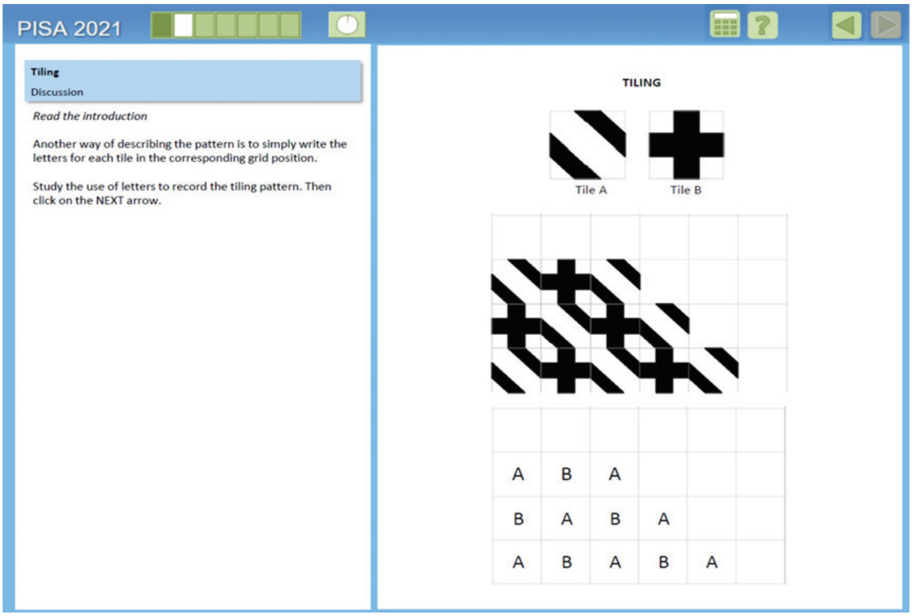
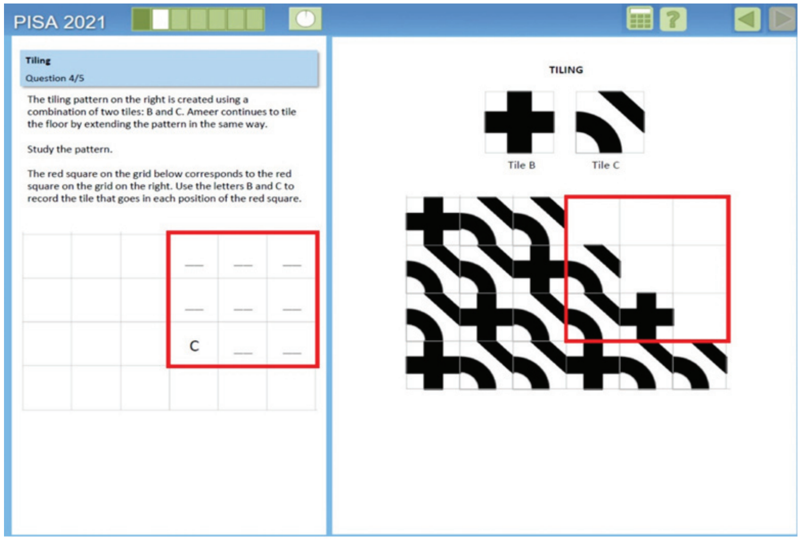


Figure 6 requests that the student recognises and completes the highlighted pattern using the form of variable representation. Students should use representations to organise and communicate their computational logical thinking. In this way, it is possible to present mathematical ideas in a concise manner that, in turn, leads to efficient algorithms satisfying logical steps to obtain algorithms (Schleicher & Partovi, 2018). Representations in this context can also be a central element when performing mathematical modelling, allowing students to abstract a simplified or idealised formulation of a real-world problem. The construction of standards is an important aspect of programming logic, it is through it that the student solves a problem, represents a solution that uses a series of logical steps (Carboni, 2015)

For OECD (2018), questions like this illustrate applications of logical structure in abstract mathematical objects, which are ways to replace rules of analysis, which can be executed by a computer, by conceptual images of these objects in order to make their properties clearer and more accessible for analysis and reflection.

Figure 6

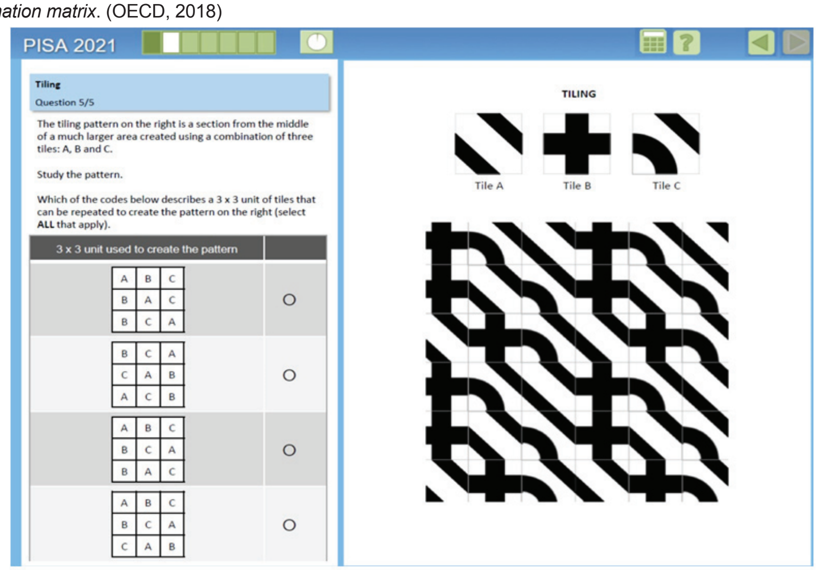
Representation in variables (OECD, 2018)



In Figure 7, we see the fifth part of the question, in which the student is asked to recognise the beginning of the pattern and determine its formation matrix, implying that there are two forms of patterns that repeat in different time spaces.

Figure 7

Formation matrix. (OECD, 2018)



At the end of the question, we observe that the students need to use knowledge to recognise the mathematical nature of a contextualised problem, especially the situations encountered in the real world, and then formulate it in mathematical terms. The change from an ambiguous, confusing, and real-world situation to a well-defined mathematical problem requires mathematical reasoning, and for its resolution, it is necessary to use concepts, algorithms, and procedures built in the classroom. The OECD (2018) points out that the student needs to evaluate the mathematical solution, interpreting the results within the original real-world situation, while they must possess and be able to demonstrate computational thinking skills as part of their problem-solving practice. These computational thinking skills applied in the formulation, use, evaluation, and reasoning include pattern recognition, decomposition, and determination.

The development of skills is in line with Rosado and Bélisle (2006) and Jenkins *et al.* (2009) when they describe the skills related to the use of digital technologies and their use critically and constructively. We highlight that the skills mentioned in the report that we understand to be present in the matter analysed are collect and use information from the Internet critically, extract inferences and solve problems.

CONCLUSION

In this study, we dealt with the knowledge of computational logic present in the PISA 2021 mathematics exam and how it considers the different levels of knowledge, characterised in literacy: Science Literacy, Mathematical Literacy and Reading Literacy. We believe that the teacher must have this knowledge to organise better the mediations and consequent constructions experienced by students in the classroom, knowledge that needs to be reflected in planning, educational practices and continuous assessments

We observed that technologies have always been mentioned in the different literacy reports as an important skill to be developed concomitantly with other literacies. However, the OECD has increasingly begun to edit official regulations and documents highlighting the use of digital technologies during student studies. These documents, which were gradually made available to teachers and the whole society, indicated that technological knowledge would be of supreme importance for the future of the exams.

Skills such as designing digital solutions, adapting or creating computer algorithms to meet one's needs, knowing how to collect and use information from the Internet critically, managing information reliability, extracting inferences, browsing digital content, and solving problems are linked to advanced reasoning and problem-solving skills and require good command of symbolic and formal language.

We understand that some of these skills are already part of the formal curriculum instituted in most countries, thus easily adaptable to the classroom. However, others are still in the process of being implemented in several countries, especially those that have knowledge of programming logic for the construction of computer algorithms.

Thus, we point out that a new form of literacy is increasingly assuming space in this external assessment exam: Digital Literacy.

We understand by Digital Literacy the critical use of Digital Technologies by the individual in such a way that they assume positions and adopt conscious and critical behaviours, with a study related to intellectual abilities that are reflected through different technological skills. In this way, the use of technology implies much more than a functional matter of learning how to use a digital device, or how to conduct online searches and check email.

Digital Literacy is centred on the individual and the critical use that one makes in the face of technologies and their information, since Digital Technologies allow the individual to present oneself to the rest of society by creating and transmitting personal statements either with the creation of blogs or personal profiles, contributing to online forums for knowledge building. We observed reflections of this Digital Literacy in what will be the PISA 2021 assessment, by making clear to society the insertion of knowledge of computational logic, with emphasis on computational thinking, in which it is still classified as a test with a mathematical focus.

The question presents a growing complexity of resolution, guaranteed by the Item Response Theory, with the formulation of a contextualised problem and the design of its solutions so that it can be executed by a computer, a human being or a combination of both.

We highlight three levels of knowledge of Computational Logic involved in the model question offered by PISA, which will be implemented in its next edition: (i) pattern recognition, (ii) logical control structures, and (iii) variable representation.

Recognising patterns is one of the initial levels of knowledge of computational logical analysis to separate categories, identify specific solutions for each of them, while considering the limitations and characteristics of each group or set. Thus, the recognition of patterns aims to classify data based on preliminary or deductive knowledge, or even on statistical information extracted from these patterns.

Logical control structures are components used for the creation of algorithms that can be of three natures: (i) simple sequences; (ii) conditional control structures, and (iii) repeating structures. In the question, we noticed the use of all three forms of control through a block language. We highlight that block languages emerged to facilitate the construction of a purely abstract knowledge for something more tangible: the fitting of commands ready for the creation of programming structures.

The representation by variables to obtain the law of pattern formation is the union of what was constructed in the problematisation of the issue with mathematical algebra, because the student needs to determine the formation matrix of the established standard.

We highlight that ensuring that all students reach a basic level of proficiency, especially in reading and mathematics, will do more to create equal opportunities in the digital world than can be achieved by expanding or subsidising access to high-tech devices and services. Even so, computational knowledge should be considered, since digital technologies can support and improve learning.

We point out that, in view of what is presented in this study, we understand that students need to be able to assess and use the information critically if they want to turn it into knowledge; recognise patterns and infer a critical position as to their consequences. This means asking questions about the sources from which the information originated, the interests of its producers, and how it represents the world. Moreover, mainly, understand how this technological development is related to broader social, political, and economic forces, aspects closely linked to the Digital Literacy Theory.

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AUTHORS' CONTRIBUTIONS STATEMENTS

F.S.S. developed the theoretical framework, conducted the research activities and data collection. A.B. supervised the project, guided data collection, and revised the theoretical framework. Both authors reviewed the collected data, discussed the results to write the final version of the text.

DATA AVAILABILITY STATEMENT

The data that support the results of this study are available in their references. In case of doubts, contact the author F.S.S.

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