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"Viewing puzzles as two-faced: theoretical and practical implications for Puzzle-based Learning"

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ABSTRACT

The Puzzle-based Learning approach has been applied to several fields of knowledge. In education research papers, the instructional usage of puzzles is considered to improve learners' motivation and engagement and help them to develop critical skills but difficulties concerning learners' interaction with puzzles have also been pointed out. Our paper investigates the dynamics of the concept of a puzzle and its interface to provide a better understanding of its form and functions, and help learners interact with puzzles. We consider Puzzle-based Learning tenets as well as their educational impacts on both critical thinking and learner engagement and provide an original proposal concerning the understanding of puzzles. Our proposal centered on the dynamics of puzzles bears conceptual and educational facets. Conceptually, puzzle dynamics is viewed as composed of two elements: a mechanism, the Puzzle Trigger, and a process, the Puzzle-Solving. From an educational point of view, the rationale for integrating Puzzle Triggers in Puzzle-based Learning is meant to help learners interact with puzzles and consequently become motivated and engaged in the Puzzle-Solving process. This way, learners' critical thinking skills are reinforced and focused on finding solutions to challenges. We illustrate the implementation of Puzzle Triggers and Puzzle-Solving by considering two instructional activities in a Software Development undergraduate course of an online learning Informatics Engineering Program.

1. Introduction

Humans learn better and improve their learning skills when they are engaged in learning, that is, when they are involved in actively processing information and not merely receiving information without actively processing it (Dehaene, 2020). Educational researchers have long been developing approaches to engage and support student learning and one of the strategies common to several learning approaches is the fostering of problem-solving skills (Michalewicz et al., 2010).

Puzzle-based Learning has been used to increase problem-solving skills in educational settings and enables the transfer of these

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skills to real-world settings (Falkner et al., 2012a, 2012b; Meyer et al., 2014; Sooriamurthi et al., 2012). Introducing puzzles is considered relevant within and outside educational contexts.

Puzzle-based Learning has been analyzed empirically via didactic experiments in various countries and fields of knowledge, such as Computer Science (Falkner et al., 2012a, 2012b); Merrick, 2010; Sooriamurthi et al., 2012), Architecture (Ramaraj and Nagammal, 2017, 2020), Biology (Susan et al., 2016), Languages (Omar and Said, 2019), Business (Kawash, 2012), Education (Slisko, 2017), Mathematics (MollerandO'Reilly, 2019; Badger et al., 2012; Jelle, 2017; Klymchuk et al., 2017; Meyer et al., 2014; Michalewicz and Michalewicz, 2008) and Physics (Gnädig et al., 2001).

In this paper we address a problem with the current literature on Puzzle-based Learning: there is no description of the dynamics of the puzzle process. For a better understanding and consideration of the Puzzle-based Learning process, our contribution consists in providing a new structural description of the puzzle dynamics. We propose that the puzzle must be viewed as having two components: a mechanism and a process. The mechanism is what we call the Puzzle Trigger, the moment in which the learner perceives the puzzle, and the process is what we call the Puzzle-Solving, that is, the learner's engagement with the actual puzzle to solve it.

This distinction between mechanism and process disentangles the initiation phase from the development phase. The initiation phase is where learners grasp a problem and find ways of solving it. The development phase is where actual puzzle resolution takes place. This distinction enables educators to approach Puzzle-based Learning in a more structured manner, as we demonstrate in Section 4 of this paper, by considering Puzzle Triggers in their planning and development efforts to engage the students in the Puzzle-Solving process.

The general goal of this paper is to look into the dynamics of the concept of puzzle and its interface to get a better understanding of its form and functions. The specific objectives of this paper are the following:

- Proposing a dual structure perspective of the dynamics of puzzles: the Puzzle Trigger mechanism and the Puzzle-Solving process;
- Formalizing and describing a mechanism that has been overlooked in the dynamics of the puzzles: the Puzzle Triggers;
- Considering the features of the Puzzle-Solving process;
- Considering the benefits of introducing the Puzzle-Trigger mechanisms and the Puzzle-Solving process in Puzzle-based Learning.

In the following sections of this paper, we consider the tenets and applications of Puzzle-based Learning, address puzzles from a dynamic perspective, introduce and formalize the concepts of Puzzle Trigger and Puzzle-Solving, present our proposal centered on the dynamics of puzzles, and demonstrate its application in learning contexts by showcasing the use of Puzzle Triggers to create Puzzle-based Learning activities in the context of Higher Education within an e-learning course on software development in an online Informatics Engineering Program.

2. Puzzle-based Learning

2.1. Tenets

Puzzle-based Learning is an educational approach aimed at developing critical thinking skills and creative thinking abilities in framing and solving descriptive and unstructured problems by means of focusing on puzzles (Ambrus, 2008; Derer & Berkant, 2020; Falkner et al., 2012a, 2012b; Falkner et al., 2010; Michalewicz & Michalewicz, 2008; Sooriamurthi et al., 2012).

Puzzles are engaging and motivating and they are necessarily linked to critical thinking. Critical thinking leverages learners' curiosity to solve puzzles and motivate learners to solve them. In educational contexts, puzzles and critical thinking work together in instructional dynamics, activities, concept explanations, assessments, and other aspects (Michalewicz et al., 2010).

The relevance of the Puzzle-based approach to investigating the human mind and the need to consider it in a scientific and systematic way in the educational setting is argued as early as the beginning of the XXth Century (Ballard, 1915). Ballard mentions some of the characteristics which make puzzle-learning potentially effective: solutions achieved by puzzle challenges are also applicable to real-world problems; puzzle application is not limited by age, that is, they apply to both young and old people; puzzle-learning is not to be confounded with traditional book-learning, since the former privileges reasoning and the latter content memorization; puzzles demand some kind of complex motor reaction; the results of their application can be valued psychologically; they do not require a previous familiarity.

Critical thinking skills and creative thinking ability in framing and solving descriptive and unstructured problems play an important role in Puzzle-based approaches. Meyer et al. (2014) report on decades-long efforts for teaching to support the structure of thinking skills, employing the term "critical thinking". Even before the term "critical thinking" first arises in the literature, its concept can be apprehended in the work on Puzzle-based Learning by Ballard (1915, 50) as he refers to the "imaginative, comparing, judging, and reasoning activities of the mind" which are called in puzzles.

A comprehensive review of Critical Thinking, taking into account its conceptualizing process, definitions, perspectives from various disciplines, theoretical and empirical research works, was provided by Asiri (2020). The author argues that critical thinking is defined in the literature in various ways, comprising several characteristics and skills. He considers that these definitions can be grouped into two categories as far as the concept of "thinking" is concerned: as a cognitive process and as an outcome, the reflection of behaviors, attitudes, feelings, and emotions (psychological and behavioral effects).

There are also, however, definitions which combine both perspectives. For instance, Garrison et al. (2001) contend that "Critical thinking is both a process and an outcome". Following this combined perspective of process and outcome, critical thinking in the context of problem-solving can be seen as the process and outcome of analyzing and evaluating thought processes related to one's problem-solving abilities.

2.2. Puzzle-based Learning instructional intervention assessments

Puzzle-based Learning is advocated as a motivating and engaging approach that raises learners' interest by introducing several kinds of puzzles and discussing problem-solving strategies (Costa, 2017; Kawash, 2012; Merrick, 2010; Meyer et al., 2014; Patel & Dave, 2019; Slisko, 2017; Thomas et al., 2013). It has been reported as having positive effects on developing learner critical thinking skills and promoting learner engagement.

Akarsu et al. (2019) raise a relevant argument concerning critical thinking and problem-solving skills in Puzzle-based Learning. They argue that Puzzle-based Learning is related to problem-solving, argumentation, and critical thinking skills. Following the same line of argumentation, Murphy et al. (2020) state that Puzzle-based Learning not only has a positive impact on learners' critical thinking skills but also on their view of learning and their creativity, which becomes enhanced by perceiving problem-solving in terms of divergent thinking, flexibility, and originality.

However, not only positive impacts have been raised by Akarsu et al. (2019). In their study, the authors conclude that although the majority of the participants (undergraduate engineering students) got the right answers for given problems, most of them were not able to provide arguments to back up their answers. They also point out that most of the participants who were able to provide arguments got the right answers. They interpret these results as indicating that when problems require critical thinking, argumentation, and problem-solving skills rather than relying on memory and understanding, the majority of the students do not succeed.

Other troublesome aspects have been raised concerning the application of Puzzle-based Learning. These concern the choice of the degree of the difficulty of the puzzles to be used in the educational contexts, the discrepancies among the results obtained in applying puzzles in the classroom, the lack of argumentative knowledge (Akarsu et al., 2019), and the difficulties concerning learners' interaction with puzzles which have to do with what skills should be learned and how to facilitate and evaluate learning (Meyer et al., 2014).

Concerning the application of Puzzle-based Learning, suggestions on how to implement them effectively have been given by Bates (2004). He recommends a set of procedures to make puzzles motivating, engaging, and interest-raising. They have to do with context application (time, simplicity, clarity, space), application procedures (room for trial and error, diversity of steps, hints), puzzle structure inherent features (challenging but not obscure or impossible), and instructional environments (the use of puzzles in narratives and games).

Motivation, engagement, and interest are situational factors which are worth considering under the dual construct perspective posed by Ainley (2012). This author points out that such situational factors can act as hooks that attract learners to an activity. The motivation factor is constructed by an underlying psychological process involving energy and directionality dimensions while the engagement factor driven by interest comprises affective, behavioral, and cognitive dimensions (Ainley, 2012; Ciric & Jovanovic, 2016; Fredricks et al., 2004; Gibbs & Poskitt, 2010). However, to engage students, factors such as the value attributed to the activity and its perceived pleasantness play a relevant role. Ainley (2012) further considers that interest is a motivational construct. When interest is combined with the engagement construct, the two of them function as a dynamic system in classroom activity interactions.

2.3. Puzzle-based Learning educational applications

From an applied perspective, comprehensive reviews on works addressing the educational endeavor to teach critical thinking skills can be found in several works (Ahern et al., 2019; Behar-Horenstein & Niu, 2011).

Behar-Horenstein and Niu (2011) reviewed 42 works, written between 1994 and 2009, about the teaching of critical thinking skills to students attending higher education courses. They conclude that equivalent ways of educational intervention may lead to different results depending on how they are implemented and that multidimensional tests, which include both qualitative and quantitative features, should be used in assessing the effects of educational intervention on student thinking skills.

Ahern et al. (2019) present a comprehensive literature review of practical interventions in engineering courses aimed at developing student Critical Thinking skills. In their conclusions, the following features were pointed out: incongruences among papers concerning methodological research procedures; a limited number of research subjects and, consequently, poor generalization and evaluation of the impact of the educational interventions; few long-term studies; lack of considering instruction bias; disconnection between theoretical and practical issues; incompatibilities between employer and educator understandings of Critical Thinking.

Given the increasing worldwide importance of distance learning in societal terms due to economic, timing, mobility and learning style constraints (Correia et al., 2014; Morais et al., 2020; Pedrosa et al., 2020; Pedrosa et al., 2019; Pozdnyakova & Pozdnyakov, 2017), this educational context can make great use of introducing Puzzle-based Learning activities to motivate learners.

Puzzles in educational contexts can be inserted into games, narratives, and exercises. Inserting puzzles in a game is, however, rather challenging since they introduce obstacles to be solved before the players reach their goals (Brathwaite & Schreiber, 2009). In the same vein, Bates (2004) argues that the introduction of puzzles in games should follow specific requirements: no time pressure; rules should be clear; the interface should be simple; space for trial and error without penalty should be provided; resetting a problem or undoing a particular move should be allowed; the steps completed by the players to solve a problem should not be repeated; plenty of hints should be given to a player to help him to solve a puzzle; puzzles should be challenging, not obscure or impossible to transverse (Bates, 2004).

To be challenging and not obscure, according to Bates (2004), puzzles in a game must be varied to interest a good number of players, sequenced to maintain their engagement, and inserted in a story or action. According to the author, these elements were present in the original games that combined puzzle exploration and solving because they were created around a story or activity, and the player held the hero role.

Bates states that there are good and bad puzzles. It all depends on how they are written. Bad puzzles can destroy the development of the plot, the character, and the story in a game, whereas good puzzles can contribute to their development. Quoting Bates: "Every puzzle is a storytelling opportunity." (Bates, 2004, 49). Thus, Bates introduces puzzles connected to narratives and challenges. The narratives, including their characters, provide the social context and the challenges are ways to get the learner to solve these challenges. As Bates puts it, puzzles are not roadblocks. In a game, the player must be helped along. Bates' proposal for this help is the scattering of varied hints in Puzzle-based frameworks. However, he does not contemplate the links between these elements, lacking consideration for how narratives can be constructed, how challenges are perceived, and how the process leading to a solution occurs with the support of the provided hints.

The two latter aspects are central topics discussed in this paper: the perceptual driving mechanism (the Puzzle Triggers), and the process of solving challenges (the Puzzle-Solving). Concerning the former aspect, narrative construction, the OCC-RDD, a technique for writing narratives using puzzles, is applied by Fontes, (2017), Fontes and Vega, (2016). The OCC-RDD is an acronym which stands for Objective, Conflict, Catastrophe, Reaction, Dilemma, and Decision. The OCC-RDD narrative is built around these descriptors. In OCC-RDD narratives, the elements are the ambiance, the events, the characters, and the social roles. Narratives incorporated in the SimProgramming approach Pedrosa et al. (2016); Pedrosa et al. (2020), focusing on software engineering didactics, also consider these elements. In Pedrosa et al. (2016) the ambiance is a business environment; the characters are the participants in the business teamwork and their roles are demonstrated in the narrated events.

In the context of Puzzle-based Learning, narratives provide opportunities for students to articulate their thought processes by examining the ambiance, the characters, and the way they interact. Meyer et al. (2014) advise: "One of the goals of a Puzzle-based Learning class is to get the student to articulate their thought process." (Meyer et al., 2014, 39); "a successful Puzzle-based Learning class is a "well-balanced mix of prepared material and spontaneous reaction to the material" (Meyer et al., 2014, 37). Narratives used in instructional materials have the potential to foster student curiosity and engagement in the learning process, helping them to articulate their thoughts and react positively to the didactic activities.

Two other points raised by Meyer et al. (2014) in relation to Puzzle-based Learning are nevertheless problematic. They are the way they describe the purpose of the puzzle and the privilege they pose on conscious reasoning over intuition. They mention that their "goal is to produce students who use puzzles to develop their general solving skills" (Meyer et al., 2014, 39). Our view is that puzzles are proposed to be solved, that is, they are prone to a determined and not a general scope, although the ability the learners develop by solving them can be generalized. Furthermore, both intuition and reasoning may act together in solving puzzles (Falkner et al., 2010).

In cognitive processing, intuition is used by individuals to evaluate situations and find solutions to complex problems. Active processing of the information to solve problems involves both intuition and reasoning. In fact, the links between intuition and reasoning are considered in studies concerned with the active processing of information in learning situations (Evans, 2010; Kahneman, 2013).

Evans (2010) refers to intuition and reasoning from a dual-process theoretical perspective of thinking as two distinct types of cognitive processing. Intuition is fast, insightful, both conscious and unconscious, and shares characteristics with perception while reasoning is slow, reflexive, conscious, and dependent on central working memory. This author relates intuition to high capacity, low effort mental processing, and parallel processing of large amounts of information, while reasoning is slow, reflective, low processing capacity, effortful, and affected by working memory loads or short time constraints. He also claims that from an educational point of view, finding ways of training people to reason well is not enough, since it is necessary to make people aware of situations in which such effortful processing needs to be applied. On the same line of thought, intuitive judgments are considered by Kahneman (2013) to refer to a combination of analysis and intuitions which are acquired by repeated experience or by heuristic operations.

Introducing puzzles independently from the educational context in which they are used or the types of activities in which they are inserted, such as narratives, games, or exercises, is considered rather challenging due to reasons pointed out by Meyer et al. (2014). According to these authors, puzzles pose challenges involving problem-solving, critical thinking, perseverance, and resilience, among other skills, and learners may feel uncomfortable facing these challenges. Some of the questions raised by these authors are: "(1) What knowledge and skills should students learn? (2) How can I facilitate their learning? (3) How do I determine how well they have learned via formative and summative feedback?". These questions are discussed by Meyer et al. (2014) from the perspective of the side effects on learners of including puzzles in educational settings and of the methods to be used by the teachers. Among the effects on learners, the following are mentioned: engagement, involvement, and interest. On the teacher side, the optimization of methods is the concern, that is, which method to choose linear/integer programming, tabu search, simulated annealing, or genetic algorithms, and how to make available an overview of the chosen methods to help learners to remember them (Meyer et al., 2014).

Puzzle-Learning and Critical-Thinking presuppose a deep mental involvement from the part of the learner regarding the challenge faced by the learners to solve a problem and their reasoning in pursuing its solution. This is aligned with the current theory on the phenomenon of Immersion, which sees as one of its conceptual dimensions the mental absorption with challenges, leading to the concept of Immersive Learning, defined as the "the emergence of the phenomenon of immersion in association with the phenomenon of learning" (Beck et al., 2024). This association is said to occur when learners experience a "technological, narrative, and challenge-based state of deep mental involvement that dims their awareness of the physical world" (ibid.).

Beck et al. (2024) surveyed accounts of actual practices and strategies reported within research on immersive learning environments, seeking to finding clusters of theoretical affinity. Their outcomes grouped strategies and practices under five clusters: "Active context", "Collaboration", "Engagement and Scaffolding", "Presence", "Real and virtual multimedia learning", and "Traditional practices".

In the context of this paper, three clusters are particularly relevant: "Active context", "Engagement and Scaffolding", and

“Presence”. They comprise several educational practices and strategies that map to the earlier concerns with Puzzle-based Learning, as described below.

The “Active Context cluster” comprises educational practices such as exploration of processes, authentic assessment, or enriching student storytelling, connected to contextual and active learning theories, including narratives and meaningful transfer.

The “Engagement and Scaffolding cluster” comprises pratices such as automated feedback and tutoring, personalization, and learning design for engagement, connected to theories such as Engagement, Scaffolding, as well as instructional design and formative assessment strategies.

The “Presence cluster” comprises the practices of experiencing and physiological/psychological state and embodied interaction, connected to educational strategies such as Presence theory, metacognition, and socio-emotional learning.

These three clusters relate to concepts explored in problem-based learning, cognitive science, learning sciences, and educational psychology that are valued in considering puzzle-related issues such as active processing, engagement, interest, learners’ traits, and pleasantness derived from experiencing reduced cognitive effort in implementing tasks and finding solutions to problems.

2.4. Puzzle definitions

In the literature on Puzzle-based Learning, puzzles are defined as the following: problems whose solutions can be achieved by providing the problem-solvers with questions and suggestions that induce mental operations which are useful for problem solution (Pólya, 1971); a problem having one or more specific objectives, among them people’s cleverness or patience (Dalgety & Hordern, 2017); a toy; a problem which is introduced by a bunch of questions and suggestions and involve mental procedures comprising the following steps: understanding the problem, establishing links between the unknown and known facts, planning, reviewing, discussing the facts leading to the problem solution, exerting control over the factors leading to problem solution and displaying useful and powerful problem-solving rules in an entertaining way (Ballard, 1915); a game, toy, or problem designed to test ingenuity or knowledge (Collins English Dictionary, 2022); as something which makes something happen in a certain way (Collins English Dictionary, 2022); an unusual problem either in content or method that is tackled to be solved (Lindley, 1897); a three-factor combination of entertaining, temporary frustration and a sudden insight (Bates, 2004); an engaging, rewarding, thought-provoking, entertaining activity leading to insights on problem-solving (Meyer et al., 2014); a non-standard, non-routine, unstructured question presented in an entertaining way (Klymchuk, 2017).

2.5. Types of puzzles

A great number of puzzles are proposed in the literature on Puzzle-based Learning from Lindley (1897) up to the present times. They may vary according to the level of difficulty (simple and complex), kind of subject (discipline-specific), comprehensiveness (general or specific), application (theoretical or real-world problems), social (icebreakers and warm-ups), or theoretical (content) orientations.

In general, puzzle types do not occur in isolation, that is, puzzles are often complex and combine more than one kind. As such, most of the time, when facing a puzzle, the solver deals with a combination of different types of puzzles.

Over the last century, authors attempted to classify puzzles based on their features (Ballard, 1915); on critical thinking features Brathwaite and Schreiber (2009) and on educational purposes (Meyer et al., 2014).

Lindley’s classification of puzzles is not systematic. It is mainly related to fields of knowledge such as Language, Mathematics, Philosophy, Logic, and Ethics. He is not concerned with categories of puzzles or education issues. His focus is on the relation between puzzles, and psychological and biological features of play activity. To get data on the interest in puzzles he applied a questionnaire, and to analyze modes of mental reactions to puzzles he conducted an experiment. The questionnaire was applied to 556 subjects from 10 to 40 years, and the answers indicated a preference for Language puzzles, among them Riddles and mechanical puzzles. The experiment consisted of the presentation of a kind of Spatial Reasoning Puzzle to schoolchildren. Its results were compared to those of adults and were interpreted by the author as indicating that the adaptation to the new gets better with age.

Ballard (1915, 6) considers discipline and complexity as criteria for classifying puzzles. The classification is done according to the number of moves, the spatial direction of the move, the choices available to pursue the solution, and the combination and position of the parts involved. He proposes the following groups of puzzles: "(a) Language and word puzzles, including riddles, conundrums, charades, and acrostics; (b) mechanical puzzles, including some dependent on dexterity and perseverance, some dependent on a trick or secret, dissected and combination puzzles, physical puzzles which involve unique applications of well known physical laws, and other puzzles more complicated; (c) mathematical puzzles, including numerical, geometrical and unicursal or tracing puzzles."

Simpler ways of classifying puzzles are referred to in the literature about Puzzle-based Learning. They consider either the development process constraints or educational goals. Development process constraints are taken by Gilbert (Bates, 2004), for example, to classify two kinds of puzzles: plot puzzles and normal puzzles. Plot puzzles introduce hints about the development of the plot and normal puzzles do not. Both plot and normal puzzles are used by Gilbert in designing games.

In its turn, educational purposes are taken by Meyer et al. (2014) to propose the following types of puzzles: Icebreakers, puzzles designed to promote strong interactions among participants; Warm-ups, which introduce a particular technique or way of thinking to train learners; General puzzles: not related to specific disciplines; Discipline-specific puzzles: related to specific disciplines and instruction levels.

A contribution to the classification of puzzles from the point of view of game design is found in Brathwaite and Schreiber, (2009). The kinds of puzzles posed by Brathwaite and Schreiber (2009) are Riddle, Lateral Thinking, Spatial Reasoning, Pattern Recognition, Logic, Exploration, and Item Use. They involve playing with words (Riddle); questioning assumptions to get the right answers (Lateral Thinking); manipulation of objects (Spatial Reasoning); recognition of patterns from given information (Pattern Recognition); generation of new information based on received information (Exploration); and puzzles that involve finding objects to use and choosing the order to use them to solve a particular challenge. A brief description of the seven types of puzzles proposed by Brathwaite and Schreiber (2009) is presented in Table 1.

From the point of view of learning, the classification of the types of puzzles found in Brathwaite and Schreiber (2009) is interesting because it is comprehensive, that is, it comprises several types of reasoning (deductive, creative, spatial, inferential, logic, analytical and associative) made by the solver when he gets into contact with a puzzle. When the solver gets in contact with a challenge one or more types of puzzles can be evoked.

3. A puzzle dynamics centered proposal

In the previous sections, we have considered the tenets of the Puzzle-based Learning approach, definitions, and types of puzzles found in the literature. Although puzzles are in some of the definitions presented in the literature concerning Puzzle-based Learning as equivalent to problems, our view is that puzzles are not to be confused with problems or even challenges or questions. Puzzles not only motivate learners but also develop both essential and transversal competencies such as reflection, logical reasoning, and problem resolution which contribute to developing the learning process over a lifetime. As such, puzzles refer to logical reasoning skills by means of which problems are approached as challenges, raise questions, and are solved. According to Abbass (2015), a challenge must show a balance between demanding and stimulating features designed to achieve a desired outcome or effect, and questioning would be a natural means to communicate it.

The fact that equivalent Puzzle-based Learning educational interventions lead to different results, as mentioned by Behar-Horenstein and Niu (2011) and the challenges related to problem-solving as mentioned by Meyer et al. (2014) are relevant to be considered.

In our view, the discomfort faced by the learners as pointed out by these authors stems from the fact that puzzles are not viewed in the literature of Puzzle-based Learning as dual structures.

We propose that puzzles are formed by two elements: a driving mechanism, the Puzzle Trigger, and a process, the Puzzle-Solving. It is the driving mechanism which triggers the process of Puzzle-Solving. The engagement in the Puzzle-Solving process is triggered by the Puzzle Trigger and involves affective, behavioral, and cognitive features.

Considering the affective, behavioral, and cognitive factors involved in motivation and engagement is relevant because it brings about the distinct components comprised in these terms and this has implications for the distinction between mechanism and process that we make in this paper.

We argue that both argumentation and critical thinking skills are components of the Puzzle-Solving process which is activated by the Puzzle Triggers. Looking at puzzles from the dual perspective of mechanism and process enables considering problem-solving, argumentation, and critical thinking.

We use the term "Puzzle Triggers" to designate a perception-driving mechanism that enables perceiving puzzles. Being a mechanism, Puzzle Triggers can be anything concrete, such as images, sound, text, or even an event that is experienced. The puzzles are triggered by the perception of one or more elements, which guide the solver to interpret them. Therefore, Puzzle Triggers, by structuring the perception of problems, originate the Puzzle-Solving. As such, a distinction is made between the problem and the problem-solving process, the Puzzle-Solving.

Puzzle Triggers can be considered in terms of quality and intensity. The quality of the Puzzle Triggers depends on the appraisal of the input, that is, the element or set of elements that activate the perception of the problem. The intensity of the Puzzle Triggers depends on the repertoire of concepts previously developed by the individuals. Thus, the quality and intensity of the Puzzle Triggers can vary even when faced with the same element or set of elements.

Puzzle Triggers are not to be confused with Reflection Triggers either (Verpoorten et al., 2012). The Reflection Trigger is defined as a "deliberate prompting approach that offers learners a structured opportunity to examine and evaluate their learning" (Verpoorten et al., 2012, 2). Therefore, Reflection Triggers refer to an approach to make learners reflect on their own learning. Puzzle Triggers, however, refer to a perception-driving mechanism that enables students to perceive puzzles. This puzzle perception is triggered by the elements that guide the solver to interpret them and address the puzzle. Thus, Puzzle Triggers comprise a problem-question and an answer-solution connection. Therefore, Puzzle Triggers, by structuring the perception of problems initiate the Puzzle-Solving. As such, a connection between the problem and its resolution is established.

Table 1
Types of puzzles described in Brathwaite and Schreiber (2009).

Types of Puzzles	Requirements on the puzzle-solvers
Riddle	Providing a nonstandard interpretation of a play of words
Lateral Thinking	Questioning assumptions
Spatial Reasoning	Manipulating objects mentally or physically
Pattern Recognition	Identifying Patterns based on presented information
Logic	Deriving additional information to find solutions
Exploration	Exploring the environment to locate entities
Item Use	Using items or combination of items to solve a challenge

The Puzzle Trigger sustains the learners' engagement through the puzzling completion. When learners get into contact with a Puzzle Trigger, their experience with the puzzling comes into being. The learners' engagement with the puzzling will depend on the immersive environment developed by the teacher, that is, it will be affected by the teaching practices and strategies. Guidance on teaching practices and strategies in immersive learning is found in Beck et al. (2024).

In sum, the Puzzle-Solving process refers to critical thoughts which set up the problem to find a solution. Given a problem, the perception-driving mechanisms open the path to the process of Puzzle-Solving, which, in turn, leads to a solution. It comprises two actions (hence its hyphenated name): the Puzzling and the Solving. Puzzling refers to the reflexive state of collecting, analyzing, and tackling the issues to solve a problem. Solving refers to finding a solution to the problem. In Fig. 1, these functions played by the Puzzle Triggers and the Puzzle-Solving process are illustrated.

As an example, to explain how the Puzzle Trigger and the Puzzle-Solving work, consider the following puzzle proposed by Pólya, (1971). The puzzle contains an anagram with the following combination of letters "DRY OXTAIL IN REAR" and the goal of the problem is finding the ordering of letters that exposes a unique word.

The main Puzzle Triggers (mechanisms) of this puzzle are the visual letters them selves, the fact that it is composed of only one hidden word and the knowledge of what is an anagram. Other Puzzle Triggers (mechanisms) would be instructions, such as: "Pick two letters to begin the anagram"; "Pick two letters to finish the anagram".

Then, the Puzzle-Solving process starts, that is, the process of using the Puzzle Triggers to create a one-word anagram. During the Puzzle-Solving process, some Puzzle Triggers can be altered, removed, or added. For example, the first two letters can be changed to "EX", and the final letters changed to "LY". So, with these changes, the puzzle can be more easily solved, and the answer to the puzzle can be eventually found: "EXTRAORDINARILY".

To illustrate how the Puzzle Triggers and the process of Puzzle-Solving can be used in educational contexts, some examples are considered in Section 4.

The role of Puzzle Triggers and Puzzle-Solving in learning situations comprises grasping the puzzle by means of getting in contact with the Puzzle Triggers, conceptualizing the problem, and performing the Puzzle-Solving to find the solution to the problem. Fig. 2 shows these steps graphically.

The first step is to notice there is a problem that needs a solution. The second step comprises the triggers which activate the flow between the problem and the solution. The third step refers to problem formalization and its understanding. The fourth step constitutes the discovery of how to solve the problem. The fifth step is "the one good" solution found.

Puzzle Triggers are activated independently of characteristics such as learners' developmental traits, previous familiarity with dealing with puzzles, or amount of experience in answering puzzles. These features must be addressed by the teachers on building activities introducing the puzzle Triggers, though. Teachers must develop teaching practices and strategies that are adequate for the learning environment and helpful for the learners to perceive the puzzle Triggers and solve the puzzles.

Strategies found in immersive learning, such as engagement, scaffolding, and learning design for student engagement (Beck et al., 2024), for instance, provide an adequate environment to contemplate puzzle Triggers. This is because those strategies are associated with educational practices that require mechanisms for their implementation - and puzzle Triggers are one specific instante of such a mechanism. A thorough review of the educational practices and strategies accounted for in immersive learning environments is provided by Beck et al. (2024).

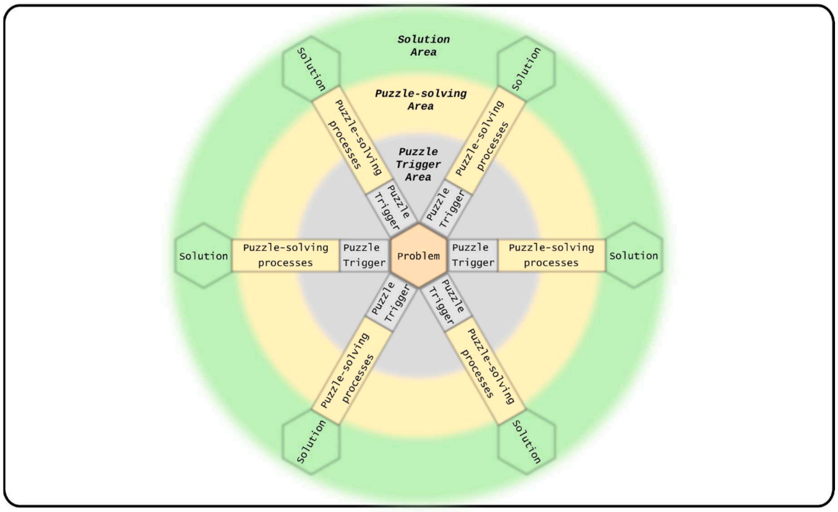


Fig. 1. Interactions among Problem, Puzzle Triggers, Puzzle-Solving, and Solution. Figure created by the authors.

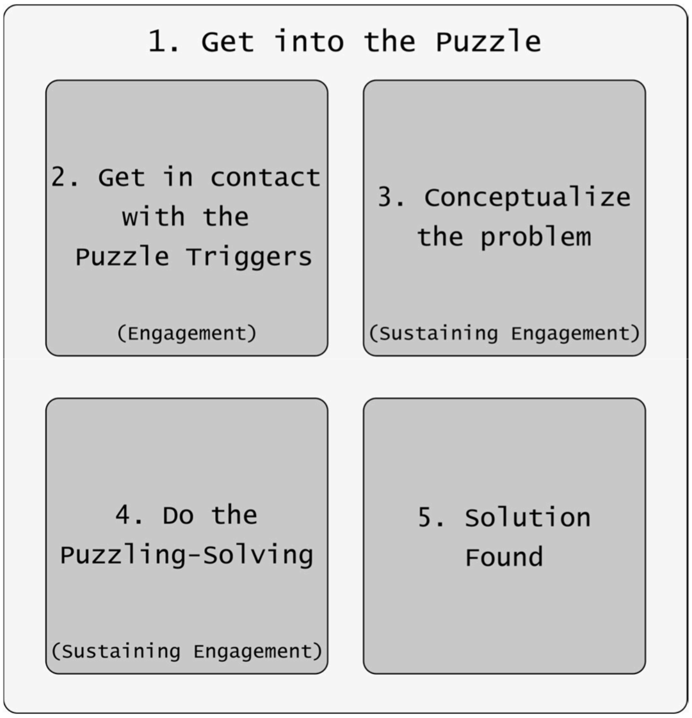
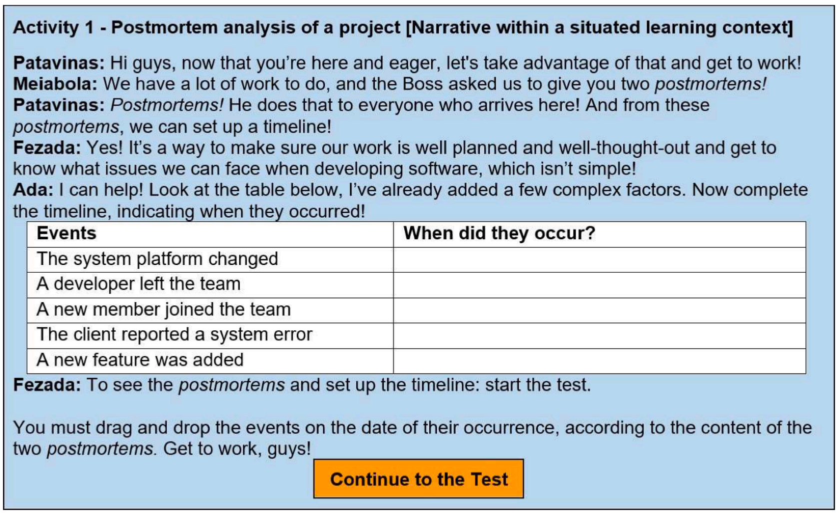


Fig. 2. Steps involved in solving a puzzle: from getting in contact with Puzzle Triggers to finding the solution to the puzzle. Figure created by the authors.

4. Applying the Puzzle dynamics centered proposal

To illustrate the concepts discussed in Section 3 about Puzzle Triggers and Puzzle-Solving, two activities produced as instructional materials for the online course Software Development Laboratory are presented. This course is offered to students enrolled in the Bachelor of Informatics Engineering online program at the Portuguese Open University (Universidade Aberta), asynchronously via its e-learning platform (Moodle). The target student audience is mostly composed of working students, often with work experience in software development.

The course is organized around six topics. Its objective is to convey best practices for developing software so that costs are minimized, software quality is maximized, and fun is obtained out of programming. The adopted pedagogical approach is e-


Activity 1 - Postmortem analysis of a project [Narrative within a situated learning context]

Patavinas: Hi guys, now that you're here and eager, let's take advantage of that and get to work!
Meiabola: We have a lot of work to do, and the Boss asked us to give you two *postmortems!*
Patavinas: *Postmortems!* He does that to everyone who arrives here! And from these *postmortems*, we can set up a timeline!
Fezada: Yes! It's a way to make sure our work is well planned and well-thought-out and get to know what issues we can face when developing software, which isn't simple!
Ada: I can help! Look at the table below, I've already added a few complex factors. Now complete the timeline, indicating when they occurred!

Events	When did they occur?
The system platform changed	
A developer left the team	
A new member joined the team	
The client reported a system error	
A new feature was added	

Fezada: To see the *postmortems* and set up the timeline: start the test.

You must drag and drop the events on the date of their occurrence, according to the content of the two *postmortems.* Get to work, guys!

Continue to the Test

Fig. 3. The narrative concerning the concept of postmortem. It presents important facts that should be noted in the postmortem report. "Patavinas", "Meiabola", "Fezada", and "Ada" are the names of characters speaking in this narrative.

SimProgramming Pedrosa et al. (2021), an e-learning adaptation of the face-to-face SimProgramming approach Nunes et al. (2017); Nunes et al. (2021); Pedrosa et al. (2016, 2019, 2017) whose framework is based on the following features: situated learning, self-regulated learning, co-regulated learning, and formative assessment.

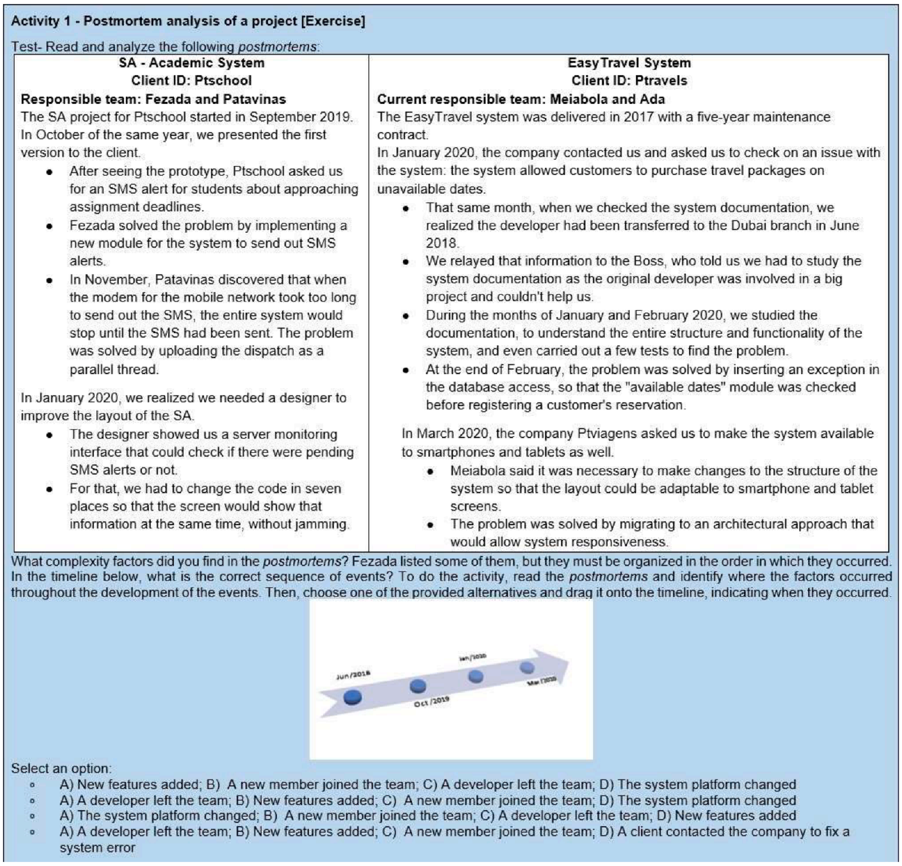
The two activities, chosen to demonstrate how the concepts of Puzzle Triggers and Puzzle-Solving, have been applied in a narrative and an exercise. They are: "Activity 1 - Postmortem analysis of a project [Narrative/Exercise]" and "Activity 2 - Understanding the legacy code [Narrative/Exercise]". The selection of these two activities was motivated by the fact that one of them introduces the software project and the other the software development. In this way, two moments of the software design are considered: the conceptualization and the implementation.

The activity entitled "Activity 1 - Postmortem analysis [Narrative/Exercise]", depicted in Figs. 3 and 4, describes how to create the postmortem of a software project. It consists of two parts: a narrative (Fig. 3) and an exercise (Fig. 4). These are interconnected. Fig. 3 shows the narrative that activates the discussion about the facts concerning the postmortem process. This prepares the students to analyze the complexity of the facts in the postmortem activity presented in Fig. 4, which includes the "Pattern Recognition" and the "Item Use" puzzles. The students are asked to read the narrative and then answer the questions posed to them as displayed in Fig. 4. These questions guide the students to think about what a postmortem is and how it can be constructed.

In Fig. 4, the mechanisms of the Puzzle Triggers comprise the text of the postmortem, the timeline image, and the questions about the postmortem. All these mechanisms activate the Puzzle-Solving process which concerns remembering the concepts introduced in the postmortem presented in Fig. 3 and identifying the events in the postmortem description.

In Fig. 4, two postmortems are described. The postmortems exhibit a list of factors. The learners are supposed to order them chronologically. Examining the factors and ordering them are actions which function as Puzzle Triggers, and these help learners to perceive puzzles related to recognizing a pattern of events (**"Pattern Recognition" Puzzle**) and organizing the factors in chronological order (**"Spatial Reasoning" Puzzle**) presented on the postmortems. The Puzzle-Solving process takes place when the learners figure out how to deal with the relation between the factors in the timeline presented in the graph, that is, when they can use their critical thinking skills which include: observing the factors in the postmortem (observation); inferring the level of complexity of the events (**intuition**); analyzing the order of the events (**analysis**) the events; perceiving the order of the events (**inference**); interpreting the postmortem (**interpretation**); and understanding the concepts from the narrative (**reasoning**) before doing the test. In terms of the Puzzle-Solving process, all these aspects help the learners to find solutions to the test questions.

Table 2 presents the scheme showing the components considered in designing the instructional activities of Activity 1. From left to



Activity 1 - Postmortem analysis of a project [Exercise]

Test- Read and analyze the following *postmortems*:

SA - Academic System **Client ID: Ptschool**	**EasyTravel System** **Client ID: Ptravels**
Responsible team: Fezada and Patavinas The SA project for Ptschool started in September 2019. In October of the same year, we presented the first version to the client. • After seeing the prototype, Ptschool asked us for an SMS alert for students about approaching assignment deadlines. • Fezada solved the problem by implementing a new module for the system to send out SMS alerts. • In November, Patavinas discovered that when the modem for the mobile network took too long to send out the SMS, the entire system would stop until the SMS had been sent. The problem was solved by uploading the dispatch as a parallel thread. In January 2020, we realized we needed a designer to improve the layout of the SA. • The designer showed us a server monitoring interface that could check if there were pending SMS alerts or not. • For that, we had to change the code in seven places so that the screen would show that information at the same time, without jamming.	**Current responsible team: Meiabola and Ada** The EasyTravel system was delivered in 2017 with a five-year maintenance contract. In January 2020, the company contacted us and asked us to check on an issue with the system: the system allowed customers to purchase travel packages on unavailable dates. • That same month, when we checked the system documentation, we realized the developer had been transferred to the Dubai branch in June 2018. • We relayed that information to the Boss, who told us we had to study the system documentation as the original developer was involved in a big project and couldn't help us. • During the months of January and February 2020, we studied the documentation, to understand the entire structure and functionality of the system, and even carried out a few tests to find the problem. • At the end of February, the problem was solved by inserting an exception in the database access, so that the "available dates" module was checked before registering a customer's reservation. In March 2020, the company Ptviagens asked us to make the system available to smartphones and tablets as well. • Meiabola said it was necessary to make changes to the structure of the system so that the layout could be adaptable to smartphone and tablet screens. • The problem was solved by migrating to an architectural approach that would allow system responsiveness.

What complexity factors did you find in the *postmortems*? Fezada listed some of them, but they must be organized in the order in which they occurred. In the timeline below, what is the correct sequence of events? To do the activity, read the *postmortems* and identify where the factors occurred throughout the development of the events. Then, choose one of the provided alternatives and drag it onto the timeline, indicating when they occurred.

Select an option:
- A) New features added; B) A new member joined the team; C) A developer left the team; D) The system platform changed
- A) A developer left the team; B) New features added; C) A new member joined the team; D) The system platform changed
- A) The system platform changed; B) A new member joined the team; C) A developer left the team; D) New features added
- A) A developer left the team; B) New features added; C) A new member joined the team; D) A client contacted the company to fix a system error

Fig. 4. Test of the important complexity facts in a postmortem software development project.

Table 2
A scheme of the elements considered in Activity 1.

Element	Description
Objectives	Attending to the requirements for developing the software. Interpreting and integrating the facts throughout the development of the software. Verifying the features which impact management decisions, code modifications, and code updating throughout the development of the software. Checking the examples given to help the understanding of code management, modification, and updating.
Type of Puzzle	Pattern Recognition and Spatial Reasoning.
Narrative / Activity	Narrative in Fig. 3 and Exercise in Fig. 4.
Puzzle Trigger	Features and facts that trigger software development. **Observation:** The mechanisms here comprise the text of the postmortem, the timeline image, and the questions about the postmortem.
Puzzle-Solving	**Puzzle-Solving Process:** recognizing the patterns in the software development to carry out the intended project. **Puzzling step:** observing and inferring the meaning of the events related to the software development scenario. **Solving step:** interpreting, understanding, and doing the project. **Observation:** The Puzzle-Solving at his stage takes place when the learners figure out how to deal with the relationship between the factors in the timeline presented in the graph.

right, the objectives of the instructional activity, the types of puzzles chosen to be explored in the narrative activity are presented and the features which constitute the Puzzle Trigger and the Puzzle-Solving process are specified.

The activity entitled "Activity 2 - Understanding the legacy code [Narrative/Exercise]" depicted in Figs. 5 and 6 introduces some software development concepts. It consists of two parts: a narrative (Fig. 5) and an exercise (Fig. 6). These are interconnected.

Fig. 5 shows a narrative that calls learner attention to procedures related to maintaining the legacy source code. This prepares the students to analyze the complexity of the legacy codes and verify the plausibility of the code execution presented in the C# language. First, the students are asked to read the narrative introducing a typical scenario in a company when someone has to perform project maintenance. After reading the narrative they are supposed to answer the question displayed in Fig. 6. This question concerns code execution in project maintenance.

Fig. 6 introduces a Riddle Puzzle. To solve it, the learners must remember concepts about C and C# programming. To show how to refactor the legacy code, the puzzle in Fig. 6 includes Puzzle Triggers dealing with the basic concepts of C# language such as object instantiation and object reference as parameters in a procedure call.

The Puzzle-Solving process is concerned with the procedures to understand how the C# code will be processed in the machine to solve the faced challenge. The critical thinking skills concern the following: observing the source code (observation); inferring the meaning of the source code (intuition); evaluating the questioning in the test (analysis); perceiving the questioning as part of a representative scenario for the maintenance of a code source (inference); interpreting the source code (interpretation); understanding the machine computation (reasoning) as questioned in the test. In terms of Puzzle-Solving, all these aspects guide the learners to find the solution to the challenges posed by the test.

Table 3 presents a scheme showing the components considered in designing the instructional activities. From left to right, the objectives of the instructional activity, the type of puzzle chosen to be explored in the narrative activity are presented and the features which constitute the Puzzle Trigger and the Puzzle-Solving process are specified.

The Puzzle Triggers introduced in the activities presented above as an example are intended to help learners to perceive puzzles, interpret them and interact with them. They can contribute to developing critical thinking skills because they provide means to motivate and engage the learners in the learning process, and as such, may exert a positive effect on their logical reasoning process since the teacher or the puzzle-builder when considering the dichotomy of the puzzle will think of strategies to display cues that call learner attention and make them access intuitive and reasoning skills to retrieve previous knowledge and acquired patterns and foster new associations during the Puzzle-Solving process opening paths to finding solutions.

Activity 2 - Understanding the legacy code [Narrative within a situated learning context]

Meiabola: Hi guys, I've got a problem here. I have spent many hours checking the source code of a program and I can't understand it...
Patavinas: Hehe... I've tried to understand it too, but I haven't had time to work on it. The documentation is not good enough... It was done by that programmer who left the team and moved to Dubai in a company outsourcing operation!
Ada: This doesn't matter! We can figure it out with similar examples. This may help!
Fezada: Maybe we can ask for an opinion from others in the team, what do you think about it?
Ada: Great idea, Fezada! We can challenge other participants who entered the company. It's an opportunity to practice and they can better get on with their colleagues.
Fezada: That's right! Guys, look at it! I have selected and made available some parts of this program to be evaluated. Click on the link I have sent. Guys, are you up to it?

Continue to the Test

Fig. 5. Narrative of the didactic topic about C# development, names are fictional characters.

Activity 2 - Understanding the legacy code [Exercise]

Test - Is the value defined by "Weight" in the **charcoal** object, after executing the instruction "pack.ValidationCharcoalSticks(validCharcoal)" zero?

```
class CharcoalPackage {
 void ValidationCharcoalSticks(CharcoalStick charcoal) {
 if (charcoal.Weight < 1) charcoal.Weight = 1;
 }
 public static void Main (string[] args) {
 // The value zero in constructor of CharcoalStick is used to define the weight of charcoal
 CharcoalStick validCharcoal = new CharcoalStick(0);
 CharcoalPackage pack = new CharcoalPackage();
 pack.ValidationCharcoalSticks(validCharcoal);
 Console.WriteLine("The weight of valid charcoal is: " + validCharcoal.Weight);
 }
```

Select an option:

- True
- False

Fig. 6. Test as Puzzle Trigger shows a recap concerning the execution of a specific instruction coded in C#.

Table 3
A scheme of the elements considered in Activity 2.

Element	Description
Objectives	Remembering programming language learned issues. Identifying the conceptual differences between C++ and C#. Doing exercises on distinguishing between C++ and C#. Interpreting some code examples in C#. Observing differences concerning the execution of C# codes.
Type of Puzzle	Riddle.
Narrative / Activity	Narrative in Fig. 5 and Exercise in Fig. 6.
Puzzle Trigger	Features and facts that trigger software development **Observation:** The mechanisms consist in dealing with the basic concepts of C# language such as object instantiation, and object reference as parameters in a procedure call.
Puzzle-Solving	**Puzzle-Solving Process:** remembering concepts about C and C# to solve the questions. Puzzling step: understanding the code and figuring out how the machine will interpret it for the question to be answered. **Solving step:** providing the correct answer. **Observation:** The Puzzle-Solving at this stage is concerned with the procedures for understanding the C# code and its machine processing.

5. Discussion

Puzzle-based Learning approaches claim that problem-solving affects motivation and engagement, but the point we raise about this claim is the following: merely presenting a puzzle does not guarantee that motivation and engagement will take place. Something more is needed and that is a perception-driving mechanism to elicit the puzzle to be solved in a specific moment of learning. This crucial element, centered on how students engage with the problems and give solutions, is not considered in Puzzled-Based Learning approaches.

According to our proposal, puzzles are better understood in learning approaches as being dual-structured, that is, as being made of two elements: the Puzzle Trigger and the Puzzle-Solving. The Puzzle Trigger is a perception-driving mechanism which triggers a process, the Puzzle-Solving.

By considering the mechanic (Puzzle Trigger) and the procedural (Puzzle-Solving) aspects involved in solving problems, educators can use the Puzzle-based Learning approach in a more structured way and help learners to think critically and develop argumentation strategies to solve problems. Our point here is that the critical thinking skills and creative thinking abilities which are meant to be achieved in Puzzle-based Learning cannot be triggered by merely posing puzzles constantly to the learners.

Learning to think critically can benefit from taking into account the distinction between the mechanic and the procedural aspects involved in solving problems, that is, between the Puzzle Triggers and the Puzzle-Solving aspects.

In our proposal, the fact that puzzles are seen as two-faced opens possibilities for instructional intervention since the dynamics of the Puzzle Trigger separates the form in which the puzzle is presented from the phase in which the learner interacts with the puzzle, becomes motivated, and engagement occurs. The distinction between the mechanism (the Puzzle Trigger) and the process (The Puzzle Solving) separates the initial phase in which the learners get into contact with the puzzle from the phase, which prompts them to find a way to start the development phase which leads to the solving of the puzzle.

It is a perception-driving mechanism which enables the students to perceive puzzles and, in this way, leads students to engage in the learning context. It can be integrated into a Puzzle-based Learning approach as a tool to enable the students to perceive puzzles. The perception and engagement with the puzzle are meant to help learners achieve their learning goals. Thus, the trigger does not drive learning or self-reflection. It engages perception, and perception leads to its own outcomes.

The Puzzle Triggers, as perception-driving mechanisms, are the ignition points to start the process of solving a certain type of puzzle. In the learning context, they can be used as a means to prompt a critical thinking process to solve a problem. This process directs the students' attention to understanding certain concepts in a specific way. Diverse kinds of puzzles such as Riddle, Lateral Thinking, Exploration, Logic, Spatial Reasoning, Pattern Recognition, and Item Use can be triggered in the process of Puzzle-Solving.

We claim that a discussion centered on puzzle dynamics must consider the puzzle dual build-up. This is a core aspect involved in solving problems. Considering these two entities is thought to help teachers to have a better understanding of the issues involved in the process of designing contents to be used in courses to help the learning process since the Puzzle Trigger is the mechanism which activates the Puzzle-Solving process and both aspects must be considered in instructional designs.

From our point of view, some questions must be considered in the Puzzle-based Learning instruction designs: How is reasoning triggered? How does problem-solving affect motivation and engagement? How does the learner become motivated? How does the learner address motivation? How can the learner's energy be directed to the engagement phase in search of the solution to a problem?

The Puzzle-based Learning instruction design might also consider determined requirements. It is important first, to define the objective to be achieved with the instructional content; second, to consider the kinds of background the learners must have to interact with the content; third, to plan the kind of critical thinking skills that are necessary to accomplish the objective; fourth, to create, based on the necessary critical thinking skills, a puzzle; fifth, to formulate Puzzle Triggers to make the learners perceive the puzzle and start the Puzzle-Solving process.

Although the introduction of Puzzle Triggers in this paper is discussed in relation to Puzzle-based Learning, it might be, potentially, applied to any educational approach which includes puzzles as an instructional activity. Learning through puzzles can make the most of involving a mechanism, which helps students to grasp a problem and prompt them to find ways of solving it and a process where the actual problem resolution takes place. Teachers can make the best use of introducing Puzzle Triggers in their planning and development of learning activities to engage learners in the Puzzle-Solving process.

A concern on the planning and developing of learning activities has to do with the dimension of the difficulty the Puzzle-Solving process can arise. Solving a puzzle is a challenging and engaging task. There is usually a little tension involved in dealing with the challenge and a feeling of frustration when the puzzling phase is not reached. The Puzzle Trigger traces the path to the puzzling process and when solution is achieved a very pleasant feeling of success is generated. This is the influential power of the Puzzle Trigger.

6. Conclusion

In this paper, puzzles have been described as having two elements: a mechanism and a process. The mechanism is the Puzzle Trigger, and the process is the Puzzle-Solving. The relevance of posing the distinction between the mechanism and the process stems from the fact that the Puzzle-Solving process depends on perceptual mechanisms, the Puzzle Triggers, which must be triggered by the learners. In this way, this proposal introduces a novel perspective on Puzzled-Based Learning approaches and makes a difference in the way in which the teachers plan, develop, or select puzzles to be applied in educational contexts, as well as in the way learners experience the puzzles to be solved.

In relation to the facts pointed out in the literature on Puzzle-based Learning, we leverage the potential positive effects of the use of puzzles for developing Critical Thinking skills and promoting learners' engagement given the evidence presented in the literature on the practical applications of Puzzle-based Learning. In relation to the troublesome aspects reported in the literature on Puzzle-based Learning, we present contributions both from the theoretical point of view (introducing the concepts of Puzzle Triggers and Puzzle-Solving) and from the practical point of view (showing how Puzzle Triggers can be introduced into instructional activities). Conceptualizing the puzzle as consisting of Triggers and a Solving process helps to visualize that these are elements (the Puzzle Triggers) that activate the puzzle and to understand that solving puzzles (the Puzzle-Solving process) is dealing with these elements.

From the theoretical point of view, our contribution concerns reasoning on how puzzles are perceived (the perceptual driving mechanism) and how the process leading to the solution takes place (the Puzzle-Solving). The postulation of this dual structure for puzzles (mechanism and process) stemmed from our investigation of the dynamics of the puzzles. Considering the perceptual driving mechanism and the Puzzle-Solving can help educators and instructional designers to overcome learner interaction with the puzzles and in this way help them to achieve better results.

From the practical point of view, we have demonstrated how the Puzzle Triggers can be implemented, by presenting two instructional activities applied to the undergraduate Informatics Engineering students attending a "Software Programming Laboratory" course. These examples illustrate how depending on instructional objectives, and the learner skills intended to be developed, Puzzle Triggers can be implemented to help learners find solutions to the problems posed to them.

In sum, puzzles are viewed in this paper as a dual structure consisting of a mechanism, the Puzzle-Trigger, and a process, the Puzzle-Solving, which, in turn, involves two steps: the Puzzling and the Solving. Puzzling refers to the reflexive state of collecting, analyzing, and tackling the issues to solve a problem while Solving refers to finding a solution to the problem. Thanks to this novel perspective of viewing the puzzle, the application of puzzles in educational contexts is not considered as merely posing puzzles to learners to solve but helping the learner perceive puzzles. As the Puzzle Triggers open the path to the Puzzle-Solving process, they are thought to engage the students in the learning context. For the path to be followed the educator must provide the learners with mechanisms that allow them to understand what they are learning (interaction with the Puzzle Triggers), why they are learning (Puzzling process), how they are learning (Solving process), and when the learning goal is reached (Solution of the puzzle).

In a future paper, we intend to undergo a quantitative and qualitative study to analyze the results of applying instructional units to a group of students containing Puzzle Triggers and the Puzzle-Solving processes in software development classes.

Author agreement statement

All authors the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

All authors confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

All authors understand that the Corresponding Author is the sole contact for the Editorial process.

He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

CRediT authorship contribution statement

Mario Madureira Fontes: Writing – original draft, Writing – review & editing. **Leonel Caseiro Morgado:** Writing – original draft, Writing – review & editing. **Pedro Pestana:** . **Daniela Pedrosa:** Writing – original draft. **José Paulo Cravino:** Writing – original draft, Writing – review & editing.

Declaration of competing interest

Not applicable, there are no known competing interests.

Data availability

No data was used for the research described in the article.

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