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Instructional Model Based on Intelligent Tutor Systems for the Development of 21st Century Competencies

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Abstract

The research aimed to strengthen 21st century competencies through the instructional design of an Intelligent Tutor System (ITS), supported by Artificial Intelligence (AI). It emphasized the importance of critical thinking, problem solving and creativity as essential skills in today's education. The study was developed in two phases: the first consisted of a hermeneutic literature analysis to identify key competencies and select a relevant pedagogical model; the second included the design of the instructional model using Unified Modeling Language (UML) and ontologies, the Kolb Test was also applied to identify learning styles, and the activities were organized according to the revised Bloom's Taxonomy, with increasing levels of complexity. The instructional model promotes metacognition and an articulated relationship between critical thinking, creativity and problem solving. Finally, the need to implement AI-based pedagogical strategies within an ethical framework in educational contexts is highlighted.

Keywords: *Intelligent Tutor System, autonomous learning, 21st century competencies, metacognition, Artificial Intelligence.*

Introduction

21st Century Competencies

21st Century Competencies are skills that today's students need to succeed in the information and knowledge society. They encompass cognitive skills essential to thrive in a knowledge-driven society.

Among the main skills is critical thinking, which emerges as a fundamental skill, not only in education, but also in everyday decision making and complex problem solving. Bejarano et al. (2014) define critical thinking as a deep reasoning process that involves a rigorous analysis of ideas, supported by a deep cognitive activity that encompasses inferences and comparisons. Likewise, Facione (2007) identifies essential components of critical thinking, such as interpretation and evaluation, which underpin the ability to approach diverse situations in a grounded and logical manner. In this context, promoting critical thinking becomes a priority in education and beyond, as it empowers individuals to make informed decisions and address complex challenges in a constantly evolving world, where the ability to analyze and discern is essential for success and progress.

Another competency is problem solving, which involves the action of approaching complex situations using scientific methods or established tools. From a mathematical perspective, it is fundamental in learning, developing skills such as observation, analysis and hypothesis

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formulation (Zomeño et al., 2019) and Castaño (2014) in turn, advocates pedagogical approaches that are based on reality and student appreciation, encouraging contextualized learning. (Albarrán & Díaz, 2021) highlight the need to review methodologies and promote changes in teaching, moving away from abstraction and exploring theories that clarify the context of problems.

Also, creativity is an essential skill in 21st century competencies, it has been studied by several authors. It is related to problem solving and the generation of unique solutions, the connection between learning and creativity allows recognizing talents and skills. According to (González-Moreno & Molero-Jurado, 2022), it influences education and is linked to variables such as intelligence and academic performance at all levels. (Troncoso A. et al., 2022) highlights the need to create enabling conditions to foster creativity and systematize creative stimulation in education.

Intelligent Tutor Systems

ITSs are artificial intelligence (AI)-driven educational tools that play an essential role in education today, according to (van Laar et al., 2017), an ITS is a software system that uses AI techniques to represent knowledge and interact with students for the purpose of teaching them. (Cataldi & Lage, 2009) describe them as systems that seek to emulate the behavior of a human tutor.

(Huapaya, 2009) notes that ITSs originate from computer-assisted instruction and focus on adaptive teaching. They use three types of knowledge: domain knowledge, teaching strategies and knowledge about the learner. The architecture of an ITS consists of an expert (domain) model that encompasses specific knowledge, a learner model that captures the learner's understanding, and a tutorial model that provides personalized instructions.

An important advance in the implementation of artificial intelligence in education (AIEd) has been the development of ITSs (Murray, 2003), (Aleven et al., 2016), (Dermeval et al., 2018). ITSs are systems that adapt to learners' needs and make recommendations to them on the next activities to be performed to achieve learning outcomes, thus guiding their learning process. ITS have been used by researchers in education, psychology and artificial intelligence. The goal of ITS is to provide students with the benefits of individualized instruction. It allows learners to practice their skills by performing tasks in highly interactive learning environments (Phobun & Vicheanpanya, 2010). With this type of systems it is possible to implement active-participatory methodologies in the learning process.

ITSs incorporate integrated expert systems to monitor a learner's performance and personalize instruction based on adaptation to the learners' learning style, current knowledge level, and appropriate teaching strategies in e-Learning systems (Phobun & Vicheanpanya, 2010). However, they are still limited to enable learning through experimentation. This type of learning promotes active learning and learner autonomy. Learning through experimentation provides a number of advantages in learners; for example, it helps in acquiring and perfecting the knowledge, augments an incomplete mastery theory and refines an incorrect mastery theory (Michalski et al., 1983).

Currently, existing ITSs convert problem-based learning into knowing-by-doing. The following approaches can be found:

- Systems that propose exercises extracted from a repository to learners in order for them to solve them. These systems then check how good the solution given by the learners is and propose new exercises to them. These exercises are chosen according to different criteria, such as their progress in the learning process or the results obtained in previous exercises (Aleven et al., 2016).

- Systems that present students with an exercise and how to solve it step by step, then, these systems create similar exercises, usually by changing data, that can be solved following the learned steps. In subsequent stages, they can also gradually fade out the number of steps in the worked solution so that students can explain how they arrived at the final solution (Green et al., 2016). Research within both approaches focuses on adapting rules that recommend learning actions rather than giving the learner the freedom to experiment (D'Aniello et al., 2018).

- Thus, an ITS evaluates the actions of each learner in an interactive environment and develops a model of their knowledge, skills, and experience. Based on this model, the ITS adapts instructional strategies in terms of both content and style, providing explanations, hints, examples, demonstrations, and practice problems relevant to each user. To provide relevant instruction to learners, an ITS is composed of three types of knowledge, organized into four software modules, as shown in Figure 1.

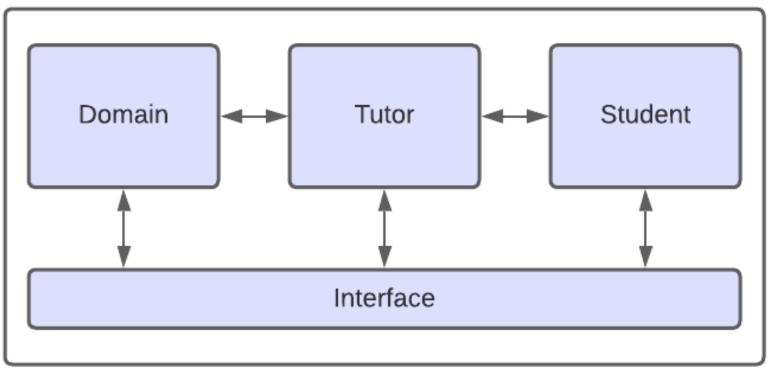


Figure 1. Architecture of an ITS, adapted from (Carbonell, 1970).

The components of an Intelligent Tutoring System

It is a computer representation of the subject matter knowledge, declarative knowledge, and problem solving ability, procedural knowledge, of a domain expert. This knowledge allows the ITS to compare the learner's actions and selections with those of an expert to assess what the learner knows and does not know. The learner model. This is a representation of the learner's level of knowledge as he/she interacts with the tutoring system. The model assesses each student's performance from his or her behavior during interaction with the tutoring system to determine his or her knowledge, perceptual skills, and reasoning skills. The model generates evidence and uses inference to provide a set of relevant instructions for each student.

Instructional Model

The instructional model contains knowledge to make decisions about instructional tactics. It relies on the diagnostic processes of the learner model to make decisions about what, when, and how to present information to a learner. For example, if a student has been assessed as a beginner in a particular procedure, this model will show some step-by-step demonstrations of the procedure before asking the user to perform the procedure on their own. As a student gains experience, this model may decide to present increasingly complex scenarios. In addition, this model can also choose topics, simulations and examples that are relevant to a learner's level of knowledge. Metacognitive competencies and self-regulated learning.

Metacognition

Metacognition in cognitive science is the ability of people to monitor and control their own learning and reasoning processes (Cox, 2005) (Koedinger et al., 2009). It has two executive processes that the subject performs on their cognitive processes; these processes are monitoring and control (Anderson & Krathwohl, 2016). Metacognition has been increasingly considered in studies that attempt to improve student learning using computer-based learning environments (Aleven et al., 2016) (Bondareva et al., 2013) (Dever et al., 2024). The interest in metacognition in the area of educational technology is mainly due to scientific evidence showing this is important for efficient problem solving, as well as for the process of autonomous learning

Metacognitive knowledge

It is the learner's knowledge about how learning, cognitive components and memory work. Reflection on learning experiences can expand metacognitive knowledge, which is defined as knowledge, awareness and a deeper understanding of one's own cognitive processes and products, judgment and monitoring of learning. Judgment and monitoring of learning refer to a learner's evaluation of the progress of cognitive activity.

Regulation and control of cognition

Regulation and metacognitive control refer to activities in which students engage in order to change the course of learning, decide, use a new study strategy (Dunlosky & Metcalfe, 2008). Encompassing a set of activities that allow students to control their learning, it can be considered a regulation of cognition (Gourgey, 1998; Hartman, 1998). Students acquire their metacognitive knowledge from metacognitive monitoring, and students control their learning from metacognitive knowledge (Jameson et al., 1990).

Under the above premises, the present study aimed to design an instructional model of an intelligent tutor system for the strengthening of 21st century competencies through self-directed learning, supported by artificial intelligence.

Methodology

Approach and type of Research

The research was based on the qualitative approach, and was conducted in two phases. The first phase, carried out a literature review using hermeneutics. This review allowed the selection of the appropriate pedagogical and instructional model for the design of the ITS. In addition, it was used to define the theoretical construct that responds to the 21st century competencies selected for instruction in the tutoring system. The second phase used the Unified Modeling Language (UML) and ontologies to design a visual representation of the tutor system pedagogical model. Using UML, diagrams were created to illustrate the architecture and the interaction between the system components. In addition, an ontology was used to precisely organize and categorize the fundamental concepts and relationships related to the pedagogical design.

Data Collection Instruments

The first phase of the research used a bibliographic instance card, the main objective of this card was to collect in an organized and structured way the relevant data from the studies and documents selected during the literature review.

Results

Phase 1. Hermeneutic analysis of previous studies, the findings allowed to establish that the 21st century competencies for the design of ITS activities are: creativity, problem solving and critical thinking, since they exert a positive influence in relation to educational technology and autonomous learning. In addition, there is a close correlation between the critical thinking competency and the dimension of autonomous learning, as shown in Figure 2. These findings supported the choice of the competencies of critical thinking, problem solving and creativity as pillars for the development of the pedagogical activities initially designed in the ITS.

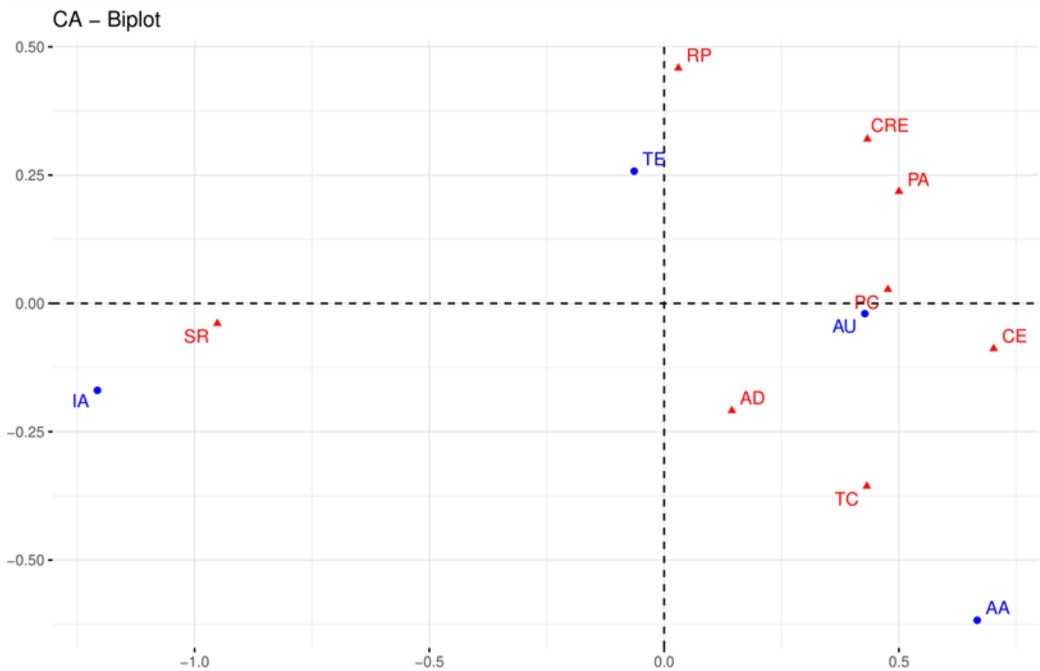


Figure 2. Analysis of Literature Review

Phase 2. Instructional and ITS architecture design

The architecture of the intelligent tutor for 21st Century competency training is a classical structure, as illustrated in Figure 3.

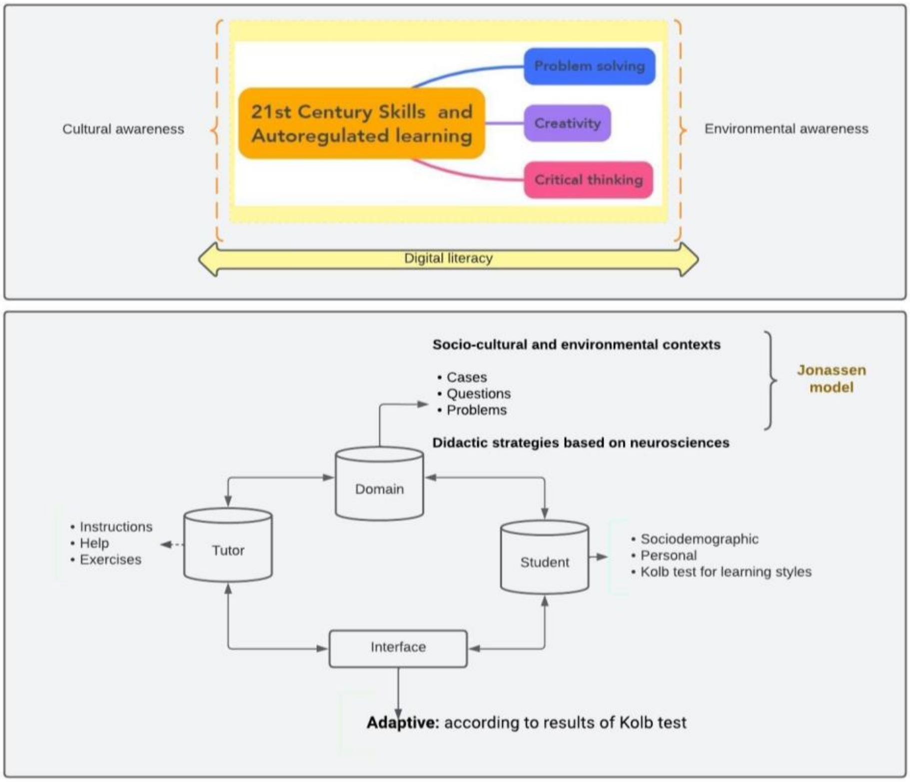


Figure 3. ITS Architecture for 21st Century Competency Development

It consists of a student module, a domain module, an expert module and an interface for user interaction.

The Student Module

Contains all the information obtained from the student's interaction with the ITS, I.E. sociodemographic information, personal data and the learning style of the students, the latter is obtained at the first interaction of the user with the ITS, at which time the Kolb test (Kolb, 1979) for learning styles is applied.

Kolb's test is an assessment tool designed to identify an individual's preferred learning style and ability to adapt and respond to different learning situations. It is based on Kolb's Experiential Learning Theory, which postulates that learning occurs through experience and that the learning process is composed of four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation.

The Kolb test consists of 12 learning situations in which the participant must choose the option that best describes his or her response or action in that situation. The situations are divided into four categories, corresponding to the four stages of the learning process: concrete experience, reflective observation, abstract conceptualization and active experimentation. The response options are based on the four ways in which people prefer to learn: by doing, observing, reflecting and theorizing. Once the test is completed, a learning profile is obtained that shows an individual's preferred learning style and ability to adapt and respond to different learning situations. The profile is represented in a four-quadrant diagram representing the four learning styles: active, reflective, theoretical and pragmatic.

The active learning style is characterized by a preference for concrete experience and active experimentation. The reflective learning style is characterized by a preference for reflective observation and abstract conceptualization. The theoretical learning style is characterized by a preference for abstract conceptualization and reflective observation. The pragmatic learning style is characterized by a preference for concrete experience and active experimentation.

The Module Domain

is based on the Jonassen instructional model, which focuses on constructivist learning environments, a pedagogical approach that seeks the active construction of knowledge by students, through interaction with materials and learning environments designed specifically for this purpose (Jonassen, 1994). It argues that students actively construct their own knowledge through reflection on their experiences and problem solving, and consists of six elements:

1. The focus of this type of model are cases, questions or problems, in that sense, this type of approach requires a context, a manipulation space and a simulation or representation.

2. Related cases help to place the user with similar experiences that have been solved in a similar way.

3. Information resources. Students need information that allows them to build their mental models and formulate hypotheses that direct their activity in solving the problem.

4. Cognitive tools, by providing complexity, novelty and authentic tasks, the learner will need support in their completion. Collaborative tools, to encourage and support communities of learners or communities that construct knowledge through computer-mediated communication.

6. Context support, environmental and contextual factors that affect the implementation of the constructivist learning environment.

Description of the Structure of the Pedagogical Activities of the Module Domain

The activities to be developed, in the module domain, pose the realization of a challenge under an ecological or sociocultural context. This challenge has three levels of complexity, which seek the development of competencies such as creativity, problem solving or critical thinking, given the results obtained in the first phase of the research. For each activity that the student solves, a reward is given, and a score is assigned according to its complexity. The student is given the opportunity to receive feedback for each of the activities he/she solves. Also, all activities contain related exercises, aids and instructions that contribute to the design of the solution, see Figure 4.

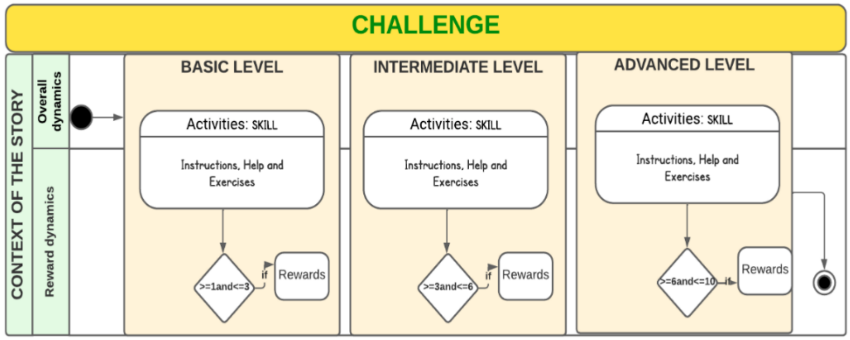
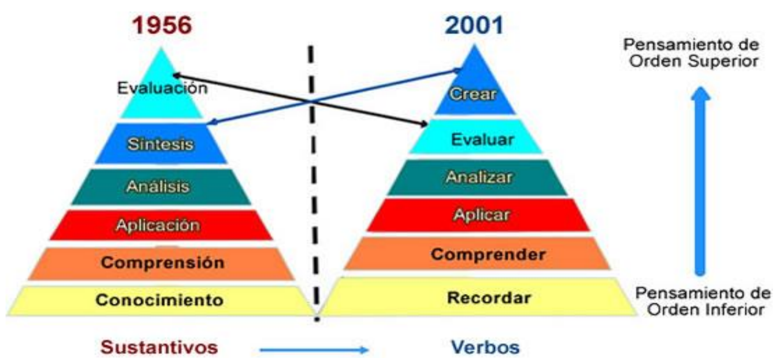


Figure 4. General Structure of The Activities in the Mastery Module

Activities According to the Levels of Complexity of the ITS

The tutor system consists of three levels of complexity based on the modified Bloom's taxonomy, the adaptation of Bloom's taxonomy made by Lorin Anderson and David R.



Krathwohl (Anderson & Krathwohl, 2016), is known as the revised Bloom's Taxonomy, this adaptation was developed in 2001 as a revision of the original taxonomy proposed by Benjamin Bloom in 1956. The original Bloom's taxonomy established six levels of cognitive thinking, organized in ascending order of complexity: knowledge, comprehension, application, analysis, synthesis, and evaluation, however (Anderson & Krathwohl, 2016) felt that this structure needed to be updated and refined to better reflect contemporary educational theories and practices, as seen in Figure 5.

Figure 5. Levels of complexity of ITS activities

The revised Bloom's taxonomy by Anderson and Krathwohl maintains the same basic cognitive levels as the original taxonomy, but renames and reorganizes them, the levels of the revised taxonomy are as follows, in ascending order of complexity:

- Recall: At this level, students demonstrate the ability to retrieve previously learned information without needing to understand or interpret it in a new context.

- Comprehend: At this level, students demonstrate the ability to understand information and make inferences from it. In addition to recalling it, they can explain and describe it in their own words.

- Apply: At this level, students can use the information and concepts learned in new or different situations and contexts. They can use the acquired knowledge to solve problems or perform specific tasks.

- Analyze: At this level, students demonstrate the ability to break down information into smaller parts and understand the relationships between those parts. They can identify patterns, organize information in meaningful ways, and make inferences based on analysis.

- Assess: At this level, students can make judgments based on established criteria and standards. They can evaluate the quality, effectiveness, or validity of information, arguments, or methods used.

- Create: At this level, students demonstrate the ability to combine elements of information and knowledge to form new concepts, ideas or products. They can generate new hypotheses, design original solutions, or create works based on their understanding and application of knowledge.

Anderson and Krathwohl's adaptation also includes the knowledge dimension, which refers to the type of knowledge being assessed at each level. This dimension encompasses four categories: factual, conceptual, procedural and metacognitive.

21st Century Competencies selected for enhancement in the ITS

Creativity

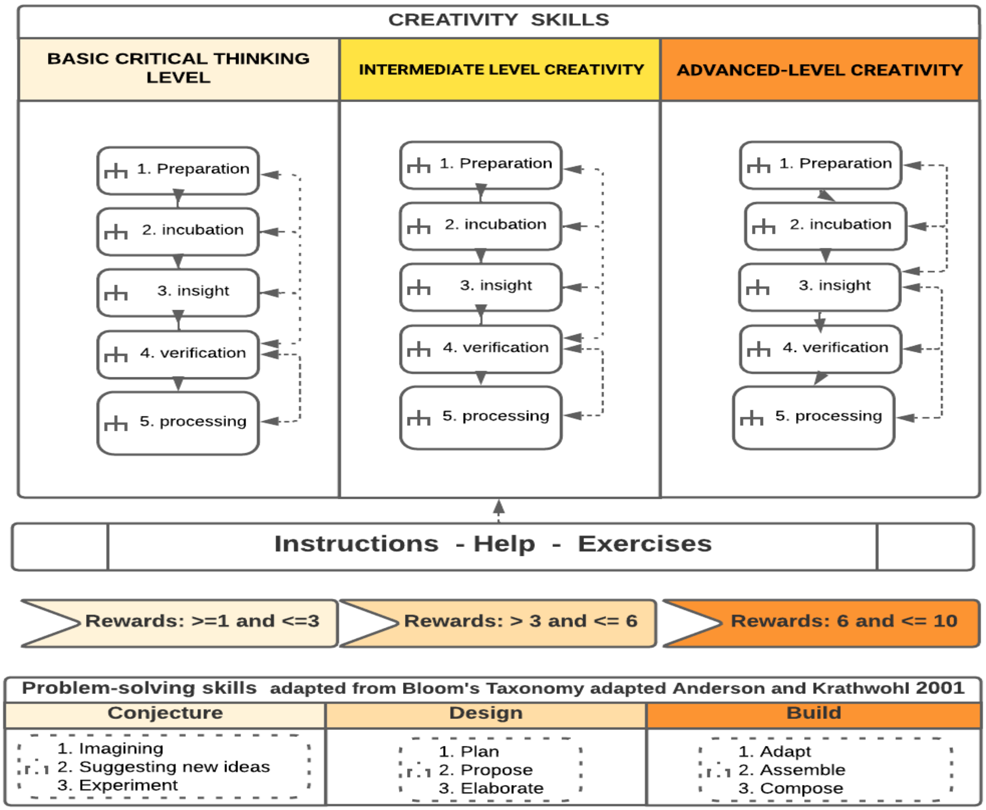


Figure 6. Description of Activities Based on Creativity

The activities that enhance creativity are designed as established by De Bono, (1992), an expert in creativity and lateral thinking, has proposed a series of stages for the development of creativity, see figure 6. Below, I will describe these stages:

- Preparation: This stage involves gathering all relevant information and knowledge related to the problem or situation in which one seeks to be creative. Preparation may also include identifying patterns and trends that may be useful in solving the problem.

- Concentration: At this stage, focus attention on the problem or situation and on the patterns and trends identified during preparation. Concentration also involves avoiding distraction and keeping the mind focused on the creative objective.

- Idea generation: At this stage, a wide variety of possible ideas and solutions should be generated, even those that may seem impractical or conventional.

Bono suggests the use of lateral thinking techniques to encourage the generation of novel and creative ideas.

- Development: Once a number of ideas have been generated, it is important to develop them and explore their feasibility and relevance to the problem or situation at hand. At this stage, different ideas and solutions can be combined to create new and more effective ones.

- Action: The last stage involves implementing the selected solution and evaluating its effectiveness. At this stage, it is important to take concrete steps to implement the solution and make adjustments if necessary.

In addition, the student has the opportunity to access exercises, instructions and aids that complement and serve as support and reference in the development of the activity.

Problem solving

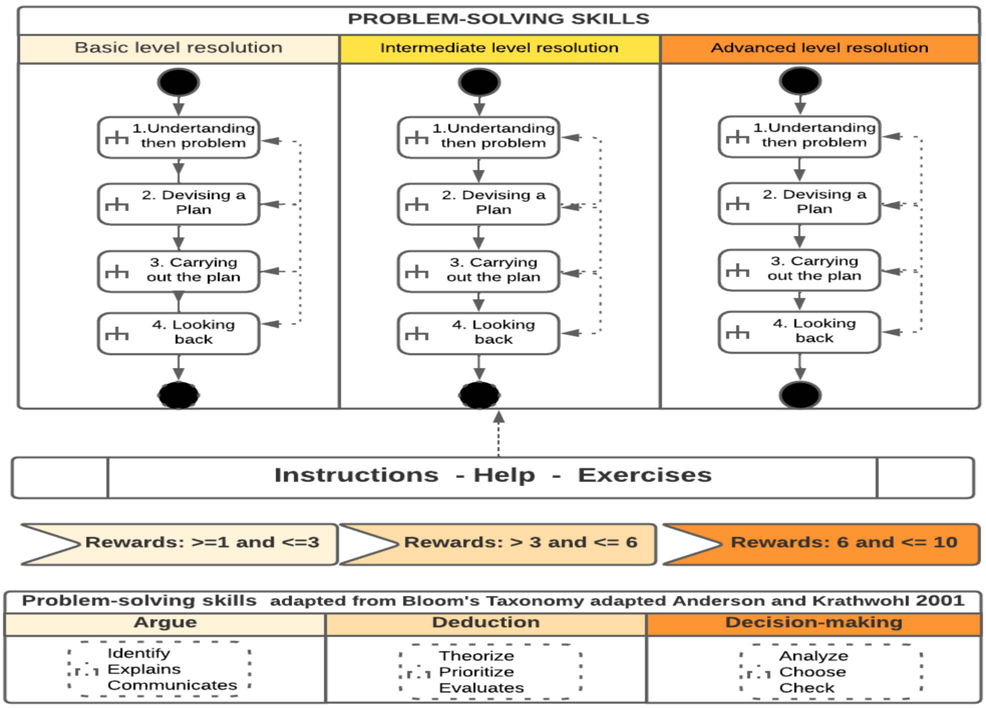


Figure 7. Description of Problem-Solving Activities

The activities that enhance problem solving are designed according to Polya (1973), who proposed a method for problem solving that consists of four stages, see figure 7:

- Understand the problem: In this stage, it is important to carefully read the problem statement and understand what the objective sought to be achieved is. You should also identify the relevant data and constraints that limit the solution to the problem.

- Devise a plan: Once the problem is understood, it is important to devise a plan to find a solution. This may include identifying strategies, techniques or methods that can be applied to solve the problem.

- Carry out the plan: At this stage, the plan devised to find a solution to the problem must be implemented. It is important to be methodical and careful in performing the calculations or procedures necessary to solve the problem.

• Verify the solution: The last stage involves verifying that the solution found is correct and meets the requirements of the problem. It is important to check the calculations and make sure that there are no errors. The solution can also be checked using different methods or approaches.

Critical Thinking

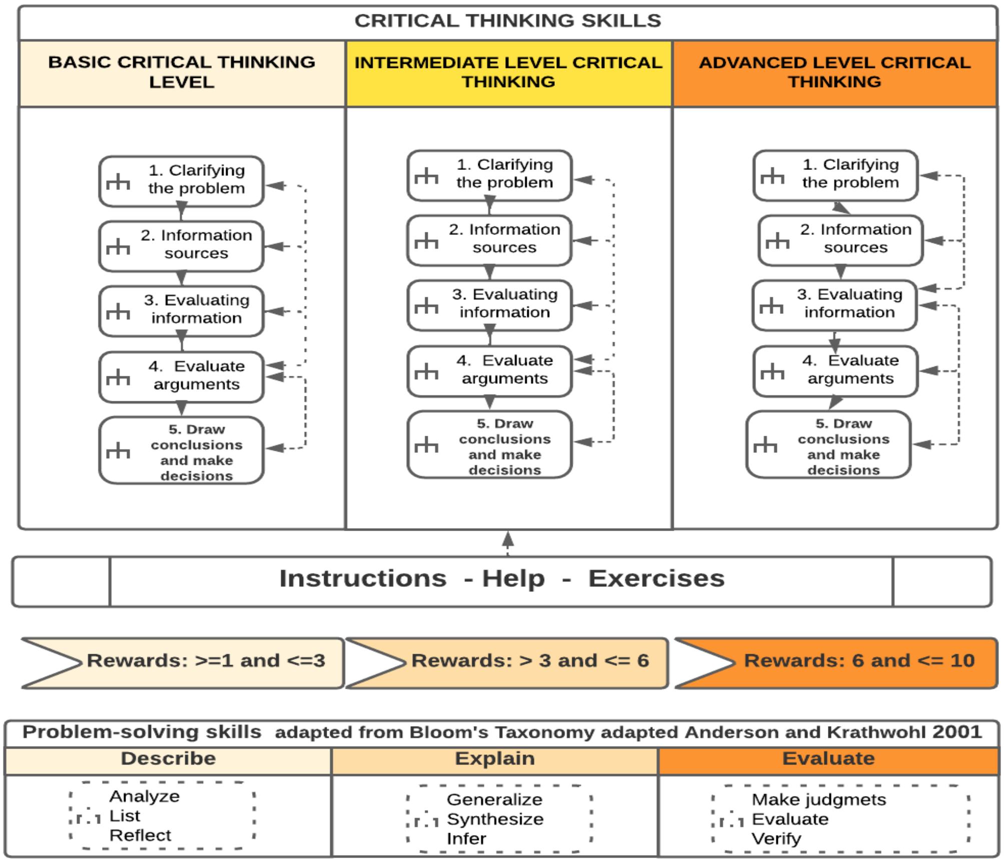


Figure 8. Description of Critical Thinking Activities.

The activities that enhance critical thinking are designed as established by Richard Paul and Linda Elder, who designed a critical thinking model consisting of six stages (Paul & Elder, 2005), see Figure 8.

These stages are described below:

• Clarify the problem: In this stage, the problem or situation being analyzed must be clearly identified and defined. It is important to understand the relevant facts and the different perspectives that may exist.

• Gather information: Once the problem has been identified, it is important to gather relevant information that can help to better understand the problem. This may include reviewing reliable sources, consulting with experts or making direct observations.

- Evaluate the information: At this stage, the information gathered should be critically evaluated and its relevance and reliability analyzed. It is important to take into account biases and assumptions that may influence the interpretation of the information.

- Identify assumptions: At this stage, underlying assumptions that may be influencing the analysis of the problem should be identified. It is important to challenge these assumptions and consider alternative perspectives.

- Evaluate arguments: At this stage, the arguments being used to support different perspectives or solutions to the problem should be critically evaluated. This involves analyzing the logic, evidence and coherence of the arguments presented.

- Reaching conclusions and making decisions: The last stage involves synthesizing the information gathered and analyses performed to reach an informed conclusion and make a decision. It is important to take into account the limitations and uncertainties that may exist in the analysis and consider how these may influence the decision.

Discussion and Conclusions

It is of utmost importance to teach metacognitive skills in the educational system because they help students develop higher order thinking process and improve their academic success (Flavell, 2004) (Larkin, 2009). Due to the impact of metacognition on higher-order thinking processes, its importance has increased. Therefore, learning environments and teaching strategies have been designed, which emphasize metacognitive knowledge and regulation in learning considering higher order thinking process (Hsu & Hsieh, 2014) (Kramarski et al., 2002) (Schraw, 1998).

On the other hand, in relation between critical thinking, problem solving and metacognition, problem solving involves the ability to identify and analyze problematic situations whose method of solution is not immediately obvious. It also includes the willingness to engage in such situations in order to achieve our full potential as constructive and reflective citizens (OECD, 2014). Individual differences in today's learning environments are quite distinctive and affect learning to a great extent (Kozikoğlu, 2019) .

Several studies have revealed a positive association between critical thinking skills, metacognitive skills and problem solving skills.

Many researchers have found a positive relationship between metacognitive skills and cognitive processes such as problem solving Anandaraj & Ramesh (2014) Kapa (2001) Karakelle (2009) Sümen & Çalisici (2016), self-regulation in learning and critical thinking Magno (2010) Sadeghi et al. (2014) Tavakolizadeh et al. (2015) Uzuntiryaki-Kondakci & Capa-Aydin (2013).

These results show consistency with the findings of similar studies (An & Cao, 2014) (Rozencwajg, 2003 (Sümen & Çalisici, 2016) which found that metacognitive skills have positive effects on students' problem solving processes. In addition, some studies (Friede et al., 2008) (Kim et al., 2022), concluded that problem-solving skills are related to critical thinking dispositions.

On the other hand, Aurah et al., (2014) found that metacognition and in particular self-regulation efficacy significantly explained problem-solving skills. In this regard, it can be concluded that critical thinking tendencies, metacognitive skills, problem-solving skills are interrelated concepts.

Liu et al. (2022) Zhang & Lu, (2021), highlights the usefulness of deep learning models to provide immediate feedback to students. These technological approaches enable effective personalization by adapting to students' individual needs and progress, which can significantly improve the learning process.

For his part, (Toala Dueñas, 2021) takes a slightly different approach by evaluating various teaching and assessment modalities in a learning environment. The results of his case studies highlight the importance of diversifying pedagogical methods and adapting to different learning styles. Combining these findings with immediate feedback and adaptation of ITSs, as proposed in the work of (Liu et al., 2022) (Zhang & Lu, 2021), could prove highly beneficial. Hence the importance of designing pedagogical strategies based on theories that contribute to the development and effective appropriation of knowledge for this type of software (Liu et al., 2022) (Zhang & Lu, 2021), are essential to create more effective and meaningful learning environments.

In conclusion, instructional design within a pedagogical model integrates pedagogical practices and the design of enriched educational scenarios, as well as the use of strategies that facilitate an effective learning path and continuous evaluation for students. In addition, emphasis is placed on the use of tools that promote the development of cognitive and metacognitive skills, with the guidance of a teacher mediator.

For its part, the pedagogical approach underlying the ITS allows validating the development of knowledge and the personalization of the user's learning paths. Therefore, it is essential to plan didactic strategies based on active methodologies, with the support of neuroeducation, that contribute to maintain the motivation and attention of students when designing educational technologies using artificial intelligence.

It is also necessary to discuss the ethical framework for the use of artificial intelligence in education. In this sense, it is essential to advance actions at all stages of the life cycle of ITSs that contribute to the development of competencies and skills for self-regulation in their use.

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