Collaborative Model for Developing Computing Skills in Basic Education

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Abstract: Following the recent inclusion of computational skills in Brazil's basic education curriculum, this study explores A+Comp, a gamified, collaborative virtual learning environment designed to enhance computational education. Inspired by online social networks and digital games, A+Comp integrates elements like virtual currency and interactive challenges. The platform aims to boost user participation and mitigate engagement disparities using the Experiential Learning Cycle and Positive Feedback Model. By combining cognitive, conative, and executive function theories with system design, the research assesses the impact of gamification and collaboration on computational competency acquisition, contributing to the discussion on innovative, inclusive learning technologies.

1 INTRODUCTION

The advancement of technology has led major nations to invest heavily in Science, Technology, Engineering, and Mathematics (STEM) fields to sustain social power, leadership, and wealth in the international system (Coccia, 2019). Moreover, to better prepare students for the future, integrating scientific practices into the school environment has become increasingly important, with problem- and project-based learning emerging as effective active methodologies for this purpose. This shift in educational practices is evident in several countries, where there is a growing consensus on the importance of 21st-century skills such as critical thinking, communication, collaboration, and creativity. However, many educational policies still focus on performance testing rather than prioritizing the development of these skills (Kennedy and Sundberg, 2020).

As pedagogical practices have evolved to meet the demands of the job market, the widespread availability of the Internet has fundamentally changed the profile of the current generation of students, who now have access to instant, global information. This transformation underscores traditional education's need to adapt and guide students in navigating this interconnected world (Boy, 2013). Similarly, collaborative problem-solving is a vital skill in today's society, and fostering STEAM projects that involve computational tools has become a significant educational trend to help students develop this competency (Lin et al., 2020).

Computational competencies were recently added to the Brazilian curriculum to broaden access to these skills and potentially reduce social inequality (Ribeiro et al., 2022). However, educators now face the challenge: how can these competencies be effectively taught in schools?

In this context, educators are focused on collaborative learning and engagement to foster computational competency development. Gamified digital platforms offer a promising approach, using rewards, customization, and challenges to boost user participation. Virtual currencies, as an alternative to traditional achievements, personalize the experience and promote user autonomy in reward selection.

This paper proposes the development of a gamified collaborative virtual environment designed for sharing activities, challenges, and content related to computational skill learning. The platform is being developed for mobile devices (Android and iOS), aligning with the target audience's preference for smartphones and tablets. Additionally, this study investigates how collaborative environments and gamified elements can contribute to user learning and engagement.

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It is believed that the combination of collaboration and gamification can create a rich environment that fosters meaningful and enjoyable learning experiences. This work aims not only to implement a technological solution but also to contribute to the scientific discussion on the role of gamification and collaboration in developing computational competencies.

The rest of the paper is described as follows: Section 2 lays out the literature review. In Section 3, we describe the virtual environment A+Comp and its user interaction model and assessment model. Finally, in Section 4, we conclude with the expected contribution to the advancement of computational education.

2 REVIEW OF LITERATURE

In this section, the different theories will be presented, complementing each other to carry out this research.

2.1 Games and Gamification

Playing a game involves engaging in an activity aimed at producing a specific state, using only permitted means, with the goal of winning while adhering to predefined rules (Suits, 1967). Playing a game involves engaging in an activity aimed at achieving a specific state using only permitted means, with the objective of winning by adhering to predefined rules (Suits, 1967). According to McGonigal (2012), games are defined by four characteristics: objective, rules, feedback system, and voluntary participation.

Through clear goals, quality feedback, and narratives capable of motivating users to engage with a higher level of involvement than they might typically devote to real-world tasks, the learning achieved through these tasks can be acquired within the alternate reality of the gaming world. "*In the 21st century, games will be the primary platform for creating the future*" (McGonigal, 2012).

Gamification uses game mechanics to solve practical problems and foster engagement within a specific audience (Menezes and Bortoli, 2018). Game-based learning involves a system where learners, players, or consumers engage and interact in a challenge defined by clear rules, receiving feedback to achieve a measurable outcome while immersed in emotional reactions, with fun serving as the key element that makes playing enjoyable (Alves, 2015). However, maintaining player motivation and satisfaction in a gamified system is a challenge that demands attention and dedication during its development. Motivating users to adopt desirable behaviors employs techniques that leverage human psychological characteristics (Nicholson, 2012). According to Nicholson, the needs and objectives of the user must take precedence throughout the design of the game to ensure meaningful gamification, where the game design is user-centered.

Various types of players directly influence their interaction with the environment, the game, and other players (Alves, 2015). Similarly, different temperaments, personalities, and learning preferences exist. One technique used in meaningful gamification is the Universal Design for Learning (UDL) framework, aimed at creating content accessible to a broad range of learners (Rose et al., 2002). According to the authors, the UDL framework includes strategies such as differentiating ways of presenting content, addressing the "what" question; diversifying activity types for content demonstration, addressing the "how" question; and varying pathways for students to internalize content and remain motivated, thus addressing the "why" question.

2.2 Continuous Cycle of Experiential Learning

Rooted in emotions, positioning, and attitudes, Kolb's learning theory (1984) outlines four distinct styles for acquiring knowledge. Moreover, Kolb defines learning as a cycle of four stages, describing how individuals learn through experiential processes. This cycle not only explains individual differences, manifested in learning styles, but also elucidates the universal process of experiential learning, akin to a training loop.

The four stages of Kolb's learning cycle or training loop describe how "concrete or immediate experiences" provide the foundation for "observations and reflections." These observations and reflections are then assimilated and transformed into "abstract concepts" that yield new implications for action. Subsequently, these concepts are "actively tested", potentially generating new experiences.

Kolb's model operates across two dimensions, and the combinations of these dimensions generate learning preferences and determine how individuals react during the learning process. Figure 1 illustrates the continuous experiential learning cycle, where individuals choose between "feeling" and "thinking" along the vertical axis. This vertical axis represents the way an experience is preferentially perceived to initiate learning—either through sensory and intuitive means or through conceptual and logical analysis. Similarly, individuals choose between "doing" or "observing" along the horizontal axis, which addresses the processing of experiences. This processing transforms experiences into learning through practical application, abstract analysis, and integration.

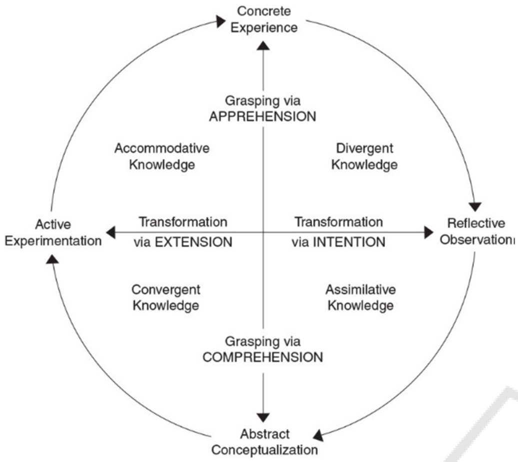

Figure 1: Structural Dimensions Underlying the Process of Experiential Learning and the Resulting Basic Knowledge Forms (Kolb, 1984, p.125).

The combination of these dimensions creates a dynamic model where individual preferences determine how experiences are perceived, processed, and transformed into actionable knowledge.

Table 1: Learning styles (Kolb, 1984).

Styles	Characteristics
Divergent	Creative and observant, proposes new ideas and approaches to achieve sensory outcomes
Assimilative	Inductive reasoning, observes and draws conclusions based on gathered data. Learns through lectures and readings
Convergent	Deductive reasoning, starts from established truths to deduce conclusions, as in mathematics and physics
Accommodative	Prefers practical classes, with intuitive problem-solving, through trial and error

According to the author, individuals decide between doing or observing at the same time as they decide whether to think or feel. The result of these two choices is the preferred learning style. Knowing a person's learning style can facilitate the acquisition of knowledge when the preferred method is used in instruction. Table 1 shows the four learning styles and their characteristics.

2.3 Collective Intelligence

The concept of Collective Intelligence (CI), as proposed by Malone, Atlee, and Lévy (2018), involves the ability of a group of individuals to work together effectively in problem-solving and decision-making. According to the authors, Collective Intelligence serves as a mechanism for addressing complex problems, contributing to a more prosperous and peaceful world by enabling individuals to collaborate efficiently to achieve common goals.

Technology, especially the Internet, connects people and boosts CI. Virtual environments, social networks, and AI amplify global collaboration. Tools like wikis, online reputation systems, and learning algorithms facilitate and scale cooperative efforts driving CI.

2.4 Cognitive, Conative and Executive Functions

In any learning process, neuroimaging examinations reveal numerous neurons interacting systemically, with this connectivity giving rise to complex neurofunctional networks responsible for higher-order capacities, referred to as cognitive, executive, and conative functions (Fonseca, 2014). According to the author, the term cognition refers to the process of acquiring knowledge facilitated through social interaction among humans. This process involves integrating tools such as attention, simultaneous and sequential processing, memory, reasoning, visualization, planning, problem-solving, execution, and the expression of information.

The Theory of Intelligence, known as the PASS Theory (Planning, Attention, Successive Processing, and Simultaneous Processing), was developed by Das, Naglieri, and Kirby (1994) based on the studies of Soviet physician and psychologist Alexander Luria. According to Luria (1966, 1973, 1980), human cognitive processing involves three functional units that work in unison. The first functional unit is responsible for cortical regulation and the maintenance of attention. The second functional unit receives, processes, and stores information through successive and simultaneous coding. The third functional unit is responsible for planning, regulating, and directing mental activity. Derived from the Latin word conatus, introduced by Spinoza, the 17th-century rationalist philosopher who argued that human behavior is determined by emotions, conative functions pertain to the individual's motivation, emotions, temperament, and personality (Fonseca, 2014). According to the author, emotions reflect a state of readiness in the organism to address certain tasks or situations, particularly those with survival value, such as threat, danger, anxiety, insecurity, or discomfort. This implies that when individuals face challenging or stressful learning situations, their availability, effort, balance, decision-making, investment, diligence, and adaptability may be impaired.

For this reason, knowledge objects must be presented to students in ways that do not neglect their emotions, feelings, and motivations, and games have proven to be effective in addressing these aspects. According to Fonseca (2014), this is crucial because negative conation can jeopardize three components essential to functional optimization: value (why I perform the task), expectation (what I achieve with the task), and affectivity (how I feel about the task). When an organism is healthy, with its basic needs satisfied and thus liberated for self-actualization, it is presumed to develop through intrinsic growth tendencies. Properly applied and successful cognitive functions yield gratification surpassing environmental determinism's extrinsic rewards (Maslow, 1954). According to Fonseca (2014), executive functions operate primarily in the prefrontal cortex, coordinating and integrating the neurofunctional triad of learning, where they are interconnected with the cognitive and conative functions previously discussed. In essence, executive functions represent the governing processes that link the brain to the body's muscles, enabling individuals to interact with the world intentionally and organized. This action plan considers past experiences and environmental demands (Santos, 2004).

The core components of executive functions include attention, perception, working memory, control, flexibility, metacognition, decision-making, and execution. Studies conducted with primary education students have demonstrated that executive functions are closely related to academic performance and that stimulating these functions can effectively enhance children's performance in their activities (Lima et al., 2009).

A review of the literature revealed that a deliberate method to develop executive functions is through digital games, which have been shown to be important and effective mediators for stimulating these functions (Vieira et al., 2017; Ramos and Rocha, 2016).

2.5 Modeling Complex Systems

Complex systems are networks composed of numerous interacting components, typically in a nonlinear manner. These components can emerge and evolve through self-organization, existing in a state that is neither entirely regular nor entirely random, thereby enabling the development of emergent behavior at a macroscopic scale (Sayama, 2015). In a complex system, the interaction among components can lead to the system's self-organization, independent of centralized control. The proposed digital environment constitutes a complex system, as its elements, meanings, objectives, and challenges are interconnected like a graph, with no predefined sequence of actions for participants to follow. Similarly, the outcomes of participants' choices within the digital environment, their performance in challenges, and the reward system can influence the actions of other participants, fostering a collaborative process aimed at enhancing collective learning.

3 THE A+COMP DIGITAL ENVIRONMENT

Students build their knowledge through access to the contents and activities shared in the A+Comp environment, but the gamified digital environment proposed in this research is being designed and developed using the Design Science Research methodology (Dresch et al., 2015) and was inspired by the design of online social networks such as Facebook and Instagram. In addition to allowing users to follow friends and track their interactions, the proposal integrates concepts from digital games like Stardew Valley, Unravel Two, and Welcome to Bloxburg. The inspiration derived from these games, coupled with everyday school experiences, has created a blend capable of triggering a creative process involving rewards, objectives, and challenges aimed at developing computational skills recently incorporated into the Brazilian educational curriculum. These skills include classifying information and its data types, devising algorithms, decomposing problems, implementing solutions using programming languages, reusing code, and understanding data transmission processes, among others.

3.1 A+Comp User Interaction Model

The A+Comp environment will be utilized with students and teachers from the 6th to 9th grades and high school in two public schools in Brazil. The proposed model specifically reflects the interaction between students and other students, teachers and students, and teachers with other teachers, because strengthening connections between different age groups promotes digital and social inclusion (Fronza et al., 2024). In the A+Comp environment, users can publish content and activities, either created or found on the internet, related to computer science education, contributing to a material curation process shared with others. Users can also validate, like, add to favorites, follow other users, and individually or collectively engage in the posted activities. Based on Kolb’s Experiential Learning Cycle, the model emphasizes the various ways users engage within the A+Comp environment, accommodating their preferred learning styles while immersing them in other styles to encourage the completion of the ideal cycle, as suggested by Kolb (1984). The model is structured around the four stages of the Experiential Learning Cycle:

- Concrete Experience (Feel/Act): Participants absorb new content by viewing materials and activities posted by others.
- Reflective Observation (Observe/Reflect): Participants evaluate posted content and activities, conducting external research to complement their acquired knowledge.
- Abstract Conceptualization (Think/ Conceptualize): Logical connections between theory and practice are established, enabling participants to begin working on activities and challenges proposed by others.
- Active Experimentation (Do/Apply): Participants apply their knowledge by proposing activities, posting content, validating tasks, and correcting activities shared by others.

Gamification occurs as each action within the aforementioned steps rewards users with a progressively increasing amount of coins, with the final step providing the highest reward, thereby incentivizing users to progress through all stages of Kolb's cycle. Upon reaching certain coins, the user unlocks a mini-game directly addressing one of the aforementioned skills.

As depicted in Figure 2, the core of the model focuses on computational competencies, which represent the environment’s primary objective.

3.2 Positive Feedback Model

The model proposed in this research employs a complex adaptive system to encourage, develop, and track the acquisition of skills and competencies through participant interactions and the resolution of digital challenges.

This system is grounded in the Positive Feedback model proposed by Batty (2007) to maintain “diminishing returns to scale”, ensuring a more balanced participation among A+Comp users.

The Positive Feedback model statistically demonstrates, within a 21x21 grid filled with distributed and activity-analogous values: the rich become richer, and the poor become poorer. An analogy can be drawn using the Brazilian educational system: individuals with more resources to invest in a quality education have greater chances of securing good jobs, while those with fewer resources find it difficult to change their socioeconomic status due to a lack of investment opportunities. This phenomenon arises because the growth rate of a quantity is positively correlated with its magnitude—that is, growth increases size, which in turn amplifies the growth rate. Positive Feedback is also known as “increasing returns to scale”, but “diminishing returns to scale” can occur when the ALPHA rate is less than one (ALPHA < 1). With decreasing returns to scale, as the quantity increases, the growth rate of that quantity decreases. In other words, the more resources there are, the harder it becomes to increase them, and more opportunities are created for those with fewer resources. This model can be tested computationally using the NetLogo software (Wilensky, 2007). In the A+Comp environment, the ALPHA rate is used to observe and maintain “decreasing returns to scale”. The idea is to prevent those with extensive knowledge of Computer Science from overshadowing less knowledgeable participants, which could lead to a lack of motivation to use the A+Comp environment. The system operates as follows: when the ALPHA rate is high, the A+Comp environment offers advantages (rewards) to users who are not participating while increasing the item store prices for users who are participating alone. Conversely, the environment provides more virtual coins for these solitary users to interact with non-participating users. Equation 1 shows how the ALPHA rate is calculated based on the number of participations over a one-week interval. The greater the number of participations, the lower the ALPHA rate.

Under such conditions, all quantities are reduced until they equalize, benefiting the disadvantaged. This model can be computationally tested using the NetLogo software (Wilensky, 2007).

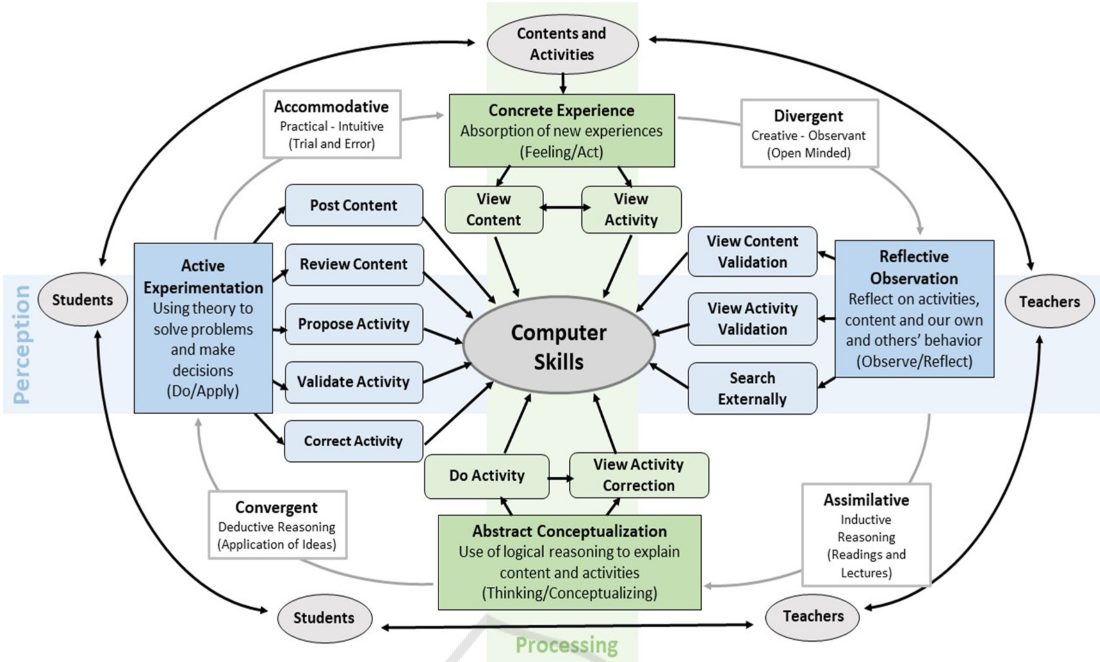

Figure 2: Interaction Model Between Users in the A+Comp Environment.

In Equation 1, T(n) represents the variable rate as a function of the number of participations during the week, denoted by n. The letter C is a constant that prevents division by zero and adjusts the decay curve of the rate, set to a value of 1. The letter K represents a constant value that adjusts the initial rate when n=0.

$$T(n) = \frac{K}{n+C} \tag{1}$$

Additionally, the Moore neighborhood is applied, where the rate increases the average of the eight closest neighbors, represented by each user's eight most active friends. This adaptability, which is not disclosed to users, involves creating fictitious virtual friends who act to raise the Moore neighborhood average of participants when necessary. Upon first accessing the A+Comp environment, users will be informed about the potential interaction with fictitious agents, although these agents will not be identified. These virtual friends will interact like any other user, liking posts, recommending activities and content, inviting users to participate in collaborative activities, and more.

3.3 Skills Development Assessment Model

In the A+Comp environment, the students build their knowledge by accessing shared content and activities through user interactions and by playing mini-games. The process unfolds as follows: the first contact with the learning objects, which include posted content and activities on predefined themes of the A+Comp environment (Programming, Robotics, Computational Thinking, Society and Technology, Logic, Digital Tools, or Digital Security), initiates the Concrete Experience phase (feel/act). Faced with a variety of posts, cognitive functions are recruited, and users process information successively and/or simultaneously. When content or activity on a specific theme captures their attention, cortical activation and focus keep them engaged.

Conative functions are activated through gamification, where the possibility of earning coins and acquiring desired items affects emotions and motivates users to stay in the environment. This first contact leads to the next stage, Reflective Observation (observe/reflect), where users can interact and express validation. Engagement with the chosen theme elevates the user to the Abstract Conceptualization stage (thinking/conceptualizing), occurring when they perform activities, triggering cognitive processes such as logical reasoning, memory, planning, and problem-solving. When users feel comfortable enough with the theme after passing through the three stages, motivated by gamification, they reach the final stage of Active Experimentation (do/apply), proposing their own activities, providing corrections, and contributing to the learning of other users.

At this moment, the executive functions that govern intentional and organized interaction with the world are concluding the learning process, coordinating, and integrating the neurofunctional triad of learning (Fonseca, 2012). This cycle repeats with each theme that captures the user's attention.

Table 2: Markers that check collection and data type abilities

1	The player can store toys in drawers labeled with tags such as "type: toy" and food items in drawers labeled with "type: food."
2	The player can store objects identified only by words in drawers labeled "type: string," objects with integers in drawers labeled "type: integer (int)," and objects with decimal numbers in drawers labeled "type: floating-point (float)."
3	The player can correctly organize the items described above, but the drawers will only be identified by tags labeled "type: string," "type: int," and "type: float."
4	The player can correctly store, in drawers with the same labels as previously described, cards containing expressions such as: “int number = 9;” “string name = anna;” “float temperature = 31,5;” “string name = anna;”
5	Using the game's programming IDE, the player can arrange the pieces of a puzzle containing parts of the previously presented code.
6	Using the game's programming IDE, the player can type the variable declaration code, following the previously presented pattern.

In addition to user interaction and content sharing, the gamified digital environment A+Comp features mini-games designed in alignment with the domains, knowledge objects, and skills outlined in the Brazilian educational curriculum (MEC, 2022). The markers aim to assess the acquisition of skills that will trigger the development of computational competencies. Other digital environments like PyGuru also analyze programming students’ actions, capturing temporal learning behaviors (Singh, 2024). Each challenge includes six markers that indicate progress in learning a particular concept. Each marker adds 1 point to the player’s learning score. Among the six marker levels, the first level is the simplest, the fifth level indicates mastery of the concept, and the sixth level represents exceptional learning. For each additional marker earned, the user receives a reward equal to the marker level multiplied by two virtual coins. Although repeating challenges does not contribute to the learning score, players can repeat tasks as often as desired. Every time a player correctly performs level-six tasks for the first time, the amount of virtual coins earned is doubled.

The Brazilian educational curriculum defines computational competencies that can be acquired through the development of specific skills, such as accurately describing problem solutions by constructing a program to implement the described solution, designing algorithms involving sequential, iterative, and conditional instructions using a programming language, or understanding the data transmission process, including how information is fragmented into packets, transmitted across multiple devices, and reconstructed at its destination (MEC, 2022). Approximately ten skills are to be developed each school year. For example, the skill of classifying information by grouping it into collections and associating each collection with a data type is evaluated through a mini-game in which the challenge involves organizing scattered data types (int, float, and string) into a cabinet with drawers representing computer memory (Figure 3). Table 2 details the minigame's markers.

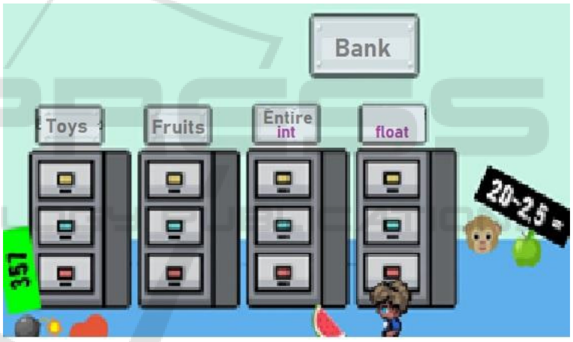

Figure 3: Minigame to assess data type classification skills.

4 CONCLUSION

This work explored the potential of a gamified and collaborative digital environment for developing computational competencies in basic education, laying a foundation for future investigations into the role of gamified and collaborative technologies in education. The empirical analysis of the use of A+Comp will provide relevant data to improve the model and validate its effectiveness across different subjects and educational contexts. In future work, we aim to implement the A+Comp environment and do usability testing with basic education students.

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