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Computational Thinking and Creativity: A Test for Interdependency

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ABSTRACT

Computational Thinking (CT) and creativity are considered fundamental skills for future citizens. We studied the associations between these two constructs among middle school students (N=174), considering two types of creativity: Creative Thinking and Computational Creativity. We did so using log files from a game-based learning platform (Kodetu) and a standardized creativity test. We found that the more creative the students were (as measured by a traditional creativity test), the more effectively they acquired CT. We also found significant positive correlations between Computational Creativity and the acquisition of CT in some levels of the game, and a positive correlation between Creative Thinking and Computational Creativity.

KEYWORDS

computational thinking, creativity, game-based learning, learning analytics, log analysis

1. INTRODUCTION

The exponential growth in the data available from a plethora of resources and the significant development of science, make it essential for people to adopt skills that complement and provide the added value of computing capabilities to any field of expertise (Hambrusch, Hoffmann, Korb, Haugan, & Hosking, 2009). Both Computational Thinking and Creativity have been recognized as essential skills for the 21st century (Kalelioğlu, Gülbahar, & Kukul, 2016; Sai d-Metwaly, Noortgate, & Kyndt, 2017) and are crucially important for human development (Czerkawski, 2015).

Computational Thinking (CT) is the conceptual foundation required to define and solve real-world problems using algorithmic methods to reach solutions that are transferable and necessary to various contexts and disciplines (Shute, Sun, & Asbell-Clarke, 2017). It is a skill that helps improving thinking abilities and provides techniques to extract knowledge hidden in the data (Buitrago Flórez et al., 2017).

Creativity is a thinking ability that enables problem-solving in an innovative manner, and the production of original and valuable products (Torrance, 1974). Despite having many definitions to this construct, there is an agreement that creativity is a multi-dimensional variable comprised of four characteristics: (1) Fluency – the ability to generate a large number of ideas and directions of thought for a particular problem; (2) Flexibility – the ability to think about as many uses and classifications as possible for a particular item or subject; (3) Originality – the ability to think of ideas that are not self-evident or banal or statistically ordinary, but rather unusual and even refuted, and (4) Elaboration – the ability to expand an existing idea, develop and improve it by integrating existing schemes with new ideas (Guilford, 1950; Torrance, 1965).

Similar to CT, creativity has been identified as crucial to human inventive potential in all disciplines, and it is evident that its influence dominates various spheres of life (Navarrete, 2013). However, for many years, these two skills remained within their content areas - CT was mainly taught in the context of Science, Technology, Engineering, and Mathematics (STEM) fields, and creativity in the fields of design and art. We have come to a point where there is an understanding that both can be nurtured and should be included across the curriculum from an early age (Beghetto, 2010; Vygotsky, 2004). Indeed, creativity involves a set of thinking tools that overlap with the fundamentals of Computer Science—specifically, observation, imagination and visualization, abstraction, and creation and identification of patterns (Yadav & Cooper, 2017)—which can support the development of creativity. For this reason, various educational initiatives worldwide have begun to establish national K-12 curricula, academic standards, and instructional computerized and unplugged activities that promote these skills (ISTE, 2017; World Economic Forum, 2015).

With the recognition of its importance, CT has been integrated into school curricula around the world, and many online platforms, especially game-based learning platforms, have been developed to support and promote its acquisition (Kim & Ko, 2017). Some of these platforms—like CodeMonkey™ or Hour of Code™—take advantage of the game-based learning approach, which promotes learning through fun, interactive and rewarding game-play, in order to increase engagement and motivation for learning and to improve academic achievements in the long run (Ibanez, Di-Serio, & Delgado-Kloos, 2014; Kazimoglu, Kiernan, Bacon, & MacKinnon, 2012; Vu & Feinstein, 2017). However, while encouraging the acquisition of CT in a fun, engaging way, these platforms promote efficiency and sometimes limit creativity (for example, when not allowing free use of coding blocks). This is most evident when a learner submits a solution which may be considered as creative, but as it is not the most efficient solution anticipated by the platform, the learner would not get a full score for it.

Research on CT and creativity has been conducted from different perspectives, looking at both creativity within the scope of CT and the influence of the two constructs on each other (Miller et al., 2013; Seo & Kim, 2016). However, only limited research exists on the relationship between these two perspectives. Creativity may be dependent on the learning context and the measuring tool (Reiter-Palmon, Illies, Kobe Cross, Buboltz, & Nimps, 2009). Therefore, we explore the associations between different measures and perspectives of creativity and look for connections between them and CT acquisition.

2. RESEARCH QUESTIONS

To avoid confusion, we use Creative Thinking to refer to a traditional measure of creativity that has no connection to the platform being used, and Computational Creativity to refer to a measure of how creativity is manifested inside the platform, as reflected by the frequency (originality) of a given solution among all other solutions (detailed in section 3.5). To meet our research goal, we formulated the following research questions:

1. What are the associations between the acquisition of CT and Creative Thinking?
2. What are the associations between the acquisition of CT and Computational Creativity?
3. What are the associations between Computational Creativity and Creative Thinking?

3. METHODOLOGY

3.1. The Learning Platform: Kodetu

Kodetu is a web app built using Google's Blockly for teaching basic programming skills (Eguíluz et al., 2017). The environment has three official games, and it is also allowing users to create their own games. Each of Kodetu's levels presents the user with a challenge in which an astronaut should get to a marked destination. The user has to define the astronaut's movements using coding blocks in the workspace. Each level of the game presents one or more CT concepts (e.g., *sequences, loops*, etc.). Moving to the next level is possible only upon completing the current level successfully. It should be noted that a user can reset the level and solve it again. The system is offered in three languages: English, Spanish, and Basque. While the app is being used, the system logs any action taken by its users.

For our broad study, a dedicated game was created in the Kodetu platform. The game includes ten levels with increased difficulty. In this paper, we present part of our work covering levels 1-9. The first four levels are designed with the aim of practicing the concept of *sequences*. Level 1 presents a trivial level to show how the system works. Level 2 and 3 involve turns and perspective. Level 4 presents a challenge where a long sequence of actions, including more than one rotation, is needed to reach the goal. Level 5 limits the number of blocks that can be used (i.e., code length) to prevent participants from using long *sequences* and to encourage them to take advantage of new code structures of *loops*. Level 6 presents a trivial challenge that deals with *sequences* and *loops*. Level 7 (Shown in Figure 1) also works on *sequences* and *loops* with limitation of blocks' usage. Level 8 limits the number of blocks that can be used (i.e., code length) to prevent participants from using long *sequences* and to encourage them to take advantage of new code structures of *conditionals*. Level 9 introduces *If-Else* conditionals and requires nested structures and a limited number of blocks. Solving the entire set of levels is intended to take 30 to 60 minutes. While the platform is being used, the system logs any action taken by its users.

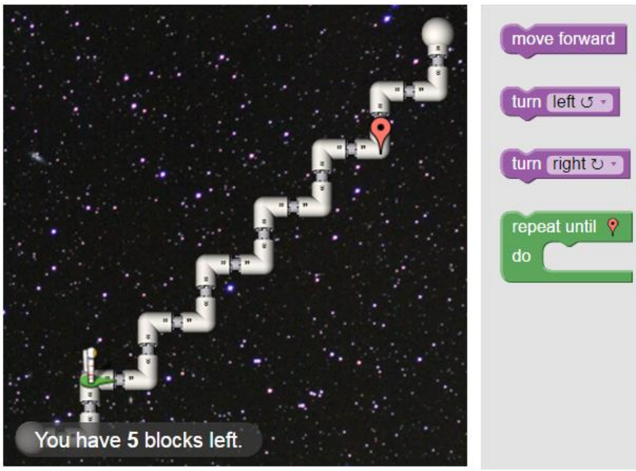

Figure 1. An Example Level of Kodetu (level 7)

3.2. Population and Research Design

For this study, we analyzed the actions of 174 middle-school Spanish students, 11-12 years old (55% boys and 45% girls) from two different schools. The students arrived to an outreach activity organized by the Faculty of Engineering of the University of Deusto and participated in a workshop about technology, programming, and robotics. During this workshop, the students played the designated Kodetu game for about 60 minutes. For the vast majority of the students, it was their first encounter with programming experience (78%, 136 of 174). In addition, 60% of students (105 of 174) reported they have a high affinity for technology.

Prior to the Kodetu session, all participants completed a pen-and-paper creativity task (Torrance's TTCT – Figural Test; see section 3.4). Data from Kodetu log files were triangulated with the data obtained via the creativity task using a unique ID for each participant. This ID was produced by Kodetu and was written down on the creativity test form by the participants. In addition, participants were asked to provide demographic data (age, gender), previous programming background (yes/no), and affinity to technology (1-low to 10-high).

3.3. Dataset and Preprocessing

The full log file included 163,137 rows, each representing an action taken by a user, including its timestamp, the level in which it was taken, its result [Success, Failure, Timeout, Error], and the code associated with this action.

3.4. Research Tool

We used the Torrance Test for Creative Thinking (TTCT) – Figural Test (Torrance, 1974) to assess Creative Thinking in four dimensions: fluency, flexibility, originality, and elaboration. In this pen-and-paper test, each student was presented with a sheet on which 12 identical, empty circles were printed. Students were asked to make as many drawings as possible using the circles as part of the drawings. An eligible drawing used the circle as part of the drawing. See examples in Figure 2.

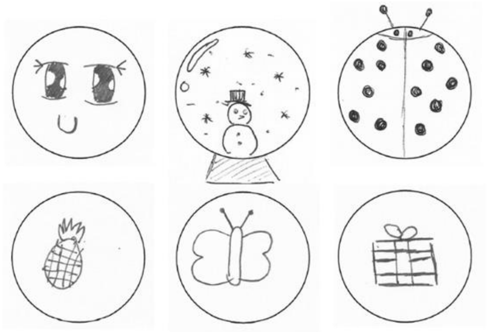

Figure 2. Example of Eligible (top row) and Non-eligible (bottom row) Drawings from TTCT – Figural Test

3.5. Variables

3.5.1. Computational Thinking

We focused on three variables to measure the acquisition of computational thinking, each computed for all levels as well as for each level separately.

- Solution Attempts.
- Correct Solution Attempts.
- Average Time [min].

3.5.2. Creative Thinking

To score the creativity task, we used eligible drawings only, that is, drawings in which the circle was considered an important part of the drawing. In order to ensure the reliability of determining eligibility, each of the first two authors coded 20 sheets for eligibility separately; then, we ran an inter-rater reliability assessment using Cohen's kappa and got a satisfying coefficient of 0.81. The authors then discussed borderline cases and agreed on guidelines for the rest of the coding, which was done by the first author.

Similarly, each of the first two authors separately coded 20 sheets for categories and then discussed their codes until full agreement achieved. The rest of the coding was done by the first author, with frequent discussions throughout this process about their very definitions and about splitting and merging categories. At the end of this iterative process, the final list consisted of 59 categories, e.g., "Emoji", "Sun", "Flower", "Signpost".

Finally, we computed the following four variables (for each student):

- Fluency – Number of eligible drawings;
- Flexibility – Number of different drawings' categories;
- Originality – Average frequency of the drawing categories, across all drawings;
- Elaboration – Number of ideas/details used in each eligible drawing;

3.5.3. Computational Creativity

Our analysis focuses on the originality of a correct solution as a proxy for creativity. This is due to the fact that the Kodetu platform, similarly to many other platforms, does not explicitly encourage multiple solutions, and once a level is solved, participants are immediately encouraged to move to the next level. Therefore, fluency, flexibility, and elaboration are not applicable in our analysis.

The originality is represented by the frequency of this solution among all the correct solutions for this level. That is, the rarer a solution is, the more creative it is considered. When there were multiple correct solutions for an individual participant, we calculated the average across her or his correct solutions. The originality was calculated for each level separately and also aggregated for all Levels.

4. FINDINGS

4.1. Descriptive Statistics of the Research Variables

In order to better understand the associations between Computational Thinking, Creative Thinking, and Computational Creativity, we first report on descriptive statistics of each of the variables. All statistical analyses used IBM SPSS version 25.

4.1.1. Computational Thinking

We found that among all participants, the average Solution Attempts was 6.16 (SD=3.08), and Correct Solution Attempt was 1.06 (SD=0.19). The Average Time it took to solve each level was 5.13 minutes (SD=11.99).

Overall, there was an increasing trend in Level Solution Attempts, with R^2=0.49 for the graph trend line (see Figure 3), indicating the increasing difficulty of the game. A similar trend was found for the Level Average Time, excluding a decrease between Level 1 to level 3, which might be related to the participants' adaptation to the interface in these initial levels. In addition, there is a decrease from level 8 to 9 that may be associated with the presentation of the concept of *conditionals* in level 8.

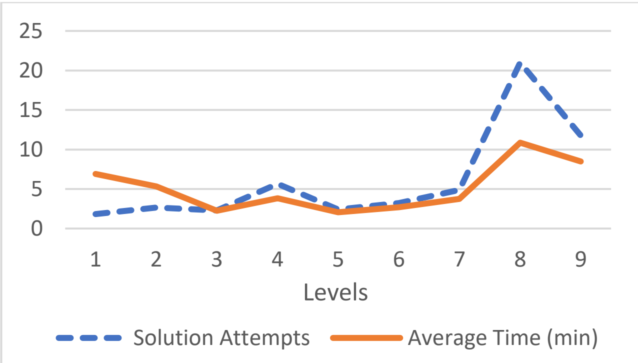

Figure 3. Solution Attempts and Average Time by Level

When comparing the performance by Gender, we found that the average Solution Attempts was greater for girls than for boys (M=6.48, SD=3.5, and M=5.93, SD=2.79, respectively). The Average Time was also greater for girls than for boys (M=3.17, SD=2.96, and M=2.87, SD=2.58, respectively).

4.1.2. Creative Thinking

As indicated above, Creative Thinking consisted of four dimensions (fluency, flexibility, originality, and elaboration). Based on normality tests (H.-Y. Kim, 2013), we assumed normality (Skewness<0.5 in absolute value) for all dimensions of Creative Thinking except originality. A summary of the statistics is presented in Table 1.

We should comment on the relatively high mean value of originality (M=0.89, SD=0.16, N=174). Recall that we defined 59 categories of drawings for the TCTT – Figural Test. The distribution of the categories was in a "long tail" shape; that is, many categories had a very low frequency (i.e., were highly original), and only a few had relatively high frequency (i.e., were not original). The least original category ("Emoji") had a frequency of 75%.

Table 1. Descriptive Statistics for Creative Thinking

Variable	Average (SD)	Median	Skewness (SE)
Fluency	6.96 (3.65)	7	-0.23 (0.18)
Flexibility	4.25 (2.94)	4	0.48 (0.18)
Originality	0.89 (0.16)	0.94	-4.43 (0.18)
Elaboration	2.88 (0.89)	2.83	-0.12 (0.18)

4.1.3. Computational Creativity

Among all participants, the Computational Creativity score was low, as indicated by an average value of 0.24 (SD=0.24). No clear trend was observed throughout the game (See Table 2). In more than half of the cases, we could not assume normality (H.-Y. Kim, 2013), as can be seen from the high levels of the Skewness coefficients (that is, higher than 1). In most levels, one dominant solution was observed despite the existence of several others, as solved by a minority of students. Exceptions were levels 7 and 8, where only a single solution was observed for the whole population, probably because of the design of these levels and their block limit. Levels 4 and 6 showed the highest variability among participants.

Table 2. Descriptive Statistics for Computational Creativity

Level	Average (SD)	Median	Skewness (SE)
1	0.17 (0.25)	0.9	2.91 (0.18)
2	0.21 (0.27)	0.11	2.35 (0.19)
3	0.1 (0.2)	0.05	3.96 (0.18)
4	0.67 (0.19)	0.7	0.49 (0.19)
5	0.03 (0.13)	0.02	7.48 (0.18)
6	0.63 (0.17)	0.67	0.67 (0.19)
7	0.02 (0.72)	-	-
8	0.02 (0.09)	-	-
9	0.45 (0.15)	0.42	-1.78 (0.2)

4.2. Creative Thinking and the Acquisition of Computational Thinking

We tested the correlation between the Computational Thinking variables and the Creative Thinking variables. We found that Flexibility and Originality were significantly negatively correlated with Average Time, with Spearman's ρ taking values of -0.16 and -0.18, respectively, at p<0.05. Likewise, we found a significant negative correlation between Flexibility and Solution Attempts, with ρ=-0.17, at p<0.05. When we examined the correlation between the two variables by level, we found five cases – levels 1, 3, 5, 6, and 7 – which demonstrated significant correlations. Note that except for one case (level 1), all correlations were negative (findings are summarized in Table 3). These results indicate that **the more creative the students were** (as measured by a traditional creativity test), **the less time and effort it took them to solve the levels in the game**.

Table 3. Correlations between Computational Thinking and Creative Thinking by Levels (N=174)

	Solution Attempts	Correct Solution Attempts	Average Time
Fluency			
Level 1	ρ=-0.04 p=0.62	ρ=0.04 p=0.65	**ρ=-0.16***
Flexibility			
Level 1	ρ=-0.04 p=0.58	ρ=-0.01 p=0.94	**ρ=0.15***
Level 7	**ρ=-0.18***	ρ=0.00 p=0.96	ρ=-0.14 p=0.07
Originality			
Level 5	**ρ=-0.15***	ρ=-0.06 p=0.42	ρ=-0.04 p=0.62
Elaboration			
Level 1	ρ=0.1 p=0.19	ρ=-0.15 p=0.05	**ρ=-0.27****
Level 3	ρ=0.11 p=0.14	ρ=-0.15 p=0.05	**ρ=-0.19****
Level 6	**ρ=-0.2****	**ρ=-0.16***	**ρ=-0.21****

* p<0.05, ** p<0.01

4.3. Computational Creativity and the Acquisition of Computational Thinking

Next, we tested the associations between Computational Thinking and Computational Creativity as the latter is reflected by the originality of a correct solution in a given level compared with all other correct solutions. We did so both for the aggregated measures, as well as for each level of the game separately. We found that overall, Computational Creativity is negatively correlated with Solution Attempts, with ρ=-0.17, at p<0.05, and with Average Time, with ρ=0.2, at p<0.01. We also found four cases – levels 3, 4, 6, and 9 – which demonstrated

significant positive correlations, as reported in Table 4. These results indicate that **the more creative the students were in producing a solution**, **the more time and effort it took them to solve levels in the game**.

Table 4. Correlations between Computational Thinking and Computational Creativity by Levels (N=174)

	Solution Attempts	Correct Solution Attempts	Average Time
Level 3	ρ=0.14 p=0.08	ρ=0.05 p=0.53	**ρ=0.27****
Level 4	ρ=0.14 p=0.06	ρ=-0.02 p=0.78	**ρ=0.25****
Level 6	**ρ=0.17***	ρ-0.08 p=0.28	ρ=0.11 p=0.16
Level 9	**ρ=0.18***	ρ=0.1 p=0.27	**ρ=0.33****

* p<0.05, ** p<0.01

4.4. Computational Creativity and Creative Thinking

Finally, we examined the associations between creativity related measures: Computational Creativity and Creative Thinking. We found a **significant positive correlation between originality and the aggregated variable of Computational Creativity**, with ρ=0.2, at $p<0.01$. In addition, when examining these correlations between the variables for each level separately, we found that in one case – levels 6 – **originality was positively correlated with Computational Creativity, with** ρ=0.19, at $p<0.05$). These results indicate that **students who created more original drawings in the TTCT task were more creative in the game**.

5. DISCUSSION

Various studies have investigated the associations between computational thinking (CT) and creative thinking, however, this study is among the pioneers who examine these associations with Computational Creativity. In this study, we investigated the associations between the acquisition of CT by middle-school students who used a game-based learning platform, referring to two types of creativity – Creative Thinking and Computational Creativity. The first was defined by a traditional creativity test, not related to CT, while the second by the originality of correct solutions within the learning platform. Overall, we found interesting associations between the three research variables. Two dimensions of Creative Thinking—namely flexibility, and originality—were negatively correlated with measures of CT. As students were more creative in the TTCT task, they needed less time and effort to solve the levels in the game. This is in line with an earlier study that indicates a positive relationship between standardized creativity testing and students' performance (Anwar, Aness, Khizar, Naseer, & Muhammad, 2012). Furthermore, these findings reinforce the claim that creativity contributes to computer science and CT in particular (Kong, 2019; Miller et al., 2013).

Notably, we found that at some level of the game, there was a positive correlation between Computational Creativity and measures of the acquisition of CT. That is, students who provided more unique and original solutions needed more time and attempts to solve these levels. This is not surprising as producing a creative solution may take more time than a "standard" solution (Akinboye, 1982; M. Baer & Oldham, 2006).

We also found some intriguing associations between the two types of creativity. Computational Creativity was positively correlated with the originality dimensions of Creative Thinking. These results may imply that creativity is context-dependent (as the associations were only demonstrated in some of the game-levels) as well as transferable from one domain to another. This supports the hierarchical model of creativity, which integrates both domain-general and domain-specific types of creativity (Baer, 2010; Hong & Milgram, 2010). It also reflects earlier findings that linking TTCT score and creativity in problem-solving in programming platforms (Liu & Lu, 2002).

While the results and insights of this study contribute in offering a better understanding of the associations between CT and type of creativity, we also want to highlight its limitations. First, we analyzed data from a single learning platform (Kodetu), and it is possible that our findings were a result of some unique characteristics of this platform. Specifically, the studied platform does not encourage multiple correct solutions and, in some cases, limits the free use of coding blocks, which may affect and limit creative submission. Furthermore, the analysis is based on students from a single country (Spain). Personal and cultural characteristics may impact the way creativity is exhibited. Therefore, we plan to broaden our perspective by examining similar platforms under different conditions and with a more multi-cultural view.

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