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Robotics-Based Interventions for Children's Creativity

Patrícia Alves-Oliveira
University of Washington
Seattle, WA, USA
patri@uw.edu

Patrícia Arriaga
Iscte-Instituto Universitário de Lisboa, CIS-IUL
Lisbon, Portugal
Patricia.Arriaga@iscte-iul.pt

Sara Ibérico Nogueira
Universidade Lusófona de Humanidades e Tecnologias
Lisbon, Portugal
saraiberico@hotmail.com

Ana Paiva
INESC-ID, University of Lisbon, and Radcliffe Institute for Advanced Study, Harvard University
Lisbon, Portugal
ana.paiva@inesc-id.pt

ABSTRACT

Robots have massively been introduced in children's lives, showing promising effects on education and learning. Parallel to this, children's creative levels show a decline related to different factors, including the standardized teaching and learning dynamics present in traditional school systems. This work aims to investigate if the activities with robots already present in schools affect children's creativity levels. To study this, we compared creative levels of children across three study conditions: (1) Experimental condition 1: Children performed STEM activities in school by learning how to program robots; (2) Experimental condition 2: Children performed STEAM activities by learning how to design robots; (3) Control condition: Children engaged in a music class. We applied the Test for Creative Thinking-Drawing Production (TCT-DP), a validated test that measures creative potential, before and after the intervention. Our results showed that the creativity levels of children increased from pre- to post-testing, revealing the effect of all intervention groups in potentiating creativity. Additionally, results showed that creative levels were significantly higher in the control condition. This result was expected since this condition consisted of an artistic musical intervention where creativity is foreseen to be stimulated. When analyzing the effects of the interventions on the two dimensions of TCT-DP (i.e., adaptiveness and innovativeness), results showed that both the control and the programming condition stimulated innovativeness. This result seems to show that STEM activities can stimulate non-conventional ways of thinking, similarly to creative activities such as a music class. While much has been studied about how STEM activities influence the knowledge of children, little is known if STEM also contributes to the stimulation of their creativity. This study promotes investigation in this topic and shows the potential of using robots to unlock creative potentials in children.

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CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; • **Applied computing** → **Education**.

KEYWORDS

Creativity support environments, computing tools, creative process, social robotics

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1 INTRODUCTION AND RELATED WORK

1.1 Robotics for Children

Digital competence, a skill highly related to Science, Technology, Engineering and Mathematics (STEM) activities and robotics, was elected one of the eight basic competencies of the European Reference Framework of key competencies for lifelong learning [7]. Digital competence is defined as an awareness and a capacity of people to properly use digital tools to identify, access, integrate, manage or evaluate digital resources [25]. It is a competence that has been therefore included in the school curriculum of many countries. This required a learning curve for teachers, who started to include didactic activities with digital technologies to teach children other curricular topics. It has been extensively recognized that experiential, hands-on educational activities provide higher motivation for learning new material, by providing real-world meaning to the otherwise abstract knowledge [11, 26]. To contribute to this hands-on learning and growing, robotics is a novel and promising tool to generate interest, motivation, and learning in topics of STEM [13]. However, little is know about the effects that STEM can have in stimulating other abilities, such as creativity, one of the most important abilities that children can have related to well-being, self-expression, and growth [36, 39].

This ability to learn concepts about curricular topics (e.g., math) through the use of robotics, was coined by Seymour Papert [31]. The main idea was to teach children to learn how the computer thinks so they could learn about their thinking. Towards his goal, he developed LOGO, one of the earliest programming languages for children [30] that enables them to see the product of their coding in a robot (called the LOGO Turtle). [38]. For example, by programming the LOGO Turtle to perform a 90º angle four times, children saw the formation of a square and start understanding the connection between geometry and squared objects or even squared houses.

Education, like other social sectors, is rapidly adopting electronic tools in the classroom [25]. As digital tools seem to promote successful teaching techniques, programming languages continue to improve and today we have languages such as Scratch, a programming language of building blocks pervasively present in robotic kits for children so they learn how to code [33].

1.2 Robotics and Creativity

During STEM activities, children are active builders of their learning [15]. Usually, these activities have an interpersonal nature, and children are organized in small groups to solve a problem and learn with each other. By looking at the cognitive processes that are involved in STEM activities, such as problem-solving, one could say they incorporate processes that are relevant for creative thinking [14, 35]. Some studies evaluated if creativity levels increase with purely digital STEM activities, showing promising results (e.g., [8]). Other studies evaluated how just by creating a story with a social robot, children's ideas are more original and elaborated [4, 5]. Other works have shown how children's creativity levels increased by being exposed to a robot that express creativity [1].

However, little is known about how creativity levels of children perform in STEM activities – such as programming a robot and designing a robot. Namely, it would be important to study if STEM activities with robots increase creativity as much as when children are involved in activities that are expected to promote their creativity, such as music classes [23]. A study performed by Ritter and Ferguson (2017) [34] showed that listening to music, especially happy music, increases levels of both convergent and divergent thinking. Songwriting is an activity that also appears to be related to creativity reasoning in both teenagers [6] and children [37]. Additionally, being playing an instrument is also associated with an increase in creativity levels of children [21]. In this study, we seek to explore if STEM activities with robots contribute to the development of creativity in the same way that a music class does.

2 OUR CONTRIBUTION

STEM activities have defined problems for children to solve. While children become efficient in acquiring a mindset for solving concrete problems, they can have a harder time solving problems that are ill-defined [28]. Some literature exists on the influence of STEM activities in children's creative thinking (e.g., [15]). In this work, we aim to expand this line of research by studying the impact of combining robotics technology and STEM activities in promoting creativity in children, which is composed of concrete and abstract problems.

The main contribution of this work is to assess, using validated measures of creativity, the impact that programming and designing a robot has on children's creative thinking. Additionally, we provide comparisons with a control group that consisted of a creative musical class, providing a fair comparison in terms of the impact on creativity levels.

2.1 Goal and Research Question

The main goal of this study was to investigate if existing activities for children that include robots (either real robots or designing a future robot) increase the creativity levels of children in comparison with a music class. Therefore, we considered the following experimental conditions: i) *experimental condition of programming robots:* children learned how to program robots according to pre-defined activities; ii) *experimental condition of designing robots*: children learned how to design behaviors for robot prototypes without needing to program the behaviors; iii) *control condition:* children engaged in a music class. As such, the research question for this study is: *can activities with robots increase children's creative abilities compared to artistic activities of music?*

3 METHOD

3.1 Participants

To estimate the sample size required for this study, an a priori power analysis was conducted using G*Power3 [12]. We considered the comparison of three independent groups using an Analysis of Variance (ANOVA) with repeated measures (pre-posttest), a medium effect size ($f = 0.25$), alpha of .05, power of .80, and a strong correlation between variables ($r = .70$). This power analysis showed that a total sample of 135 participants would be required.

Three different schools were involved in this study and a total sample of 150 children participated. The distribution of the participants across conditions was the following: eight participants were involved in the pilot testing, 43 were allocated in the program condition, 43 in the design condition, and 56 in the control condition. To avoid bias, each study condition was performed in a different school. Three participants were removed from the analyses: one because they had a diagnose of a developmental disorder, although they were involved in the experimental activities to avoid feelings of exclusion; and two participants because they have not responded to the outcome measures in the post-test. These three participants and those involved in the pilot testing were not included in the main analysis for this study.

A detailed description containing the demographics for each group is presented in Table 1. This table includes the distribution of children by condition, taking into account their gender, age, and grade. We used the grading system for Portuguese schools in which children are evaluated at the end of the semester with Poor, Moderate/Good, and Very Good/Excellent.

3.2 Measures

We used the Test for Creative Thinking–Drawing Production (TCT-DP) to measure creativity at pre- and post-test levels using Forms A and B. TCT-DP is a well-established test in the field of creativity, applied to persons of a broad age range, including children; it is culture-fair and helps to identify high creative potentials as well as low levels of creative, neglected, and poorly developed ones [17, 18, 40]. This test has been validated for the Portuguese adult population [2] and normative values were calculated for the young population [16].

The TCT-DP test consists of a sheet of paper with six graphic elements of a circle, a dot, a dashed line, a 90-degree angle, a curved line, and a small open square, that are placed at fixed and

Table 1: Sample demographics, including gender, age, and grade distribution across conditions.

	Total (N=140)	Program condition (N=41)	Design condition (N=43)	Control condition (N=56)	Tests
Gender	75F, 73M	18F, 23M	22F, 21M	32F, 24M	X22(2, N=140)=1.66, $p = .435$
Female	75	18	22	32	
Male	73	23	21	24	
Age (M, SD; Min–Max)	7.89, 1.51; 6 – 10	7.63, 1.34; 6 – 10	7.87, 1.26; 6 – 10	8.05, .80; 7 – 9	$F(2, 133)$=1.661, $p = .194$
Grade					X22(2, N=140)=31.85, $p < .001$
Moderate/Good	86	12	26	48	
Very Good/ Excellent	54	29	17	8	

Table 2: Personality dimensions according to the Big Five Model of Personality (left column). Adaptation of the terminology for children (right column.

Personality dimensions (and opposing poles)	Adaptation of terminology for children
Neuroticism (vs. Emotional stability)	Not used in this study
Extraversion (vs. Introversion)	Social (vs. Shy)
Openness (vs. Closedness to experience)	Imaginative (vs. Flat)
Agreeableness (vs. Antagonism)	Kind (vs. Grumpy)
Conscientiousness (vs. Lack of direction)	Not used in this study

Figure 1: *Left:* Close up on the Dash robot used in the program condition. *Right:* Children using a tablet with Scratch programming language to program the Dash robot.

pre-established locations on the page. All of the elements, except for the small open square, are enclosed in a large rectangular frame, and this forms a short of an incomplete drawing. The locations of the graphic elements are mirrored in Form B compared to Form A. Participants are instructed to *"complete the drawing that an artist started but has not finished"*. Collected drawings were coded according to a 14-point scoring system explained below [41].

- *Continuations (CN)* — Number of graphic elements used among the initial elements proposed;
- *Completions (CM)* — Number of graphic elements used in a meaningful way;
- *New Elements (NE)* — Number of new items added to the composition;
- *Connections with lines (CL)* — Number of contacts established between the initial graphic elements;
- *Connections made that contribute to a theme (CTH)* — Degree to which the elements were connected thematically;
- *Boundary-breaking being fragment-dependent (BFD)* — Use of the element outside the frame;
- *Boundary-breaking being fragment-independent (BFI)* — Use of added elements outside the frame;
- *Perspective (PE)* — Use of three-dimensional drawing techniques;
- *Humor, affectivity/emotionality/expressive power of the drawing (HU)* — Creation of a humorist or emotional atmosphere;
- *Unconventionality A (UCA)* — Unconventional manipulation of the paper;
- *Unconventionality B (UCB)* — Use of abstract, surrealistic, fictional and/or symbolic themes;
- *Unconventionality C (UCC)* — Use of words, numbers, and/or cartoon-like elements;

Figure 2: *Left:* Paper prototypes of robots used in the design condition were made using origami techniques and each cube was built with a mechanism that integrates a crayon inside so that children could represent the movements of the robot by drawing them in large paper sheets. We embed a crayon in one of the cube faces was a design methodology that motivated children to represent the robot's movements in a 2D space, avoiding movements in a 3D plane (such as flying and jumping) as real robots are not able to do so. *Right:* Example of a trajectory performed by a child.

- *Unconventionality D (UCD)* — Non-stereotypical utilization of fragments of figures;
- *Speed (SP)* — Time for completion of the drawing. Speed response time is recorded; this was not possible for this sample because it was administered to a large group at one time. This procedure occurred in previous application of the TCT-DP, including applications made by the developers of this scale, suggesting that speed might not be a required variable to assess creative potential using TCT-DP [10].

We started by exploring the presence of extreme values at baseline (pre-test values of TCT-DP). Results showed no extreme value and thus, no presence of outliers. TCT-DP test was also analyzed taking into account the two dimensions of *Adaptiveness* and *Innovativeness*, which refer to two different ways of thinking [29]. Adaptiveness refers to conventional ways of thinking (and includes the fragments Continuations, Completions, Connecting Fragments, and Searching for a Theme), while Innovativeness refers to unconventional ways of thinking (and includes the remaining fragments). Internal consistency of Adaptiveness and Innovativeness revealed to be acceptable (α = .80 and .78, respectively). Internal consistency was also calculated at the pre- and post-test. We performed two ANOVAs, instead of one Multivariate Analysis of Variance (MANOVA), because Adaptiveness and Innovativeness are strongly correlated at pretest, $r(140) = .63, p < .001$.

Two coders independently coded 30% of the data to establish an inter-coder agreement, and this data was selected randomly by using Randomizer [1]. Coders were blinded to the study condition. Cohen's k was run to determine the level of agreement, showing a strong agreement on Adaptiveness at both pre-test, $k = .89$(95% CI, 1.03, −0.75), $p < .001$, and post-test, $k = .85$(95% CI, 1.01, −.69), $p < .001$. There was agreement on Innovativeness at pre-test, $k = .617$(95% CI, .82, −0.41), $p < .001$, and a fair to good agreement at post-test, $k = .329$(95% CI, .53, −.11), $p < .001$ [3, 22].

3.3 Procedure

Participants whose parents had signed the consent form to participate in this study were invited to fill in a brief sociodemographic questionnaire that contained a question about their age and gender. Note that the grades of children, also collected in the scope of this study, were provided by the schoolteachers at the end of the study. Afterward, the TCT-DP Form A was handed to children. We initiated the intervention when all children filled in the test.

Children included in the *experimental condition of programming a robot* had the main task of learning to use Scratch language [32] to give commands to the Dash and Dot robots[2] (see Figure 1). Children worked in small groups of 3 – 4 and were instructed to program a mail-delivery robot. This task consisted of writing lines of code to make the robot go from point A to point B, which were pre-defined in locations of the classroom floor (see Figure 1). By working in groups, they used the iPads to program the robot and improved their program as they observed the robot performing the movements on the floor. Children developed knowledge of geometric and mathematics since they had to make the robot turn (and thus, understand angles and distances). The activity lasted 45min and is a typical STEM task included in schools.

Children included in the *experimental condition of designing a robot* were instructed to think about different personalities for the robot, without needing to program the robot. Personality traits were included in the instructions for this condition as they provide a starting point for children to perform design explorations, being open-ended and allowing space for creativity to emerge. The experimenter instructed children on the different personality traits they would design in a robot.

To develop a personality for a robot, we relied on the Big Five Model of Personality, also entitled as the Five Factor Model developed by McCrae and Costa (1997) [27], and on the correspondent NEO Personality Inventory Revised (NEO PI-R). In this model, personality is described according to five factors (Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness to experience), each of these factors is a continuum with an opposing pole [9] encompassing several traits. Thus, Extraversion corresponds to a dimension that includes traits such as sociable, talkative, assertive, energetic; Agreeableness relates with good-natured, cooperative, and trustful characteristics; Conscientiousness concerns a disposition for control, self-discipline, and responsible; Neuroticism includes traits such as nervous, unstable, and insecure; and Openness to experience with intellectual, imaginative, insightful, and curious traits [19]. The dimensions chosen for this activity with children were Extraversion and Agreeableness because they are the ones that are more related to the social facets of personality and, therefore, the ones that could be better captured in social interactions with a robot. Also, we also selected Openness to experience because it includes traits related to creativity and we aimed to explore how children designed for this trait. As this terminology is very unfamiliar to children and used more technically within psychology, we adapted the trait concepts by using adjectives that were understandable for children. Therefore, Social and Shy to represented Extraversion and Introversion, Kind and Grumpy represented Agreeableness and Antagonism, and Imaginative and Flat represented Openness and Closeness to experience, and (see Table 2). This was the terminology used with children. Children were then

[1]Randomizer website: https://www.random.org/

[2]Dash and Dot robots by Ardozia: https://ardozia.com/robots/

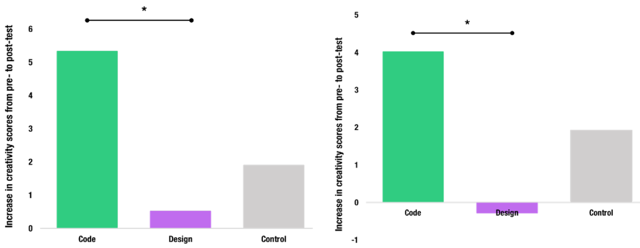

Figure 3: *Left:* Changes of TCT-DP global scores from baseline to post-intervention as a function of group condition, *p < .05. *Right:* Changes of TCT-DP innovativeness scores from baseline to post-intervention as a function of group condition, *p < .05.

assigned to produce movements for the personality dimensions using a low fidelity robot prototype in the form of a cube (see Figure 2). Children worked in small groups of 3 – 4 and were responsible for producing the movement for each personality trait together (see Figure 2). Therefore, they took turns using the paper-robot prototype, and by moving the robot according to the instructed personality trait, they were able to design behaviors for a social robot.

Children included in the *control condition* took a music class where they were invited to learn a new song and sing it. Additionally, children played instruments, such as the flute, and performed musical rhythms using their bodies as instruments. The control condition for this study consisted of a creative activity to provide a fair baseline to the other two experimental conditions. When the activities were finished, children were invited to complete Form B of the TCT-DP with a similar instruction as the one provided for Form A.

4 RESULTS

To compare the three group conditions (program, design, and control) on creativity (global, adaptiveness, and innovation) as a function of the phase (pre- and post-test), three independent two-way mixed analyses of variance (ANOVAs) 3 (groups: Program, Design, Control) X 2 (phase: pre-test, post-test) were conducted.

Results for the global TCT-DP test showed a main effect of the phase, $F(1, 137) = 11.89, p < .001, \eta p2 = .08$, indicating that creativity increased from the pre-test($M = 18.26, SE = 0.88$) to the post-test ($M = 20.92, SE = 0.86$). Additionally, the results showed a main effect of the group, $F(2, 137) = 7.91, p < .001, \eta p2 = .10$, indicating that participants in the control condition presented higher creativity scores ($M = 23.59, SE = 1.22$) than participants in the design condition ($M = 16.49, SE = 1.39$), $p < .001$, and in the program condition ($M = 18.68, SE = 1.43$), $p = .01$. No significant differences were found between the program and the design conditions, $p = .273$. Additionally, we compared the mean values of the TCT-DP test to the normative values for this population. As we can see by looking at Table 3, the values are in line with the norm for the Portuguese population [29] when we look at the pre- and post-tests.

Results also showed that the difference between groups was present at baseline, suggesting that the control group was already higher in creativity potential before the intervention. Moreover, the interaction between the group condition and phase, $F(1, 137) = .08, p = .049, \eta p2 = .04$, indicated that the statistically significant increase in post-test from baseline was only found for the program group, $F(1, 137) = 14.21, p < .001, \eta p2 = .09$. For the other groups, the scores after the intervention were relatively similar to the baseline, $ps > .05$. Given the imbalance between groups in the creativity scores at pre-test, an additional one-way ANOVA was conducted to adjust for this baseline difference, by using a change score between the post- and the pre-test scores (higher scores correspond to higher increase from baseline). The overall results of the one-way ANOVA was significant, $F(2, 137) = 3.08, p = .049, \eta p2 = .04$. The comparison between each level revealed that the creativity increase in the program group was significantly higher ($\Delta M = 5.32; \Delta SE = 1.41$) than the increase in the design group ($\Delta M = 0.51; \Delta SE = 1.38$), $t(137) = 2.44, p = .016$, but no statistical differences were found between these groups and the control condition ($\Delta M = 2.14; \Delta SE = 1.21$), $ps > .05$ (see Figure 3 on the left).

To better understand this decrease, we computed the means for each item of the TCT-DP considering the change in the scores between the pre- and post-tests. Results showed that the design group decreased creativity performance compared to baseline on the items CTH, PE, HU, and UCD and maintained the performance on the UCC item; the program group decreased creativity performance only on the HU item and maintained the performance on the BFI item; while the control group decreased creativity performance on the CM, UCB, and UCD items (see Figure 4 for a visual on these means).

The ANOVA 3 X 2 results for Adaptiveness showed a main effect of phase, indicating an increase in the Adaptiveness scores from pre-test ($M = 8.85, SE = 0.39$) to the post-tests ($M = 9.70, SE = 0.42$), $F(1, 137) = 5.52, p = .02, \eta p2 = .04$ for the global sample. Again, we found higher scores in the post-test on Adaptiveness in the control group compared to the other two groups. However, because these results were also found at baseline, we adjusted for this baseline imbalance, by using a change score between the post from the pre-test scores and running an additional one-way ANOVA. The results from this analysis revealed that the three groups were relatively similar in the increase in Adaptiveness after the intervention, $F(2, 137) = 0.48, p = .621, \eta p2 = .01$ (see Table 4).

Regarding Innovativeness, results also showed an increase from the pre-test ($M = 9.41, SE = 0.62$) to the post-test ($M = 11.28, SE = 0.63$), $F(1, 137) = 11.28, p = .001, \eta p2 = .08$ for the global sample. The interaction between phase and group showed a significant increase from baseline in both the control, $F(1, 137) = 4.60, p = .034, \eta p2 = .03$, and the program conditions, $F(1, 137) = 15.53, p < .001, \eta p2 = .10$. Similar to the results on Adaptiveness, we found higher baseline scores on creativity in the control group compared to the other two groups. Thus, we adjusted for this imbalance by using a change score between the post from the pre-test. An additional one-way ANOVA using this change score in creativity levels revealed differences between conditions, $F(2, 137) = 4.55, p = .012, \eta p2 = .06$, and in particular between the program group ($\Delta M = 4.02; \Delta SE = 1.02$) and the design group ($\Delta M =$

Table 3: Values of TCT-DP according to study conditions at the pre- and post-test, compared to normative values for the Portuguese population [29].

	Program	Design	Control	Normative values 7-8 years old	Normative values 8-9 years old
TCT-DP pre-test (M, SD)	16.05, 9.68	16.23, 9.16	22.36, 11.66	23.3, 9.90	18.4, 8.00
TCT-DP post-test (M, SD)	21.39, 9.01	16.74, 9.05	25.14, 11.60	23.3, 9.90	18.4, 8.00

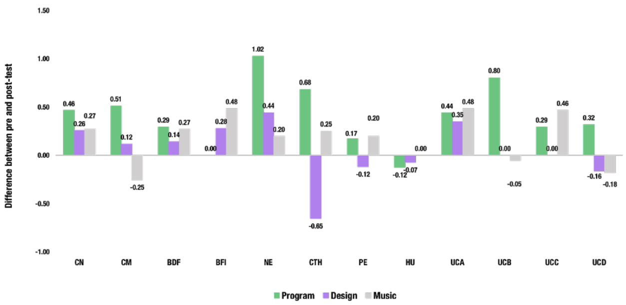

Figure 4: Difference between pre- and post-testing for each TCT-DP item. Items detail: CN - Continuations, CM - Completions, BFD - Boundary breaking being fragment dependent, BFI - Boundary breaking being fragment independent, NE - New elements, CTH - Connections made that contribute to a theme, PE - Perspective, HU - Humor, UCA - Unconventional manipulations, UCB - Symbolic, abstract, fictional, UCC - Symbol-figure combinations, UCD - Non-stereotypical utilization of fragments/figures.

$-0.28; \Delta SE = 1.00$), $t(137) = 3.02, p = .003$. No statistical differences were found between these two groups and the control condition ($\Delta M = 1.88; \Delta SE = 0.87$), $ps > .05$ (see Figure 3 on the right).

5 DISCUSSION AND CONCLUSION

The main aim of this study was to examine if creativity increased when children performed STEM activities using robots (designing and programming robots) compared to an artistic music class. Children's creativity was measured using the TCT-DP test, which measures the total score of graphic-figural creativity and additional two dimensions of creative thought: Adaptiveness (related to conventional thinking) and Innovativeness (related to non-conventional thinking). Results were analyzed taking into account the global score of TCT-DP, each dimension, and individual TCT-DP items.

Regarding the global score of creativity, results showed an increase from pre- to post-test in all conditions for the global sample. This result indicated a positive effect of interventions on rising creativity levels of children. By comparing our results with the normative values for this test in the Portuguese population, we can see that the values for all of our study conditions are somewhat aligned with the normative scores.

Results also showed that children in the control condition already had higher scores of creativity at the baseline level. After controlling for this unbalance by analyzing change scores, the results indicated that the increase in creativity was significantly higher in the program condition compared to the design condition. This means that being involved in STEM activities that involve programming robots increased children's creativity levels related to unconventional thinking which is important, since learning how to program have been massively incorporated in schools as part of their curriculum with the main aim of teaching children new ways to interact with technology. Our results thus suggest that such activities potentiate creativity levels in children, which can be considered a positive side effect of STEM.

When considering the two creativity dimensions of TCT-DP, Adaptiveness and Innovativeness, results showed that both Adaptiveness and Innovativeness increased from pre- to post-test, demonstrating that these two dimensions of creativity were stimulated in all groups. When considering the interaction effect of the groups and phase on Innovativeness, results showed a significant increase in control and programming conditions. However, the effect size for the programming condition appeared as higher than the effect size of the control condition. This seems to show a high magnitude effect of programming robots have on children's creativity. Moreover, since the control condition had higher creativity scores for both dimensions at baseline, we again performed an analysis considering the variance of scores. Results showed a higher variance of scores in the programming condition compared to the design condition for the Innovativeness dimension. No significant difference was found for Adaptiveness. Therefore, the main gain in global creativity scores seems to be led by a gain in the Innovativeness dimension. We recall that Innovativeness is related to breaking limits, having humor, and the ability to think in perspective, contrasting with Adaptiveness that is related to conventional thinking and manipulations [29].

It is thus interesting to see that programming robots stimulate Innovativeness in children. We associate this result to the nature of the programming task, in which children had to experiment by trial and error multiple ways of completing the programming activities, which in turn stimulated aspects of non-conventional thinking. Despite the programming condition having higher creativity scores than control, this difference was not deemed significant. This seems to show that despite no difference was found, creativity levels were still high. Therefore, being involved in art-related activities (control condition) continues to be an effective way to potentiate creativity in children. This result was foreseen for the

Table 4: Mean values of TCT-DP dimensions adaptiveness and innovativeness across groups.

	Program	Design	Control
TCT-DP Adaptiveness pre-test (M, SD)	7.78, 4.48	7.86, 3.88	10.91, 5.15
TCT-DP Adaptiveness post-test (M, SD)	9.07, 4.17	8.65, 4.24	11.36, 5.78
TCT-DP innovativeness pre-test (M, SD)	8.24, 6.77	8.37, 6.77	11.61, 7.99
TCT-DP Innovativeness post-test (M, SD)	12.27, 7.48	8.09, 6.47	13.48, 7.98

control condition, making it a fair benchmark comparison to the experimental conditions.

In conclusion, our study seems to show that STEM activities with robots have the potential to stimulate non-conventional ways of thinking in children, which is similar to the impact of creative activities, such as a music class. This means that STEM activities with robots can have benefits in different cognitive abilities of children that go beyond learning about curricular topics (such as geometry and math), to nurture creative thought. Therefore, this study demonstrated the potential of using robots to unlock creative potentials in children, which is aligned with several research trends in the field of creativity and robots [1, 4, 5].

5.1 Limitations and future directions

This study had some limitations that we would acknowledge. The first concerns the use of a quasi-experimental design study, as each condition was conducted at a different school. The reasoning behind this choice concerned the ethical guidelines towards children when different interventions are involved (e.g., to avoid children that are included in the control condition to feel disappointed if they learn that their colleagues were involved in an experimental condition that is perceived as more interesting) [24]. Although we have tried to control children's variables, namely age, gender, and grades, there are might be differences between schools, such as the school culture, that could have influenced the results. Nevertheless, all the involved schools were private schools from the region of Lisbon and were comparable in terms of size (i.e., number of classes per school year, similar number of children in each class) and tuition (i.e., similarly priced schools). There was also an association between condition and grade which is important to be counter-balanced in future studies.

Another limitation is related to the nature of the activities between the experimental and control conditions. Children were organized in small groups in the experimental conditions, however, the control condition was performed in the context of a music class (thus, including the classroom as a whole and not divided into smaller groups). As group effects are extensively documented in the literature (e.g., [20]), large differences in group size as the one present in our study, might have affected the results. Along with the control condition not being a group activity, it was also not an embodied-making activity. For further studies, we suggest changing the control condition to a group-based "making" activity, such as crafts, sculpting, painting, etc. Our control condition was a highly creative stimulating condition for children and worked more as a comparison condition than a control.

An additional limitation is that children in the experimental condition of programming robots had prior experience with the robots, which was not the case for children in the experimental condition that designed a robot. The level of familiarity could have influenced the results.

In light of the results found in the limitations of this study, we would like to propose that future studies take into account additional demographic variables of children to ensure comparable results, as well as account for the control of variables such as familiarity with STEM tools. In addition, an extra study condition in which children are not involved in any activity (which would be a "real" control) could provide additional insights into this line of research.

As a take-home message, our study showed that STEM activities with robots impact the creative potential of children, which was never been studied before. Particularly, activities with robots impact children's unconventional thinking, an important part of creative thought. In sum, this study shows the potential of using robots to nurture creativity.

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REFERENCES

[1] Safinah Ali, Tyler Moroso, and Cynthia Breazeal. 2019. Can children learn creativity from a social robot? In *Proceedings of the 2019 on Creativity and Cognition*. 359–368.
[2] Leonor Almeida and Sara Ibérico Nogueira. 2010. Estudo preliminar do teste test for creative thinking-drawing production (tct-dp). *Psychologica* 52-I (2010), 193–210.
[3] Douglas G Altman. 1990. *Practical statistics for medical research.* CRC press.
[4] Patrícia Alves-Oliveira, Patrícia Arriaga, Matthew A Cronin, and Ana Paiva. 2020. Creativity encounters between children and robots. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*. 379–388.
[5] Patrícia Alves-Oliveira, Patrícia Arriaga, Ana Paiva, and Guy Hoffman. 2021. Children as Robot Designers. In *Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*. 399–408.
[6] Katherine D Arbuthnott and Glenn C Sutter. 2019. Songwriting for nature: increasing nature connection and well-being through musical creativity. *Environmental Education Research* 25, 9 (2019), 1300–1318.
[7] European Comission. 2018. *Council Recommendation on Key Competences for Lifelong Learning.* https://ec.europa.eu/education/education-in-the-eu/council-recommendation-on-key-competences-for-lifelong-learning_en

[8] Cathérine Conradty and Franz X Bogner. 2018. From STEM to STEAM: How to monitor creativity. *Creativity Research Journal* 30, 3 (2018), 233–240.
[9] Paul T Costa and Robert R McCrae. 2010. NEO-PI-3. *London: Sigma Assessment Systems* (2010).
[10] Stephen J Dollinger, Klaus K Urban, and Troy A James. 2004. Creativity and openness: Further validation of two creative product measures. *Creativity Research Journal* 16, 1 (2004), 35–47.
[11] Chip Donohue. 2014. *Technology and digital media in the early years: Tools for teaching and learning*. Routledge.
[12] Franz Faul, Edgar Erdfelder, Albert-Georg Lang, and Axel Buchner. 2007. G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior research methods* 39, 2 (2007), 175–191.
[13] Andrea Gomoll, Cindy E Hmelo-Silver, Selma Šabanović, and Matthew Francisco. 2016. Dragons, ladybugs, and softballs: Girls' STEM engagement with human-centered robotics. *Journal of Science Education and Technology* 25, 6 (2016), 899–914.
[14] Mackenzie Harms, Victoria L Kennel, and Roni Reiter-Palmon. 2017. Team creativity: Cognitive processes underlying problem solving. In *Team creativity and innovation*. Oxford University Press, 61–86.
[15] María-Blanca Ibáñez and Carlos Delgado-Kloos. 2018. Augmented reality for STEM learning: A systematic review. *Computers & Education* 123 (2018), 109–123.
[16] S Ibérico Nogueira, L Almeida, and TS Lima. 2017. Factorial invariance across gender in the Portuguese version for the Test for Creative Thinking-Drawing Production. In *15th ICIE International Conference on Excellence, Innovation, & Creativity in Basic-Higher Education & Psychology Latest Development in Research & Practices Faculty of Psychology–University of Lisbon, Portugal.*
[17] Hans G Jellen and Klaus K Urban. 1986. The TCT-DP (test for creative thinking-drawing production): an instrument that can be applied to most age and ability groups. *Creative Child & Adult Quarterly* (1986).
[18] Hans G Jellen and Klaus K Urban. 1989. Assessing creative potential world-wide: the first cross-cultural application of the test for creative thinking—drawing production (TCT-DP). *Gifted Education International* 6, 2 (1989), 78–86.
[19] Oliver P John, Sanjay Srivastava, et al. 1999. *The Big-Five trait taxonomy: History, measurement, and theoretical perspectives*. Vol. 2. University of California Berkeley.
[20] Steven J Karau and Jason W Hart. 1998. Group cohesiveness and social loafing: Effects of a social interaction manipulation on individual motivation within groups. *Group Dynamics: Theory, Research, and Practice* 2, 3 (1998), 185.
[21] Dimitra Kokotsaki. 2016. Engagement and Creativity in Music Education. *Trends in Music Information Seeking, Behavior, and Retrieval for Creativity* (2016), 295–309.
[22] J Richard Landis and Gary G Koch. 1977. The measurement of observer agreement for categorical data. *biometrics* (1977), 159–174.
[23] Pirkko Liikanen. 1975. Increasing creativity through art education among pre-school children. *Jyväskylä Studies in Education, Psychology & Social Research* (1975).
[24] Maria Lohan, Áine Aventin, Lisa Maguire, Rhonda Curran, Clíona McDowell, Ashley Agus, Cam Donaldson, Mike Clarke, Mark Linden, Carmel Kelly, et al. 2017. Increasing boys' and girls' intentions to avoid teenage pregnancy: a cluster randomised controlled feasibility trial of an interactive video drama-based intervention in post-primary schools in Northern Ireland. (2017).
[25] Allan Martin. 2005. DigEuLit–a European framework for digital literacy: a progress report. *Journal of eLiteracy* 2, 2 (2005), 130–136.
[26] Maja J Mataric, Nathan P Koenig, and David Feil-Seifer. 2007. Materials for Enabling Hands-On Robotics and STEM Education.. In *AAAI spring symposium: Semantic scientific knowledge integration*. 99–102.
[27] Robert R McCrae and Paul T Costa Jr. 1997. Personality trait structure as a human universal. *American psychologist* 52, 5 (1997), 509.
[28] C Page Moreau and Marit Gundersen Engeset. 2016. The downstream consequences of problem-solving mindsets: How playing with LEGO influences creativity. *Journal of Marketing Research* 53, 1 (2016), 18–30.
[29] Sara Ibérico Nogueira, Leonor S Almeida, and Tiago Souza Lima. 2017. Two tracks of thought: A structural model of the test for creative thinking-drawing production (tct-dp). *Creativity Research Journal* 29, 2 (2017), 206–211.
[30] Seymour Papert. 1999. What is Logo? Who needs it. *Logo philosophy and implementation* (1999), 4–16.
[31] Seymour A Papert. 2020. *Mindstorms: Children, computers, and powerful ideas*. Basic books.
[32] Mitchel Resnick, John Maloney, Andrés Monroy-Hernández, Natalie Rusk, Evelyn Eastmond, Karen Brennan, Amon Millner, Eric Rosenbaum, Jay Silver, Brian Silverman, et al. 2009. Scratch: programming for all. *Commun. ACM* 52, 11 (2009), 60–67.
[33] Mitchel Resnick, Fred Martin, Randy Sargent, and Brian Silverman. 1996. Programmable bricks: Toys to think with. *IBM Systems journal* 35, 3.4 (1996), 443–452.
[34] Simone M Ritter and Sam Ferguson. 2017. Happy creativity: Listening to happy music facilitates divergent thinking. *PloS one* 12, 9 (2017), e0182210.
[35] Kimiko Ryokai, Michael Jongseon Lee, and Jonathan Micah Breitbart. 2009. Children's storytelling and programming with robotic characters. In *Proceedings of the seventh ACM conference on Creativity and cognition*. 19–28.
[36] Gabriela Sá, Cristina Sylla, Vítor Martins, Ana Caruso, and Douglas Menegazzi. 2019. Multiculturalism and Creativity in Storytelling-Visual Development of a Digital Manipulative for Young Children. In *Proceedings of the 2019 on Creativity and Cognition*. 369–381.
[37] Natalie Sarrazin. 2016. Children's Musical Play: Musicality and Creativity. *Music and the Child* (2016).
[38] Cynthia J Solomon and Seymour Papert. 1976. A case study of a young child doing Turtle Graphics in LOGO. In *Proceedings of the June 7-10, 1976, national computer conference and exposition*. 1049–1056.
[39] Paul T Sowden, Lucie Clements, Chrishelle Redlich, and Carine Lewis. 2015. Improvisation facilitates divergent thinking and creativity: Realizing a benefit of primary school arts education. *Psychology of Aesthetics, Creativity, and the Arts* 9, 2 (2015), 128.
[40] Klaus K Urban. 2005. Assessing Creativity: The Test for Creative Thinking-Drawing Production (TCT-DP). *International Education Journal* 6, 2 (2005), 272–280.
[41] Klaus K Urban and HG Jellen. 1996. Manual of Test for Creative Thinking-Drawing Production (TCT-DP). *Amesterdam: Harcourt* (1996).

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