education sciences

Article

The Influence of Music Producing and Creativity on Computational Thinking in Primary School Children

Nardie Fanchamps [1,*], Emily Van Gool [2], Anna Folkertsma [3] and Kim De Meyst [4]

1 Faculty of Educational Sciences, Department of Technology Enhanced Learning & Innovations, Open University, 6419 AT Heerlen, The Netherlands
2 Faculty for Teacher Education, Department de Nieuwste Pabo, Fontys University of Applied Sciences, 5612 MA Eindhoven, The Netherlands; evangool57@gmail.com
3 BS De Hovenier, 6065 AJ Montfort, The Netherlands; annafolkertsma@swalmenroer.nl
4 Image-Line, 9000 BE Ghent, Belgium; kim@image-line.com
* Correspondence: nardie.fanchamps@ou.nl; Tel.: +31-6-539-67-133

Abstract: Computational thinking (CT) can be developed in a multitude of ways. Well-known examples are plugged-in and unplugged applications that focus primarily on the (combined) usage of visual, textual, or tangible modalities. Less obvious are applications where CT development can be established via an auditory modality, to which the importance of creativity is attributed. When reasoning from such a different contextual perspective, it is interesting to investigate whether the self-creation of electronic music influences CT development and what added value can be attributed to creativity. Therefore, a mixed-methods study was conducted on primary school pupils aged 10 to 13 using FL-Studio Mobile© music-producing software. Quantitative data were obtained using a pre-test–post-test assessment administered via a validated Computational Thinking Test (CTt). Qualitative data were obtained by conducting interviews to ascertain identifiable effects on CT sub-characteristics to determine the influence of creativity and creative thinking and children's perceptions in this regard. Our results indicate that applying music-making software has measurable effects on CT development, particularly with respect to invoking and using auditory modalities. Notable findings were identified on the CT sub-characteristics "loops", "conditionals", "functions", "nesting", and "CT tasks required". Our study shows that producing music using technology stimulates creativity, which seems to be an important parameter for CT development. Differences between girls and boys were observable. Further research on the interaction between CT and creativity, combining different modalities, is recommended.

Keywords: technology-enhanced learning; computational thinking; creativity; music producing; auditory modality

Citation: Fanchamps, N.; Van Gool, E.; Folkertsma, A.; De Meyst, K. The Influence of Music Producing and Creativity on Computational Thinking in Primary School Children. *Educ. Sci.* **2024**, *14*, 1380. https://doi.org/10.3390/educsci14121380

Academic Editors: Emily Relkin and María Zapata Cáceres

Received: 30 October 2024
Revised: 25 November 2024
Accepted: 6 December 2024
Published: 16 December 2024

1. Introduction

A wide variety of available plugged-in and unplugged approaches offer demonstrable opportunities for the development of computational thinking (CT). The utilization of and proceeds gained from such applications—by means of either technology-based programmable artifacts and environments, such as robotics, simulations, and serious games, or the use of concrete and tangible materials, such as board games or bodily experiences—have already proven their added value in this regard. When using such applications, the interventions to be performed and the subsequent determination of the effects of the programming actions occur mainly through visual perception via observation, reading text, or writing syntax or through physical, kinesthetic experience. Furthermore, stimulating creativity appears to be an important parameter in the development of CT. The definition of CT includes an interrelated set of skills (i.e., problem decomposition, algorithmic thinking, pattern recognition, debugging, parallelization, and abstraction) and practices needed to solve complex problems by applying concepts derived from computer science, a way of learning topics in many disciplines, and meet the requirements of fully participating in a computational world [1]. Furthermore, computational processes are a way of understanding natural and social phenomena and explaining and interpreting the world as an amalgamation of information processes [2]. The application of CT skills and the approaches through which they are developed appears to be of pre-eminent importance in other school subjects for developing problem-solving approaches [3].

Previous studies have indicated that creative thinking and acting can lead to extraordinary discoveries in the process of solving challenging problems and that the learning environment used can be conditional in this regard. Based on the aforementioned approach, clear evidence for interrelationships between CT and creativity [4] can be obtained by referring to the positive effects of creativity on CT development through the application of educational robotics [5,6]. However, unplugged creative activities also harvest strong potential regarding CT development [7]. Unplugged tasks might induce creativity when familiar approaches are extended with fresh, new ideas.

Unplugged activities for CT learning and programming can be defined as a means of learning to understand concepts derived from computer science without using digital technology [8,9]. Unplugged programming originates from the computer science unplugged (CSU) movement [10]. One of the principles of the CSU is engaging in learning activities that teach computer science thinking without using digital technology, making use of ad hoc available materials like puzzles, engaging board games, cards, string, crayons, markers, folding leaves, and other kinds of tangible materials or one's own body, but not computers, to express creativity [11]. Studies conducted by Rodriguez et al. [12] and Thies and Vahrenhold [13] that involved students showed that the learning revenue regarding CT gained through unplugged activities was at least as high as that from learning through the use of a digital approach. The results from research conducted by del Olmo-Muñoz et al. [9] and Brackmann et al. [14] show that students can learn CT skills via unplugged activities and that this way of unplugged learning is at least as effective as learning based on a computer-aided approach. The attractive feature of unplugged activities is often the contrast between the materials and the computer science concepts elaborated. This paves the way to explore multifaceted opportunities to facilitate CT development.

Creativity and creative thinking appear to be important factors for approaching and solving challenging problems. Creativity is primarily associated with art, music, writing, expression, and artistic and aesthetic endeavors [15–17], but it is also linked with the development of a new product that is judged to be innovative, appropriate, useful, or valuable [16,18,19]. Creative thinking encompasses the ability to come up with unique, original, and innovative solutions to problems and includes fostering insight, identifying interconnections between disparate ideas, divergent thinking, and the ability to reuse ideas [16,20–22]. Elaborating upon this perspective, previous research distinguishes between creative thinking and computational creativity; while creative thinking should be seen as the innovative process of solving challenging problems, computational creativity is characterized by the application of computer technology to mimic, study, stimulate, and enhance human creativity [23,24]. Moreover, creative thinking is an important aspect of critical thinking and includes a different perspective on CT [18]. When applying CT characteristics in problem solving, a certain level of creative thinking is required to conceive of and formulate the solutions devised. According to Mishra et al. [25], computing can be a creative activity because it engages cognition and thus unravels creativity, allowing the user to use technology to develop new applications, opportunities, and solutions. Creative thinking can be clearly distinguished from creativity. Sawyer et al. [17] define creativity as "*a new mental combination expressed in the world*" (pp. 3–15), while DeSchryver et al. [18] define creative thinking as "*cognitive activity consisting of different subsets of these component thinking skills mediated by the more aesthetic components of traditional creativity*" (p. 428).

An exploration of the literature reveals an obvious association between CT and auditory modality through music-making. Recently published research frequently addresses how the principles of CT can facilitate music-making itself via the application of technology, how musical notation systems can be taught via reconstructing algorithms, and in what ways musical skill can be enhanced via the transmission of CT skills from a meta-cognitive perspective [26,27]. Although previous studies indicate that there is a link between music-making and CT, in which combining self-producing music and programming into one activity enables an identifiable development of CT [28,29], a more specified line of thinking, that is, how producing electronic music via applying technology can facilitate CT development, has only been marginally explored [30]. However, it is precisely the underlying creative aspect of producing and making music through which developmentally appropriate opportunities occur via the need to be creative in order to solve problems and thus purposefully engage in CT development [31].

Considering the above, it would be valuable to determine whether less common approaches can also have a distinctive impact on the (further) development of CT. Therefore, we investigated whether addressing auditory modalities through the self-creation of electronic music using technology-enhanced music-producing software has an effect on CT development and what important influences therein can be attributed to creativity. To this end, an exploratory mixed-methods design study was conducted using 21 primary school students aged 10 to 13 in which CT proficiency was assessed using the validated Computational Thinking Test (CTt) [32]. To obtain more in-depth information, interviews were conducted after each session to gain insight into the extent to which creativity and creative thinking played a role. In general, we also explored whether there were characteristic differences between girls with boys. The selection of a mixed-methods design was motivated by the fact that by combining the elements of quantitative and qualitative research, a better and more complete understanding of the findings of the study could be established in order to answer the research question in more depth and detail based on a higher level of validity and allow generalization from all the findings [33].

2. Materials and Methods

This exploratory study was conducted using twenty-one primary school students aged 10–13 in the south of the Netherlands, focusing on the last cycle of primary education (grade 6). In six sessions lasting one hour each, the participating students worked together in dyads to independently produce an electronic dance music track (EDM) using the professional music-producing software FL Studio Mobile© (Figures 1 and 2). In each of these six sessions, an instructional part, a processing part, a self-designed part, an intermediate and final evaluation part, and an appreciation part were applied.

All the students first received basic instructions on how the music-producing software works, what functions were available via the different buttons, how music is arranged, the structure of an EDM music track (e.g., intro–break–build-up and drop–outro), how sound samples and instruments from the music library to be selected can be dragged into the worksheet, how to add effects to all music samples, etc. After all the basics were explored and mastered, the students were tasked with designing and creating their own EDM track, wherein they could independently make their own choices regarding rhythm, instruments, percussion, sound samples, vocals, effects, and volume settings. Based on their creative dispositions, the students could subsequently make their own choices and decide how they wanted to shape the EDM track further. The students were increasingly allowed to take their own initiatives and directions, each time asking to draw upon their own creativity to design parts of the music, with the final goal being a completely elaborated EDM track.

Prior to and after the practical music producing part, the students were administered the validated CT questionnaire (CTt) designed specifically for this target group (10–16-year-olds) to assess their proficiency in CT. The aim of the CTt is to assess one's developmental level regarding CT for a given subject. The operationalization of the construct to be measured included the ability to formulate and solve problems by relying on the fundamental concepts of computing and using the logic and syntax of programming languages. The CTt was administered through a multiple-choice-answer/alternatives-style design. For each question item, the answer alternatives could be presented in one of two styles: visual arrow blocks or visual Scratch-based programming graphics (Figures 3 and 4) [32]. Both styles are also common in popular environments for learning programming, such as Code.org [34]. In total, the CTt contains 28 items that relate to the various computational concepts involved, i.e., “basic direction” (28 items), “loops” (“repeat times”: 13 items, “repeat until”: 12 items), “conditionals” (“if—simple”: 6 items; “if/else—complex”: 4 items; “while”: 4 items), and “functions” (“simple functions”: 4 items; “functions with parameters”: 0 items). The existence or nonexistence of “nesting” could be derived (19 items). The computational task required (“completion”: 9 items; “debugging”: 5 items; “sequencing”: 14 items) providing the right solution for each of the 28 questionnaire items could be inferred. Afterwards, all the data obtained from this CTt questionnaire survey were entered into SPSS version 29 for further data analysis, which allowed us to determine whether characteristic findings could be identified.

Figure 1. Students composing music.

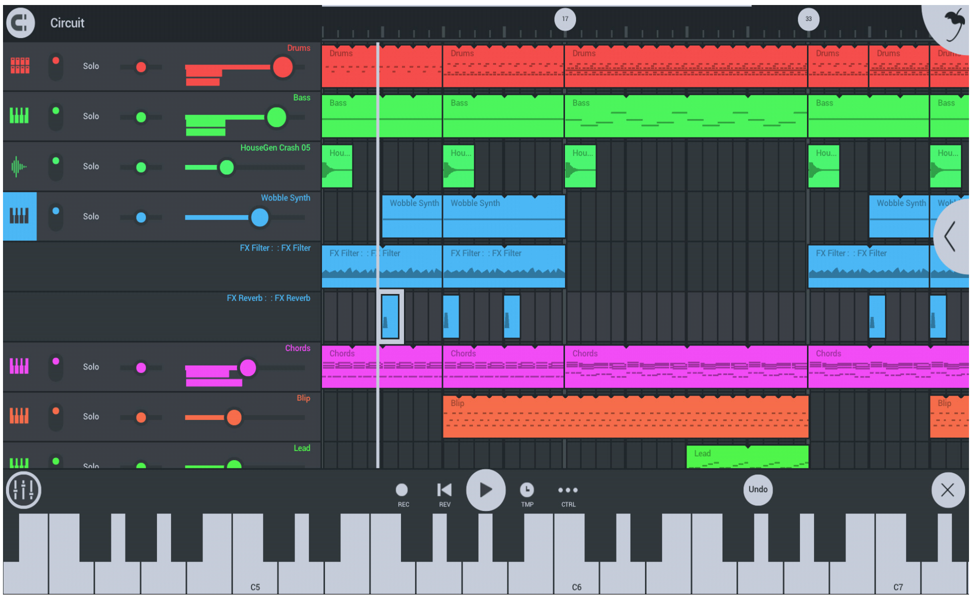

Figure 2. Impression FL-Studio Mobile© music-producing software (https://www.image-line.com/fl-studio-mobile/, accessed on 29 October 2024).

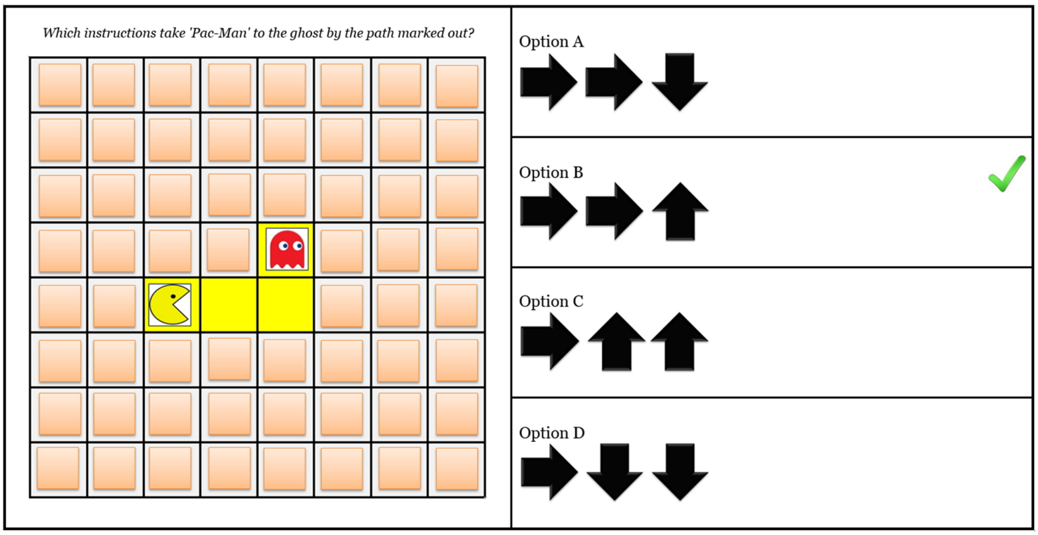

Figure 3. Example question: CTt questionnaire.

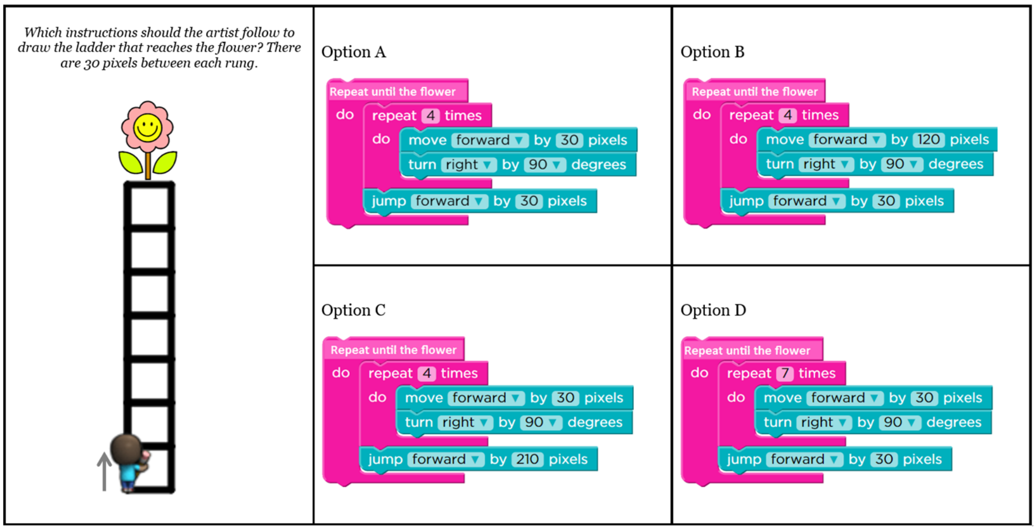

Figure 4. Example question: CTt questionnaire.

To determine the reliability of the scale, we calculated Cronbach's alpha. It should be noted that for Cronbach's alpha, a value of 0.80–0.90 is considered a good reliability factor [35]. The developers of the CTt indicate that for fifth- and sixth-graders (N = 176), Cronbach's alpha should be $\alpha = 0.721$ [32]. We measured a Cronbach's alpha value of $\alpha = 0.825$, thus complying with the required level of internal consistency for our scale with respect to our sample. This slightly higher value for Cronbach's alpha can be explained by the fact that the research sample size was smaller than the one the designers of the CTt used to validate the test. In addition, the age of the research population included in this study was toward the lower limit of the test, a factor that could have influenced the reliability calculated. Taking this into account, the CTt performed was as reported by the original authors, and the measurement results obtained were therefore used as such.

Regarding the connection between CT and creativity, we applied the same principles as formulated by Brennan et al. [36] in their 3D framework. In this framework, a relationship between CT, creativity, and creating is assumed through CT practices. In our study, in which technology-enhanced EDM music tracks were produced using digital technology, we focused on developing CT skills and incorporated the findings pertaining to a creative attitude. We grounded our study on studies by Doleck et al. [7] and Israel-Fishelson et al. [4], who demonstrated that creativity is strongly related to CT. We focused on perceptions of creativity through flexibility, analytical problem solving, entrepreneurship, perseverance, imagination, and collaboration [20]. Since the validated CTt questionnaire selected cannot be applied to investigate the relationship between CT and creativity, in addition to the quantitative data collected, qualitative data were also obtained regarding the importance of creativity and CT development. Therefore, we prepared a survey operationalized via semi-structured interviews conducted after each session (Appendix A)—consisting of 14 questions rated via a 3-point Likert scale ("not true, sometimes, and true"), including 3 open-ended questions—which was benchmarked with a focus group of educational subject matter experts prior to this study. Through applying this survey after each session, each student was questioned as to the extent to which he/she had a grasp of CT sub-characteristics, the extent to which creativity and creative thinking played a role, and their own perceptions in this regard. This questionnaire contained questions such as "Do you remember the arrangement you used in your work?"; "Were you able to understand and organize the information you were given?"; "Were you able to find and also resolve/debug errors?"; "Did you use repetition to remix?"; and "In what ways were you creative? Where does that show?". Based on the survey data obtained, we conducted an analysis, which reflected more detail on the development of the students, in addition to a quantitative analysis of the CTt questionnaire.

Furthermore, in addition to the questionnaire and survey administered, free observations were carried out during each session, in which behavior upon approach, the level of cooperation between students, and other remarkable perceptions were recorded. In addition, all music creations produced by the students were studied to further explore the students' expressions of creativity. Figure 5 displays the research design.

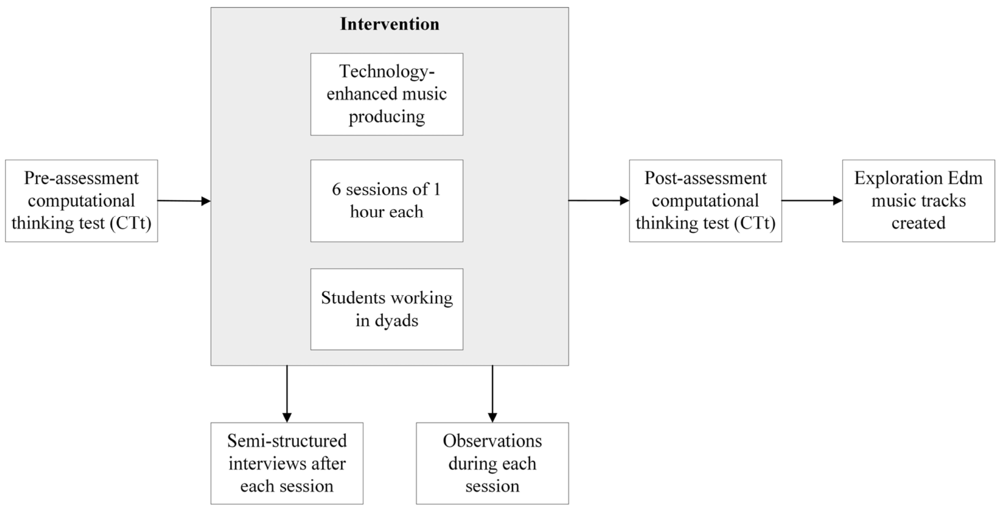

Figure 5. Research design.

3. Results

First, based on the chosen conceptual approach, all the students were more than capable of independently designing and producing an EDM dance track using their own creative approach and from their own design perspective. Due to the structured design and utilization framework, each student managed to understand and apply all the necessary components of the music-producing software FL Studio Mobile©. The graphically oriented interface within this music-producing software seamlessly guided the students through the process, with the related choices made by the students themselves. The processes of drawing up chords; designing a catchy melody; selecting their own music fragments, samples, and instruments; assigning them to the mixer; arranging all elements into the playlist; and then building the track in layers all went well. Adding markers to build and structure the music track also made the process feasible and manageable. All the students managed to design and arrange a full EDM track in six sessions. As a result, the musical results are all different, extraordinary, special, and appealing.

Second, regarding a determinable development in CT, an analysis of the data obtained from the validated CTt questionnaire (Table 1) shows that the students scored better on all the measured characteristics in the post-test in comparison with the pre-test.

Table 1. Results of the analysis of the CTt questionnaire.

Variables	Pre-Test		Post-Test	
	M	SD	M	SD
Basic Directions (28)	0.51	0.122	0.64	0.106
Loops: repeat times	0.47	0.143	0.67	0.127
Loops: repeat until	0.44	0.129	0.52	0.151
Loops: combined	0.45	0.115	0.60	0.113
Conditionals: if/simple	0.30	0.202	0.40	0.179
Conditionals: if–else	0.45	0.292	0.43	0.287
Conditionals: while	0.32	0.211	0.41	0.216
Conditionals: combined	0.36	0.167	0.41	0.167
Functions	0.42	0.329	0.75	0.262
Nesting	0.37	0.137	0.51	0.131
CT-skill: completion	0.48	0.184	0.66	0.119
CT-skill: debugging	0.60	0.210	0.71	0.196
CT-skill: sequencing	0.50	0.133	0.60	0.146

Note: Variable = established value; basic directions = number of questions on the CTt questionnaire answered correctly; loops, conditionals, and functions = established computational thinking concepts addressed; nesting = whether an item solution involves a script with nesting computational concepts; CT-skill completion = completion of an incomplete given set of commands; CT-skill debugging = debug an incorrect given set of commands; CT-skill sequencing = sequence, stating in an orderly manner, a set of commands; M = average; SD = standard deviation.

To determine which CT (sub)characteristics were significantly affected in a measurable manner by the intervention and what measurable effects could be attributed to it, a paired-sample *t*-test was performed (Table 2).

Table 2. Development of computational thinking.

Variables	Paired-Sample *t*-Test (n = 21)		
	t	*p*	*g*
Basic Directions (28)	−9.36	0.001 *	0.065
Loops: repeat times	−7.26	0.001 *	0.135
Loops: repeat until	−2.39	0.014 *	0.159
Loops: combined	−7.14	0.001 *	0.095
Conditionals: if/simple	−2.34	0.015 *	0.194
Conditionals: if–else	0.37	0.358	0.306
Conditionals: while	−1.50	0.074	0.264
Conditionals: combined	−1.67	0.055 *	0.147
Functions	−4.93	0.001 *	0.322
Nesting	−8.01	0.001 *	0.085
CT-skill: completion	−3.97	0.001 *	0.214
CT-skill: debugging	−2.34	0.015 *	0.233
CT-skill: sequencing	−3.75	0.001 *	0.125

Note: Variable = measurable value; basic directions = number of questions answered correctly on the CT questionnaire; computational concept addressed = loops, conditionals, functions, and nesting; completion = completed using CT; debugging = reformulating of problems; sequencing = sequence; M = mean value; t = t-value paired samples; p = p-value paired samples; g = effect size based on Hedges' g for different sample sizes; * = significant effect measured (≤0.05).

The results of the statistical analysis conducted show that significant differences were found for the full CTt questionnaire ("Basic Directions") as well as for the computational concepts addressed: (a) "loops—repeat times", "loops—repeat until", "loops—combined";

(b) "conditionals—if/simple"; (c) "simple functions"; (d) "nesting"; and (e) for the computational task required—"completion, debugging, and sequencing". From the data presented, by calculating Hedges' g, it can also be inferred that the intervention applied had a small (g = 0.2) to low-medium effect (g = 0.5) on the various sub-characteristics of CT.

Third, an independent *t*-test comparing girls (n = 12) with boys (n = 9) indicated significant differences with a small effect according to Cohen's d on the computational concept addressed for "loops—repeat until" (t(19) = 2.059, $p = 0.027$, and d = 0.14), "conditionals—while" (t(19) = 1.902, $p = 0.036$, and d = 0.22), and the computational task required for "debugging" (t(19) = 2.447, $p = 0.012$, and d = 0.18).

Fourth, further analysis of the administered survey asking questions regarding CT sub-characteristics ("problem (re)-formulation, data collection, data analysis, data visualization, problem decomposition, abstraction, algorithms and procedures, automation, simulation and modeling, and parallelization") revealed that, in general, as the number of sessions progressed, the scores for recognition ("true") increased and even doubled in total when comparing the first session with the last one. We noticed that the students applied the rating "sometimes" to the characteristic "problem decomposition" (breaking down a task into smaller orderly tasks) and the component "algorithms and procedures" (following a series of ordered steps to solve a problem) the most. Interestingly, the CT sub-characteristic "analyzing data" (logically arranging, analyzing, and understanding data) received high scores. In addition, the CT sub-characteristic "visualize data" (being able to use and process information) predominantly had the highest score among students in all meetings. Furthermore, the results show that during the experiment, the students started to recognize their own abilities more regarding the skills related to CT. The scores for "not true" decreased by 35% in total, while the scores for "true" increased by 8%, which substantiates and reflects this shift. Moreover, after the end of the first session, there was a certain unanimity in the recognition of skills related to CT. However, as the research progressed, we saw more dispersion in the responses, and the items "sometimes" and "not true" were chosen to a greater extent. In particular, the question related to "algorithms and procedures" increased by a staggering 85% from "not true" to "sometimes".

Fifth, in order to determine whether there were developments in creativity and creative thinking, the students were asked to answer three open-ended questions after each session. These questions were about (1) "The way students felt they had been creative", (2) "The perceived extent of collaboration", and (3) "Whether students could apply what they had learned to other subjects at school". On the extent of creativity experienced, students described this as having been inspired and said that they were satisfied with the result. Responses such as "*Yes, we were able to use new things to which I got creative*" or "*Yes, we have now created our own song by designing our own chords, beat and melody*" were recorded. Regarding how working in dyads and collaborating were perceived, the students said that their experience was very positive. The students provided statements like "*Yes, we could think of things together*" or "*Much nicer, because you have help from someone else*". The ability to make connections in order to apply what was learned in another teaching activity is more difficult for students to recognize and articulate. Some comments include "*Yes, in projects*" and "*I think so, but how I don't know exactly how*".

Sixth, similar statements were recorded in several observation reports. One observation report mentions that the students had an in-depth conversation about what choices to make and that they saved the composite EDM tracks when both students found them appealing. It was also clear that the students made substantive comments on draft sections of their tracks. Another observation reveals that the students were able to quickly pick up what they had learned completely independently, with the elaboration mentioning that the students autonomously referred to what they had performed the previous time. Determining whether applying what was learned from producing music could have an effect on other school subjects proved to be a difficult connection for students to make. The statements recorded included "*I can apply it in making music, I find it difficult to determine how and in which subject at school this helps me further, but I can apply it at home*". However, there were several responses that did make such a connection. These students formulated this as follows: "*I can apply it in discovering my own mistakes, and sometimes I can apply it in math in school*". All observation reports noted high levels of focus, concentration, perceived enjoyment of work, and optimal cooperation among students. Even when collaboration resulted in a discussion or strong disagreement, work continued mindfully. The findings in the observation reports reported students consulting together, having in-depth discussions, actively questioning and trying to convince each other of steps to take, arriving at a consensus on which music sample or melody to use or create, etc. The students also pointed out that they adopted an attentive attitude when explanations were given or when questions were answered. One observation report mentions that "*As the sessions progressed, the music tracks took on more substance and shape. Special findings emerged. In the process, students became somewhat more aware of what the other duos were producing and were somewhat eager to hear from each other their own tracks that they had created, but certainly also the tracks that other duos had designed*". Another meaningful comment made by students themselves and reflected in an observation report is particularly noteworthy: "*Maybe at the next session, we can figure it out all by ourselves and try it without any help*". "*Yes, but we still have to understand and learn it all by ourselves first*".

The seventh major finding concerns the differences observed between girls and boys. The population studied consisted of 12 girls and 9 boys. If we break down the results of the questionnaires by gender, we can see a significant shift in emphasis among girls as the study progresses. If we compare the total number of answers given between session 6 and session 1, we can see a 50% increase in the application of the rating "not true" to the different surveyed categories, while the frequency of the rating "true" decreased by 15%. A possible explanation is that in sessions 5 and 6, the students had significantly more confidence in performing tasks independently. For example, the students were asked to design their own music tracks and/or improve their own already-completed work. The data collected among boys showed an opposite trend. As more independence was required, boys rated their own development in CT skills after sessions 5 and 6 in increasing order. Their scores for the rating "true" increased by 31%, while the rating "not true" decreased by 93%. After the last session, boys collectively scored the highest for the rating "true". A possible explanation is that the boys became less critical, but their self-confidence in that which they had produced as music showed an upward trend. Upon examining the different characteristics regarding CT, we can see that 25% of the girls indicated that they had no difficulty with "analysis" and "automation", while 83% indicated that they had difficulty with "problem formulation", "data visualization", and "parallelization". Among the girls, the total scores indicated that 81% felt that the end result (their self-composed EDM music tracks) was good. The boys almost unanimously indicated that they had no difficulty with data visualization, abstraction, automation, parallelization, simulation, or modeling. With a score of 100%, they all wholeheartedly agreed that their end results (their self-composed EDM tracks) had turned out well. The unanimity of the results obtained among boys is remarkable.

Apart from all the data obtained from the survey and observations, the EDM tracks created were also examined more closely to obtain an indication of the level of creativity and uniqueness. What is striking to report is that all the EDM tracks differ in the choices selected, samples used, arrangement, and combinations made. Despite the fact that all the tracks follow the same build-up and design structure, they all have an originality and unique sound introduced by the students themselves. The students' ability to select and combine available samples and instruments by themselves certainly contributes to this, as does the facilitator's provision of space for the students' own choices and creative process.

4. Discussion

Our experimental research shows that applying less obvious learning environments can lead to an overall development in CT among primary school students. The deployment of technology-enhanced music-producing software revealed that enhancements in the computational concepts addressed, the detectability of nesting, and all the measured computational tasks that were required indicated a significant increase. It can be argued that this development can be unambiguously identified through the use of music-producing software as an intervention. The findings obtained are in line with the claims made by Baratè et al. [37] and Chong [28], who highlight the impact that making and producing music can have on developing CT from an early age. In this regard, composing music can provide a playful and creative background but also allow comprehension of and reinforce both the added value and limitations of purely analytical thinking processes [38]. After all, being able to analyze and fathom musical structures and put music samples in the correct key and pitch is mostly analytically oriented. However, the ability to freely design, compose, and create music based on variations and multiples of sounds and music samples that can be freely chosen from a library is actually enhanced by creativity and creative thinking [39]. The focus on the auditory modality points to interesting development opportunities in this respect [40]. Our choice of working with FL Studio Mobile© music-producing software made it possible to actively stimulate CT, creativity development, and creative thinking related to composing and making music. A comparable focus regarding the importance of creativity and creative thinking in CT activities can also be found in the studies conducted by Petrie [29], Fanchamps et al. [30], and Walzer [31] on how creative activities, through music composition using technology, promote more positive attitudes toward programming and thus have a clear effect on CT. Furthermore, our findings align with the research conducted by Israel-Fishelson et al. [4], who also found significant differences for both creativity constructs when comparing girls and boys, revealing that girls were significantly more creative than boys in terms of both creative thinking and computational creativity. However, too little is known regarding which combination of modalities is ideal for facilitating CT development via the application of technology-enhanced music-producing software and the use of related graphics utilization within this specific software for creative music composition [41]. Further research on this intersection between CT and creativity combining auditory and visual modalities is therefore recommended.

The setup and research design applied show that students can learn a lot from and with each other. This is evident from the high ratings the students gave regarding their levels of cooperation and from the observation reports. This assertion is supported by the findings of Baratè et al. [37], Bell et al. [8], and Ruthmann et al. [42], who noted that music coding activities with a focus on CT development are most optimal in a collaborative context, such as in a classroom. This claim can also be further substantiated by the research conducted by Sharma et al. [43] regarding the importance of designing highly collaborative and engaging coding activities for children to stimulate a positive learning attitude.

Interestingly, our research reveals identifiable differences between girls and boys with regard to CT development, the added value of collaboration, and variations in satisfaction regarding the quality of one's own work. These identifiable differences between girls and boys are also reflected in the research reported by Jiang et al. [44], Lee et al. [45], and Sun et al. [46], who found significant gender differences in tasks aimed at developing CT both in terms of accuracy and planning time. They reported that girls spent significantly more time planning tasks without achieving better performance, and girls were significantly less accurate in performing tasks than boys. The results obtained from our study are similar to those of previous studies conducted by Montuori et al. [47] and Sullivan et al. [48], who indicated that gender differences in programming can emerge at an early age but do not appear to be mediated by differences in cognitive skills. One possible interpretation of the gender differences observed in our study is that the girls and boys may have developed different levels of self-confidence in or beliefs regarding making music or programming from an early age as a result of their previous experiences. In addition, the boys might have been more motivated by interpreting the composition of an EDM music track as a competition. Moreover, our research regarding the added value of collaborating on CT activities reveals findings that are in line with the studies by Kong et al. [49] and

Lai et al. [50], who reported that a collaborative learning approach in CT may, over time, compensate for gender differences and different prior experiences and thus lead to equitable and equally achievable learning experiences. It is also argued that discussion and reflection on a specific task can help children develop an understanding that transcends what they can achieve on their own [51]. It is therefore likely that gender differences occur only in some dimensions of CT, partially depending on cognitive prerequisites. Therefore, further research on socio-pedagogical influences and gender differences is needed to confirm and extend all the findings presented in our study.

5. Conclusions

Our in-depth analysis based on studying and interpreting the findings obtained from the qualitative part of this research, obtained by conducting surveys combined with interviews after each session and drawing on observations, provides additional insights regarding the quantitative findings identified. Our findings indicate that an auditory modality can offer promising opportunities for promoting CT development. This approach, alongside more common approaches in CT intervention research involving frequent visual observations or by means of physical, kinesthetic experiences, allows possible effects on CT to be identified. The influences of creativity and creative thinking also appear to be important parameters in solving challenging problems related to the deployment of the CT skills required. In addition, this further exploration sheds more light on where explicit differences in approaches, applicability, understanding, awareness, conception, creativity, and the intended added value of working together arise. At the same time, it provides explanations regarding differential appreciation, disparities in the approaches used, and the extent of independence when comparing girls to boys for the (further) development of CT. The results presented pave the way for further research into the impact of auditory modalities on the development of CT, the degree to which this influence can be attributed to creativity and creative thinking, and the opportunities that technology-enhanced applications for music-making can offer in this regard.

Limitations and Further Directions

In addition to the findings addressed, several limitations and considerations can be identified regarding the results presented in this study. As a result, a certain lack of generalizability of the results obtained must be taken into account. Despite the sufficient number of respondents in this mixed-methods design study, for which a significant development in almost all CT sub-characteristics was demonstrated, we recommend increasing the number of respondents in follow-up research. In addition, the age categories among respondents can be further expanded. By considering both recommendations, we expect that even more impactful results can be obtained. It is also worth investigating whether other types of technology-enhanced music-producing software applications would generate the same yields or if a comparison to unplugged music-making using tangible instruments can generate the same yields. We also recommend exploring whether other types of modalities (feel, taste, smell, etc.) or a combination of these modalities can have further reinforcing effects on CT development. Furthermore, different results might have emerged if we had asked the girls and boys to work individually.

Author Contributions: Conceptualization, N.F. and E.V.G.; methodology, N.F. and E.V.G.; software, K.D.M.; validation, N.F., E.V.G. and A.F.; formal analysis, N.F. and E.V.G.; investigation, N.F., E.V.G. and A.F.; resources, K.D.M.; data curation, N.F. and E.V.G.; writing—original draft preparation N.F., E.V.G., A.F. and K.D.M.; writing—review and editing, N.F. and E.V.G.; visualization, N.F.; supervision, E.V.G.; project administration, N.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki approved by the Institutional Ethics Committee cETO of the Open University of the Netherlands (Ceto_RP102/U202302855) on 6 April 2023.

Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author since this research was conducted on minors, for which their parents gave consent.

Acknowledgments: We would like to thank the students and teachers at the primary school BS De Hovenier, Montfort, the Netherlands, for their cooperation. In addition, a special word of appreciation goes out to the Belgium-based music software company Image-Line Software Kim De Meyst for providing the digital audio workstation program FL Studio Mobile©.

Conflicts of Interest: Author Kim De Meyst is employed by the Image-Line. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix A

Attached as Table A1 is the qualitative survey operationalized by semi-structured interviews.

Table A1. Qualitative survey operationalized in semi-structured interviews used in this study.

Nr	Question	Not True	Sometimes	True
1	Did you know what you needed to do?			
2	Were you able to find all the data you needed?			
3	Were you able to understand and organize the information you were given?			
4	Did you get all the information about the material you got to use?			
5	Do you remember the ordering you used in your work?			
6	Did you get to the heart of what you wanted to learn?			
7	Did you see mistakes in your work?			
8	Did you use repetition to remix?			
9	Did you get the assignments completed?			
10	Did your final product turn out well?			
11	Were you able to find and fix errors?			
12	Open question: In what ways have you been creative? What showed that?			
13	Open ended question: How did working together go? What was it like doing this music project together with someone else?			
14	Open ended question: Can you apply what you learnt while working with music producing software in other subjects at school (and how?)?			

References

1. Wing, J.M. Computational Thinking. *Commun. ACM* **2006**, *49*, 33–35. [CrossRef]
2. Denning, P.J.; Tedre, M. *Computational Thinking*; MIT Press: Cambridge, MA, USA, 2019.
3. Van Bergen, S.; Fanchamps, N. The Impact of Robotic Programming Environments on Computational Thinking with an Effect on Word Reading Fluency and Decoding. In *Technology Enhanced Learning for Inclusive and Equitable Quality Education*; Ferreira Mello, R., Rummel, N., Jivet, I., Pishtari, G., Ruipérez Valiente, J.A., Eds.; EC-TEL 2024. Lecture Notes in Computer Science; Springer: Cham, Switzerand, 2024; Volume 15160. [CrossRef]

4. Israel-Fishelson, R.; Hershkovitz, A. Studying interrelations of computational thinking and creativity: A scoping review (2011–2020). *Comput. Educ.* **2022**, *176*, 104353. [CrossRef]
5. Chevalier, M.; Giang, C.; Piatti, A.; Mondada, F. Fostering computational thinking through educational robotics: A model for creative computational problem solving. *Int. J. STEM Educ.* **2020**, *7*, 1–18. [CrossRef]
6. Noh, J.; Lee, J. Effects of robotics programming on the computational thinking and creativity of elementary school students. *Educ. Technol. Res. Dev.* **2020**, *68*, 463–484. [CrossRef]
7. Doleck, T.; Bazelais, P.; Lemay, D.J.; Saxena, A.; Basnet, R.B. Algorithmic thinking, cooperativity, creativity, critical thinking, and problem solving: Exploring the relationship between computational thinking skills and academic performance. *J. Comput. Educ.* **2017**, *4*, 355–369. [CrossRef]
8. Bell, T.; Witten, I.H.; Fellows, M. *Computer Science Unplugged: Off-Line Activities and Games for All Ages*; Citeseer: Christchurch, New Zealand, 1998; 240p.
9. Del Olmo-Muñoz, J.; Cózar-Gutiérrez, R.; González-Calero, J.A. Computational thinking through unplugged activities in early years of Primary Education. *Comput. Educ.* **2020**, *150*, 19. [CrossRef]
10. Wahyudin, W.; Rishanty, A.M.; Nursalman, M.; Nazir, S.; Riza, L.S. Learning through computer science unplugged on team assisted individualization on the computational thinking ability. *Linguist. Cult. Rev.* **2021**, *5*, 1442–1452. [CrossRef]
11. Weigend, M.; Vaníček, J.; Pluhár, Z.; Pesek, I. Computational thinking education through creative unplugged activities. *Olymp. Inform.* **2019**, *13*, 171–192. [CrossRef]
12. Rodriguez, B.; Kennicutt, S.; Rader, C.; Camp, T. Assessing computational thinking in CS unplugged activities. In Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education, Seattle, WA, USA, 8–11 March 2017.
13. Thies, R.; Vahrenhold, J. On plugging "unplugged" into CS classes. In Proceedings of the 44th ACM Technical Symposium on Computer Science Education, Denver, CO, USA, 6–9 March 2013.
14. Brackmann, C.P.; Román-González, M.; Robles, G.; Moreno-León, J.; Casali, A.; Barone, D. Development of computational thinking skills through unplugged activities in primary school. In Proceedings of the 12th Workshop on Primary and Secondary Computing Education, Nijmegen, The Netherlands, 8–10 November 2017.
15. Dagiene, V.; Futschek, G.; Stupuriene, G. Creativity in solving short tasks for learning computational thinking. *Constr. Found.* **2019**, *14*, 382–396.
16. Hong, E.; Milgram, R.M. Creative thinking ability: Domain generality and specificity. *Creat. Res. J.* **2010**, *22*, 272–287. [CrossRef]
17. Sawyer, R.K.; Henriksen, D. *Explaining Creativity: The Science of Human Innovation*; Oxford University Press: Oxford, UK, 2024.
18. DeSchryver, M.D.; Yadav, A. Creative and computational thinking in the context of new literacies: Working with teachers to scaffold complex technology-mediated approaches to teaching and learning. *J. Technol. Teach. Educ.* **2015**, *23*, 411–431.
19. Runco, M.A.; Jaeger, G.J. The standard definition of creativity. *Create. Res. J.* **2012**, *24*, 92–96. [CrossRef]
20. Fukui, M.; Sasaki, Y.; Hirashima, T. An Exploratory Study of the Relationship between Computational Thinking and Creative Attitudes Among University Students. In Proceedings of the CTE-STEM 2022 Conference, Delft, The Netherlands, 15–17 June 2022. [CrossRef]
21. Kim, K.H. The Torrance tests of creative Thinking—Figural or verbal: Which one should we use? *Creat. Theor. Res. Appl.* **2017**, *4*, 302–321. [CrossRef]
22. Miller, L.D.; Soh, L.K.; Chiriacescu, V.; Ingraham, E.; Shell, D.F.; Ramsay, S.; Hazley, M.P. Improving learning of computational thinking using creative thinking exercises in CS-1 computer science courses. In Proceedings of the Education Conference, FIE, Oklahoma City, OK, USA, 23–26 October 2013; pp. 1426–1432. [CrossRef]
23. Israel-Fishelson, R.; Hershkovitz, A.; Eguíluz, A.; Garaizar, P.; Guenaga, M. A Log-Based Analysis of the Associations Between Creativity and Computational Thinking. *J. Educ. Comput. Res.* **2021**, *59*, 926–959. [CrossRef]
24. Israel-Fishelson, R.; Hershkovitz, A.; Eguíluz, A.; Garaizar, P.; Guenaga, M. The associations between computational thinking and creativity: The role of personal characteristics. *J. Educ. Comput. Res.* **2021**, *58*, 1415–1447. [CrossRef]
25. Mishra, P.; Yadav, A.; Deep-Play Research Group. Rethinking technology & creativity in the 21st century. *TechTrends* **2013**, *57*, 10–14.
26. Baratè, A.; Ludovico, L.A.; Mangione, G.R. A web framework to develop computational thinking through music coding. In Proceedings of the 2nd International Conference on New Music Concepts (ICNMC 2016), Trevisio, Italy, 3–4 March 2016.
27. Bull, G.; Garofalo, J.; Nguyen, N.R. An Introduction to Computational Thinking Through Art, Music, and Games. In Proceedings of the 31st Annual Conference of the Society for Information Technology and Teacher Education, Las Vegas, NV, USA, 18–22 March 2019.
28. Chong, E.K. Teaching and Learning Music Through the Lens of Computational Thinking. In Proceedings of the International Conference on Art and Arts Education (ICAAE 2018), Yogyakarta, Indonesia, 29 October 2018; Atlantis Press: Berlin/Heidelberg, Germany, 2018.
29. Petrie, C. Interdisciplinary computational thinking with music and programming: A case study on algorithmic music composition with Sonic Pi. *Comput. Sci. Educ.* **2022**, *32*, 260–282. [CrossRef]
30. Fanchamps, L.; Van Gool, E.; Van Dongen, J.; Straus, M.; De Meyst, K. The Effect of Music Producing on Computational Thinking Among Primary School Students in Childcare. In Proceedings of the 8th APSCE International Conference on Computational Thinking and STEM Education, Beijing, China, 28–30 May 2024; Asia-Pacific Society for Computers in Education: Beijing, China, 2024.
31. Walzer, D. Towards an understanding of creativity in independent music production. *Creat. Ind. J.* **2023**, *16*, 42–55. [CrossRef]

32. Román-González, M.; Pérez-González, J.-C.; Jiménez-Fernández, C. Which cognitive abilities underlie computational thinking? Criterion validity of the Computational Thinking Test. *Comput. Hum. Behav.* **2017**, *72*, 678–691. [CrossRef]
33. Field, A. *Discovering Statistics Using IBM SPSS Statistics*; Sage Publications Limited: Washington, DC, USA, 2024.
34. Kalelioğlu, F. A new way of teaching programming skills to K-12 students: Code.org. *Comput. Hum. Behav.* **2015**, *52*, 200–210. [CrossRef]
35. Santos, J.R.A. Cronbach's alpha: A tool for assessing the reliability of scales. *J. Ext.* **1999**, *37*, 1–5.
36. Brennan, K.; Resnick, M. New frameworks for studying and assessing the development of computational thinking. AERA. In Proceedings of the 2012 Annual Meeting of the American Educational Research Association, Vancouver, BC, Canada, 13–17 April 2012.
37. Baratè, A.; Ludovico, L.A.; Malchiodi, D. Fostering computational thinking in primary school through a LEGO®-based music notation. *Procedia Comput. Sci.* **2017**, *112*, 1334–1344. [CrossRef]
38. Edwards, M. Algorithmic composition: Computational thinking in music. *Commun. ACM* **2011**, *54*, 58–67. [CrossRef]
39. Gorson, J.; Patel, N.; Beheshti, E.; Magerko, B.; Horn, M. TunePad: Computational thinking through sound composition. In Proceedings of the 2017 Conference on Interaction Design and Children, Stanford, CA, USA, 27–30 June 2017.
40. Wu, S.-Y.; Su, Y.-S. Visual programming environments and computational thinking performance of fifth-and sixth-grade students. *J. Educ. Comput. Res.* **2021**, *59*, 1075–1092. [CrossRef]
41. Bell, J.; Bell, T. Integrating computational thinking with a music education context. *Inform. Educ.* **2018**, *17*, 151–166. [CrossRef]
42. Ruthmann, A.; Heines, J.M.; Greher, G.R.; Laidler, P.; Saulters, C. Teaching computational thinking through musical live coding in scratch. In Proceedings of the 41st ACM Technical Symposium on Computer Science Education, Milwaukee, WI, USA, 10–13 March 2010.
43. Sharma, K.; Papavlasopoulou, S.; Giannakos, M. Coding games and robots to enhance computational thinking: How collaboration and engagement moderate children's attitudes? *Int. J. Child-Comput. Interact.* **2019**, *21*, 65–76. [CrossRef]
44. Jiang, S.; Wong, G.K. Exploring age and gender differences of computational thinkers in primary school: A developmental perspective. *J. Comput. Assist. Learn.* **2022**, *38*, 60–75. [CrossRef]
45. Lee, J.; Jung, Y.; Park, H. Gender differences in computational thinking, creativity, and academic interest on elementary SW education. *J. Korean Assoc. Inf. Educ.* **2017**, *21*, 381–391. [CrossRef]
46. Sun, L.; Hu, L.; Zhou, D. Programming attitudes predict computational thinking: Analysis of differences in gender and programming experience. *Comput. Educ.* **2022**, *181*, 104457. [CrossRef]
47. Montuori, C.; Ronconi, L.; Vardanega, T.; Arfé, B. Exploring gender differences in coding at the beginning of primary school. *Front. Psychol.* **2022**, *13*, 887280. [CrossRef] [PubMed]
48. Sullivan, A.; Bers, M.U. Robotics in the early childhood classroom: Learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade. *Int. J. Technol. Des. Educ.* **2016**, *26*, 17. [CrossRef]
49. Kong, S.-C.; Chiu, M.M.; Lai, M. A study of primary school students' interest, collaboration attitude, and programming empowerment in computational thinking education. *Comput. Educ.* **2018**, *127*, 178–189. [CrossRef]
50. Lai, X.; Ye, J.; Wong, G.K.W. Effectiveness of collaboration in developing computational thinking skills: A systematic review of social cognitive factors. *J. Comput. Assist. Learn.* **2023**, *39*, 1418–1435. [CrossRef]
51. Echeverría, L.; Cobos, R.; Morales, M. Improving the students computational thinking skills with collaborative learning techniques. *IEEE Rev. Iberoam. Tecnol. Aprendiz.* **2019**, *14*, 196–206. [CrossRef]