A Hybrid Approach to Teaching Computational Thinking at a K-1 and K-2 Level

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ABSTRACT

Computational Thinking (CT) has been described as taking an approach to solving problems, designing systems and understanding human behavior that draws on concepts fundamental to computing. It is the ability to integrate human creativity and insight with concepts derived from Computer Science. We argue that it is best to learn the fundamentals of CT at a young age, when the mind is most malleable, instead of much later when these concepts are taught as part of Computer Science courses. However, challenges arise not only when trying to teach these complex concepts to young children, but also when applying these teachings through kindergarten environments. We present a definition of the basic fundamental CT concepts and then describe a unique hybrid approach of offline and online activities to teach these fundamentals to students at the kindergarten (K1 and K2) level (children aged 4-6 years old). Finally we validate this approach with a pilot class to determine its learning effectiveness.

KEYWORDS

E-Learning, Child Education, Computational Thinking

1 INTRODUCTION

The "4C'S" – critical thinking, creativity, collaboration and communication have already been recognized as core 21st Century skills to be embedded into school curricula. As technology such as A.I., machine learning and robotics advance rapidly; our children are faced with the prospect that over 80% of future job needs will be disrupted. The need to understand how to use computational tools and to be able to problem-solve is becoming a fundamental competency. "Computational Thinking" is the "5th C" of 21st century skills and is being embedded as part of core curricula in education systems across the world.

Computational Thinking (CT) has first been described by Papert [13] and Wing [20] as taking an approach to solving problems, designing systems and understanding human behavior that uses concepts fundamental to computing. It is the ability to integrate human creativity and insight with concepts derived from Computer Science. We can list previously defined CT skills from outside sources, such as[2], into a general diagram to highlight the four most fundamental of CT skills. These CT skills are described as follows:

Algorithmic Thinking: Getting to a solution through the clear definition of the instructions that need to be followed.

Decomposition: Also known as factoring, is to break down a complex problem or system into parts that are easier to conceive, understand, program and maintain.

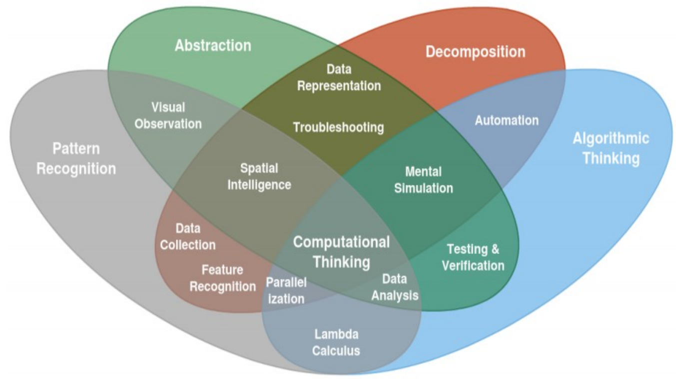

Figure 1: Categorization of previously defined CT elements. Although not comprehensive all listed topics lie under one of the listed categories and are a core part of kindergarten curriculum.

Abstraction: To generalize several complex solutions or definitions based on similarities or common rules. Then apply these generalizations to an alternative context.

Pattern Recognition: The process of classifying input data into objects or classes based on key features, and infer new solutions based on previously classified data.

We assert that these skills should be taught at an early age, when the child is most malleable [17]. There are two major challenges that must be addressed when teaching to this audience. One of the most difficult challenges is how to approach teaching these skills to children given that at the K1 and K2 level, their language and motor skills are still developing. The second challenge lies in providing a digital teaching medium which can be accepted. This is primarily due to resistance to the use of teaching through a digital platform [19] even though it is an effective medium for teaching concepts that are hard to understand [10].

In this paper we present a methodology for teaching these fundamental CT skills using a hybrid of online and offline activities through a tablet computer and physical practice / worksheets. We discuss the design of the online animated videos which teach the high level concept of the basic CT skills which is then augmented through teacher interactions. We also discuss the design of digital games to facilitate simulated practice of these CT skills, and their translation to real-world offline activities within the class. We evaluate the effectiveness of this methodology through a pilot study in which a short implementation of this design is used.
Overall, the core contributions of this work are:

- The first formal derivation and definition of the fundamental CT skills.
- The design of a hybrid approach of online and offline activities to teach the fundamental CT skills applicable to K1 & K2 groups.
- An empirical method of evaluating the student CT skills taught using this approach.

We believe that through this hybrid design, children can learn the concepts of CT and apply these problem solving skills early on in their lives and continue developing these skills to significantly improve their future academic progress and daily life activities.

2 RELATED WORK

We assert it is imperative these fundamental CT skills are taught at an early age. To devise a valid approach, a careful analysis of previous frameworks for teaching CT, and methods for engaging children must be conducted. In this section we discuss three key avenues of related work; (i) CT in education; (ii) engaging children using digital media as a teaching platform; and (iii) the use of simulation as a method to practise CT skills.

2.1 Computational Thinking in Education

The idea of teaching CT is not new. In the 1960's, Alan Perlis was one of the first who argued for the need for college students of all disciplines to learn programming and the "theory of computation" [8, 14]. Teaching CT shouldn't be limited to college courses as introducing these CT concepts can be applied as a tool to improve the skills taught in K-12, and key problem solving skills used outside of school [2]. Similarly, we also derive how the basic subjects of CT supplement the basic components of the general K1 and K-2 curriculum (Table 1). This is not the only instance of applying CT in an educational environment [9]. Here the authors approach learning CT through digital game mediums. The benefit of this approach is that it allows students to learn the application of CT in pre-programmed simulation environment. Although this approach has shown to be effective, the games and interfaces used are aimed towards older audiences, likely making them too complex for younger children to adopt and use. This makes this it difficult to directly apply this approach without making it more child friendly. Although not implemented, Falkner Et. Al [6] discusess how and when CT should be taught. However, their questionnaire suggests that teachers at that level only consider CT as a useful subject in Information Technology and Mathematics subjects. Because classes are designed to teach children as young as 6 years old (in K-2 grades) coding as a supplemental enrichment class [1], we assert the fundamentals of CT must be taught as an additional core subject instead of an enrichment class to maximize the impact of the benefits. To the best of our knowledge, our teaching method is the first that can be applied to allow teaching fundamental CT concepts to children at a K1-K2 level which can be accepted by kindergartens.

2.2 Using Digital Media to Teach Children

Utilizing Media as a platform for teaching is not a new concept, infact it was Meir Et Al [11] in the late 1960's who explored how educational media, would contribute to the early years of childhood. Although this is only exploring physical art media it supports later investigations by Burns Et. Al [4], which highlighted that video can be used as an interactive teaching medium, provided that it is carefully designed and integrated with online in-class materials. Additionally, Lieberman et. Al [10] investigates the effectiveness of digital media as a teaching platform for younger children (aged 3 to 6), showing that digitally assisted media can greatly assist in explaining high level concepts in a way that children can understand. These studies sparked the creation and usage of video games and media for entertainment and education (also known as edutainment). Such mediums in teaching environments have highlighted increased attention during use and retention of information afterwards when engaging with edutainment media at an educational capacity [16]. Examples for such edutainment tools are: mathematics [5], Creativity and Learning [12], and Reading and Literacy [15] (Teaching English to children with English as a second language). Our work extends this by utilizing animated video which introduces and teaches difficult high level CT concepts to children in a way that can be understood, engaging and interactive.

2.3 State of CT Teaching in K-12

In the UK, the "Barefoot Computing" approach using traditional paper and pen has been adopted since 2014, with trained teachers teaching CT in primary schools. In recent years, CT are being taught using new tools [18] in hardware such as Arduino and educational robots and coding software such as Scratch and Scratch Junior. However, limitations of these tools are as follows (i) high cost of hardware; (ii) unable to teach the full CT concepts; and (iii) require significant investment in trained teachers. All these factors limit how CT can be effectively delivered and deployed at scale in kindergartens. The right use of mobile devices can enhance the learning experience of students as well as strengthen teacher-development programs. Our work differs by applying specifically-designed software content on a mobile platform [7].

2.4 Use of Gamification and Simulation to Practice CT Concepts

As the core of kindergarten education is learnt through play, we strongly encourage the use of digital simulation environments, which in turn are transformed into video games, the process of gamification. Gamification allows for stress free, engaging and entertaining online practice of CT concepts. This in turn will relieve anxiety that can be experienced when applying the high level concepts to real world contexts. Examples of such simulation environments are shown by [9, 12]. However, these games are designed with older target audiences in mind. Our work crucially differs from related work in two ways. First: multiple games that simulate separate CT concepts are used in our digital application; Second, our user interface and experience is designed and implemented with simplicity in mind, allowing younger children to fully enjoy the experience whilst practicing the fundamental CT concepts.

3 DESIGN OF A HYBRID APPROACH FOR K1 & K2

This section describes the design of a unique approach for teaching the complex CT fundamentals in a way that can be understood by younger children. We also discuss how teachers facilitate the

A)	Pattern Recognition	Abstraction	Decomposition	Algorithmic Thinking
Pearly Whirly	-	-	-	++
Manta Match Mania	-	+	++	-
Crabby Patty	++	+	-	-
Tumble Trouble	+	-	-	++
Chomp Chomp	++	++	-	-

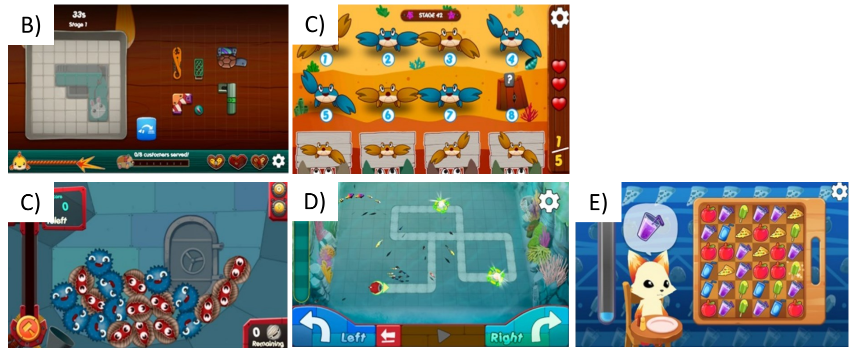

Figure 2: (a) How each game weighs against the four CT skills. Each + denotes a stronger relationship, each - denotes a weaker relationship. (b), (c), (d), (e), (f) each show in-game screenshots of Manta Match Mania, Tumble Trouble, Pearly Whirly, Crabby Patty and Chomp Chomp respectively.

additional activities and how they can evaluate and report the students progression in the curriculum.

3.1 Design requirements

From looking at current kindergarten curriculum as well as general feedback from acting kindergarten principals and teachers, we summarize that the curriculum design requires the following:

- Children should learn through play and exploration
- Children should be encouraged to learn even if the concept is complex
- Children should be exposed to digital medium whilst applying concepts to real world scenarios, limiting their screen time
- Curriculum should be intuitive for teachers to understand and teach, even if they are not proficient in the subject being taught
- Curriculum should be designed so that teachers are only required to supplement the lessons, and can be done with little to no pre-requisite knowledge of the subject
- Teachers should be able to evaluate the progress of the class and/or an individual student

3.2 Teaching through Animations

As the starting sequence in scaffolding, children would watch a pre-scripted video animation when they are first introduced to a new complex CT concept. The animation features “Doodle” as the primary teacher cum online character who will engage the children; complementing the “offline” kindergarten teacher whose role is to re-enforce learning. This allows teachers with limited CT proficiency to confidently teach these complex concepts. The animations are done in the same spirit of educational children TV shows, utilizing pauses between questions as well as humorous gags to keep the attention of the children and allow them to actively engage. The animations are ordered to first introduce each CT skill, provide examples on what this skill entails, then expand and show how the skill is applied to real-world situations.

3.3 CT practice through Games

The online practice is provided via the a digital application which is run on an android tablet device. This application features the child avatar known as the ’Buddy’ who builds a relationship with the child and game story as the Buddy helps them in small ways (Such as giving hints on how to complete difficult levels). This further enhances the engagement whilst relieving the anxiety of the educational factor being displayed to the children. The application contains six games which incorporate one or more CT elements in the game-play (See Table 4(a) for CT relations). By transposing CT exercises via gamification, we are able to allow kids a safe virtual environment to practice CT skills. The 5 Games which are included in the School of Fish application are:

Pearly Whirly: This game instructs kids to pre-program the ’Sally Submarine’ to navigate through a maze and collect each of the pearls. The kids pre-program a series of either a ’left’ or ’right’ command. Upon execution the submarine will continuously move forward whilst making either a left or right turn at each junction based on the next command in a sequence. The level is completed when Sally is able to navigate the maze and collect all of the pearls in one sequence of inputs.

Manta Match Mania: This game runs in the same spirit of a tangram puzzle. Players have to utilize the ’junk’ puzzle pieces on the right and arrange them so that they cover the requested ’junk part’ on the left. This needs to be done within a given time frame otherwise the player loses one of 3 lives and retries the puzzle. Each time a ’junk part’ is successfully constructed the player earns some ’pig coins’ and continues to the next puzzle. The game is completed when enough pig coins are collected.

Crabby Patty: Players are presented with a 3x2 or 4x2 array of crabs who will pose to form a pattern, with one of the crabs being hidden under a bucket. The aim is to select one of four solutions which they think matches the hidden crab. This is repeated until all the puzzles are solved, with incorrect answers removing one ’life’. The game ends when all puzzles are solved or all lives are lost.

Tumble Trouble: Colored critters fill the screen, and the player tries to clear the critters by drawing lines to match 4 or more in a row. This game adds two twists however; first they must clear a

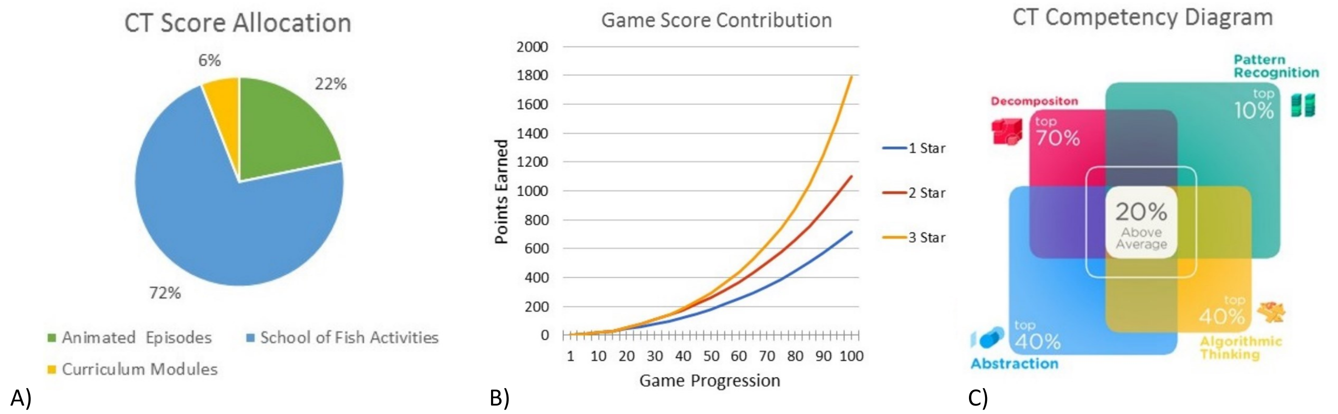

Figure 3: Charts and figures related to the CT score. (a) shows how the overall Raw CT score is distributed over the 3 main topics. (b) shows how the stars earned in the games translate to the raw CT scores, which are distributed across the 4 CT subjects. (c) shows how this CT score is displayed to teachers, in this example the child is compared to the rest of the class.

specific number of critters from a limited supply, second a special 'clam' critter requires surrounding critters to be cleared several times before the clam is cleared. The game is complete either when these two goals are met, or there are no more possible moves.

Chomp Chomp: A supplemental game. Players are presented with their buddy requesting a particular kind of food, and a 5x5 grid of randomized food from 5 particular types. The objective of the player is to 'feed' the buddy by filling his 'hunger gauge'. They do this by swapping food around to match 3 of the same type of food which fills this gauge. The game ends when the hunger bar is filled.

3.4 Integration of Online Activities

The final sequence of the scaffolding journey where offline activities are used to reinforce the skill acquisition process by getting children to apply the CT skills learnt through the online games to real-world teacher-led play activities. This is implemented with the toys and equipment the kindergartens already have in classrooms to perform activities which practice CT and problem-solving as play activities, so as not to discourage kids from interacting and allows the kids to enjoy the learning experience. Teachers help the kids follow the instructions given, and are instructed to allow the kids to figure out the solutions themselves. Some examples of these activities include but are not limited to:

- Making various animals with building blocks
- Recognizing patterns from the surrounding environments
- Planning the steps of what the child will do during the day
- Breaking a big jigsaw puzzle into smaller parts then use abstraction to group them, making the puzzle easier to solve
- Breaking a large math equation into smaller parts

3.5 Evaluating and Grading Student Performance

Teachers require a means of grading and evaluating the progress of a student through the curriculum. A method of grading is provided via a dashboard application, which allows teachers to mark attendance to modules and track the child progress. This progress is empirically evaluated in two ways, The CT competency index and the puzzle quiz delivered at the start, mid and end of the curriculum. We define the CT competency index as an empirical point system and allocate points across three main topics:

- Curriculum modules: for which a child is awarded points upon completion of the given module
- Animations: for which a child is awarded points upon watching one of the Doodle animated lessons.
- Online Activities: Each of the core CT Games described in Section 3.3 have 100 levels. Each of these levels can be completed with a rating from 1 to 3 stars. 3 stars are given if the best approach/solution to the level was used. The total of all earned stars for each game contribute to points in the CT skill category which that game practices. Figure 3(b) shows the exponential rate in which the stars affect the final raw CT score.

Figure 3(a) shows how the raw CT score is divided across the three topics. The curriculum modules only comprise 6 score for two reasons; One is that the animations and online activities are usually a subset of the curriculum, hence a big part of the score is redistributed into the animated episodes (where the concepts are taught) and the online game activities (where they are practiced and reinforced). The second reason is that the delivery of these classes cannot be monitored, making the marking of these modules a subjective judgment from the teacher (which they do by marking the student as attended) and therefore cannot be empirically measured.

The final raw CT score is calculated as follows:

$$RawCTSubjectScore = GameContributions + ModuleContributions + AnimationContributions$$

Where:

$$GameContributions = \frac{\sum_{i=1}^{4}(CTGameScore[i]Multiplier[i])}{4}$$

For each of the four games that contribute to the final raw score.

Figure 5 shows how each game contributes to each of the four subjects. We do not directly show the raw scores to the teacher, instead we show a graphical comparison of either a child's score compared to the rest of the class or a child's score against the rest of enlisted users via a percentage comparison (Figure 3(c)). This allows the teacher to highlight that a child may be weaker in a particular skill and can suggest ways that that child can improve to the parent when reporting progress. We also use a variation of Raven's progressive matrices [3] to test their ability to systematically decompose patterns, selecting the correct missing piece. This variation does not calculate IQ, but only the raw correct answers as a grading metric. This test is taken before the start, halfway during, and after the curriculum is complete.

4 PILOT STUDY: EVALUATING THE TEACHING EFFECTIVENESS

This pilot study aims to validate how effectiveness of the methodology and curriculum described in this paper in teaching the fundamental CT skills. For this we developed a 12 hour variation of our curriculum, containing the introduction to each CT skill, some online interactive practice in class via the tablet device, and some offline activities. Additional worksheets are given out to be completed outside of class hours either with teacher or parental supervision. Before the classes begun, the children were given the introduction to the course where they learn how to use a tablet. They are then asked to complete the puzzle test described in Section 3.5. This test is given a second time after the completion of the course. Our hypothesis stated that:

- **H1** Children improve the amount of correct answers given in the puzzle test after taking the classes
- **H2** Any improvement is independent from whether the children have previously used a tablet device before.

4.1 Participants

Two classes of mixed K1 and K2 students aged 4-6 years old were selected from volunteer kindergartens. The first class C1 has had no previous exposure to tablet devices whilst C2 already uses some tablets as part of their curriculum. Before forms were distributed by the teachers to the child's parents, only children who's parents have completed and signed the form were allowed to participate. C1 contained 15 students comprised of 6 female and 9 males, C2 comprised of 10 students 5 male, 4 female Making 25 students total. Later 2 males from C1 and 2 females and 1 male from C2 were removed from the experiment results due to absence from some of the classes.

4.2 Task and Procedure

A 12 hour implementation of the designed described in Section 3 is used in this experiment. In this shortened version the modules which introduce each of the fundamental CT concepts as well as one online and one offline activity which practices the respective skill is used. The children first learn how to use a tablet and conduct the first puzzle test (described in Section 3.5) on the first day, then the classes run on days 2 - 5, The second puzzle test is then executed on day 6. These classes are taught by a researcher whilst a kindergarten teacher is present at all times to supervise and facilitate as needed. Please see the additional materials for this 6 day curriculum.

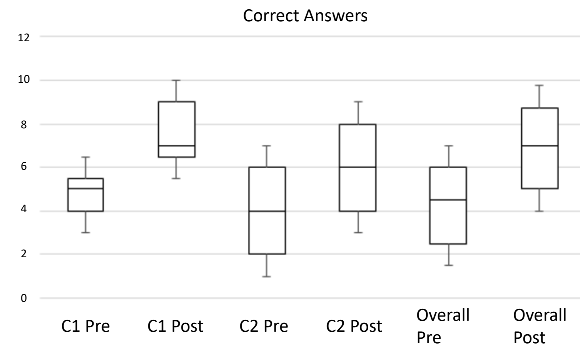

Figure 4: Results of the pilot study. We can see some improvement of the amount of correct answers and that this improvement is similar in both classrooms. The large variance does suggest that the sample size might be too small.

4.3 Variables

Dependent Variables: Empirically we looked at the amount of correct answers given in the test. Each answer is collected as a binary outcome. Observations of how the students partake in the classes and engage with the content are made and general feedback from the supervising kindergarten teachers and principals are collected through interviews. Independent Variables:

Class∈ { C1, C2 } between-subjects

We measured the scores between the two classes to see if having previous experience with the tablet device causes any affect on the effectiveness of the curriculum. C1 has had no previous interaction with tablet devices while C2 has.

TestTakenAt∈ { Pre, Post } within-subjects

We measured the scores of the puzzle test before and after the 10 hour course was taken to see if there is an improvement.

4.4 Results

The results of this pilot study are described in three ways; The directly measured variables, the observations made during class participation and the feedback given by the supervising teachers & principals.

Measured Results: As this was a between subjects pilot, for each of the measured dependent variables described in Section 4.3 we analyze each the measured Dependent Variables using a two-way ANOVA test against the Independent Variables. **H1** stated that after the classes the children will have more correct answers. Figure 4 shows at what rate a child answered each question correctly before and after the classes, from this we can say this improvement is applied to questions which previously had a lower percentage of being correct. The results from the two-way repeated measures ANOVA test further support **H1**, showing a significant interaction effect between the pre and post-test scenario for both C1 & C2 on the amount of correct answers in the puzzle test with confidence level $p < 0.05$ (~0.003). **H2** states that any improvement in test results is independent from whether the children have previously used a tablet device before. Both two-way ANOVA results highlighted in Figure 10 and 11 show that there is no significant interaction ($p > 0.05$, ~0.379) between the two classes on the amount of correct answers in the Pre and Post test environments, therefore **H2** is accepted.

Observed Results: The children were actively engaging with the classes, they answered the questions that were queried by Doodle during the animated episodes. They would answer questions asked by the experiment conductor as well as the supervising teacher. The children at first had difficulty engaging with the online activities but after a small amount of practice were able to complete the given activities. An interesting observation was made during the execution of the puzzle tests. The students took longer and were systematically solving the questions in the post test environment.

Feedback Results: The teachers and principals were briefly interviewed before and after the classes and post test were conducted. Overall principals were positive about the unique style of how the classes were executed. At first they rejected the idea of tablet computers being used in class but after watching how the kids actively engaged during tablet play they later retracted their rejection. They were concerned that some training (although minimal) in the use of the game and dashboard applications might be required in order for such a curriculum to be effective.

4.5 Discussion

Our measured results support both **H1** and **H2**. We recognize that the sample size is too small for a within subjects experiment. This was unavoidable due to the fact that kindergarten classes typically only contain 5-15 students per supervising teacher. Even with this small size the results were significant. We observed that during the post test the children took a more systematic approach to solving the puzzles. This raises the question as to whether a child exposed to this teaching method will take a different approach to solving problems due to a changed mindset and can be investigated in future studies. We also observed that the children engaged very well with the Doodle character as he taught the concepts in the animated videos and enjoyed the online activities in the tablet. The feedback from the teachers additionally state that the children enjoyed practicing these skills outside of the classroom as well as through the interactive offline activities.

5 CONCLUSION AND FUTURE WORK

This work represents a first step into a method of teaching CT to a K1 & K2 audience, and opens up several new venues for future work. Although the experiment described in this paper validated the hypothesis that our unique hybrid design of offline and online activities is effective in teaching a subject as complex as CT to a K1 & K2 audience, we acknowledge that these results are only preliminary and are an estimate due to a small sample size. Still, these results are significant and suggest that future work involve the full implementation of a curriculum which utilizes this hybrid approach be completed. Furthermore a repeated experiment using this full implementation with a larger sample size will lead to the same conclusions. The results also suggested after the children were exposed to this new problem solving methodology, they took a new approaches to solving the puzzle test. This raises the question on whether we need new test methods to further evaluate each of the fundamental CT skills individually rather than as a whole. Additional future psychological studies can possibly reveal on how a child's problem solving mindset changes after being exposed to a curriculum which teaches CT methodology.

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6 ADDITIONAL MATERIALS

Additional materials can be found online here:
http://bit.ly/3s0UY84
These materials include the shortened curriculum used for the study, a table summarizing each game's contribution to the overall CT score, and sample questions used as part of the study's evaluation.
Sample Doodle episodes can be found here:
http://bit.ly/3vkdBGp