Behavior and Cognition Processing of Educational Tabletop Coding Games

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Abstract

Many countries have been actively promoting computational thinking since it was put forward, and visual programming language, robots and educational tabletop games are commonly used in its promotion. To understand the relationship between students' learning of coding principles in educational tabletop games and players' cognitive processing at key points in time, students' behavior while playing the Interstellar Explorer tabletop game was observed by a brainwave EEG (electroencephalography) instrument and video and analyzed with cognitive processing. The results showed that a continuous increase in attention and meditation reflected a low level of knowledge and understanding as well as high-level application, analysis and evaluation of cognitive processing. This study explores the relationship between the state of students playing tabletop games and their behavior during play and then derives the relationship between their behavior and cognitive processing. It is recommended that the design of tabletop games consider how the learning content matches the game mechanics and examine whether cognitive processing is present according to Bloom's taxonomy. In addition, to enhance players' cognitive ability, it is recommended that tabletop games provide the ability to use contextual content and multiple strategies.

Keywords: Computational thinking, Coding education, Cognitive processing, Brainwave, Tabletop game

1 Introduction

Wing of Carnegie Mellon University introduced the concept of the literacy of computational thinking in 2006. He indicated that computational thinking involves the application of basic concepts of computer science to design systems, solve problems, and understand human behavior [1]. Computational thinking is a basic capability that a person should have in addition to basic literacy, such as reading, writing and counting, and is not exclusively for computer scientists. Following Wing, relevant organizations and scholars have developed views on computational thinking [2-3], and many advanced countries have begun to develop curriculum standards and teacher training for computational thinking literacy [4-6]. According to Brown, Sentance, Crick, & Humphreys [7], computer science has been taught to all students above the age of five across the UK (England, Scotland, Wales and Northern Ireland), whereas primary school students learn to grasp computational thinking skills [8] via BBC micro:bit in Sweden.

It can be seen from the above changes in educational trends that many countries have trained teachers and include content on computational thinking in the curriculum [9]. Students can thus become literate in computational thinking beginning in childhood, suggesting the importance of developing children's thinking ability at an early age. Training in computational thinking ability is usually achieved through writing code [10-11]. However, Costelloe [12] and Powers, Ecott, & Hirshfield [13] pointed out that schoolchildren who begin to learn programming often encounter difficulties and feel frustrated with the concept of grammar and coding design. Because the text interface used by traditional programming requires input of various grammar instructions, this method may cause students to feel bored and may not stimulate their interest in learning [14]. In addition, Zhao & Shute [16] reported that when students try to learn to use text-based programming languages, close attention to syntax details is required. Therefore, in order to improve the interest of students in learning, visual programming language (e.g., Scratch) and robots (e.g., mBot), which emphasize logic and structure over calculation [18], have begun to be developed by research units or manufacturers [19-20].

In addition, in recent years, due to the prevalence of tabletop games, computer science has become unplugged [21], and related textbooks and applications have begun to attract attention. Tabletop games comprise all card games, board games, tile-based games, and other games that require face-to-face

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participation by a number of game players [22]. Educational tabletop games have educational value and promote learning motivation through play, enabling the players to learn relevant knowledge [23]. Currently, related program logic tabletop games include Robot Wars, Robot Turtles, Code master and Code & Go Mouse Mania Tabletop game, etc. Most of these tabletop games are based on a checkerboard pattern for learning the concept of computational thinking through different cards.

When the current education system attaches importance to computational thinking education and educational tabletop games, scholars are exploring how to evaluate their learning outcome. At present, in the field of computational thinking, some scholars are also committed to developing the computational thinking evaluation framework for schoolchildren. For example, Brennan and Resnick [24] developed a computational thinking assessment framework to conduct literacy analysis of computational thinking through topical production. Werner, Denner, Campe, and Kawamoto [25] used the 3D game record on the alice.org website to understand the computing performance of schoolchildren. Selby, Dorling, & Woollard [26] developed a framework for computational thinking and evaluated whether children used the concept of computational thinking through qualitative observation. The above assessment methods for computational thinking literacy are diversified, and the development of an assessment framework is the first step in most assessments of computational thinking literacy. Other approaches such as thematic production, qualitative analysis and system record analysis are common analytical methods. However, from the perspective of learning, the study of computational thinking is the study of not only the learning of program logic; decomposition, pattern recognition and abstraction are also the processes involved in problem analysis and solutions [27], and these processes demonstrate cognitive processing. Hou [28] proposed that the design of educational tabletop games should consider cognitive analysis, which allows teachers or tabletop game developers to check whether the contents of the table games correspond to the cognitive goals of remembering, understanding, application, analysis, evaluation and creation. Bloom's taxonomy, proffered by Anderson & Krathwohl [29] and Anderson [30], is frequently used to evaluate cognitive processing and has been discussed by a number of studies regarding its application in computational thinking. Although Johnson & Fuller [31] observed a huge divergence when this taxonomy is applied to computational thinking, scholars such as Thompson, Luxton-Reilly, Whalley, Hu, & Robbins [32] presented a range of coding abilities for every cognitive object and offered relevant examples. Therefore, the present study investigates the relationship between the learning behavior and cognitive goals of the students when they are playing tabletop games via behavior observation.

When we try to understand the relationship between students' learning behaviors and cognitive goals through behavior observation when they are playing tabletop games, because there are many behaviors to be observed, it is difficult to understand the relationship between each time point and the behavior that will occur. Therefore, we will use the key point in time to explore the behavior at this time and the representative meaning. It is challenging to analyze people's emotions and reactions by dictation, questionnaire or observational analysis because this process involves the reappearance of past experience in memory, and it is difficult to describe directly. Therefore, this part can be measured with an electroencephalogram (EEG). The reason brainwaves occur is that the brain and neuron transmission generate current, and the electrical activity emitted by the brain is called brainwaves. Hans Berger divided normal brainwaves into four categories based on their frequency range: α, β, θ, δ waves [33]. The frequency of brainwaves is calculated by the cycle and vibrations generated per second. The more vibrations per second, the higher the frequency of brainwaves. In the field of education, brainwave instruments are often used by researchers to measure student learning to understand the learning experience and participation of students. Students are allowed to wear brainwave instruments in the classroom, and a computer or mobile device that the teacher can monitor is used to receive brainwave data, which provides teachers with the ability to adjust the teaching to suit the learning style of the students [34-35].

In summary, learning computational thinking through program logic tabletop games is the current trend, but at present, there is no research exploring the learning behavior of students playing coding tabletop games with cognitive processing or aimed at obtaining emotional states at key time points (i.e., attention and meditation degree) with brainwaves. Therefore, this study explored the relationship between the state of students playing tabletop games and the behavior of play and then derived the relationship between their behavioral meaning and cognitive processing. Finally, according to the results, recommendations on teaching design that integrates coding logic tabletop games and game mechanism design were provided to teachers. These useful suggestions may provide more objective criteria for manufacturers to develop instructional aids and can provide direction for teachers to design activities related to computational thinking.

2 Methodology

2.1 Participants and Research Procedure

The research subjects in this study were mainly students in grades 5-6 in primary school with tabletop game players of suitable age. A total of 12 students

participated in the competition via voluntary registration. Every 2 students were randomly assigned to one group, and there were 6 groups in total. The experiment was conducted on holidays, and the process was as follows:

a. The researcher verbally informed parents and students of the experimental process, purpose and research equipment, and an informed consent form was signed.

b. All participating students were taught to play the tabletop game Interstellar Explorer for 120 minutes, which included 30 minutes of explanation and the remaining 90 minutes for the groups to practice on their own.

c. The students were grouped to play the Interstellar Explorer tabletop game, and the time for each group was controlled within 30 minutes (all experimental groups were engaged in the game for 20-30 minutes). While the students were playing, video was recorded and ECG was used to collect brainwave signals.

d. Afterward, students were interviewed about the game situation and brainwave signals.

2.2 Instrument

2.2.1 Interstellar Explorer

The Interstellar Explorer tabletop game [37] (Figure 1) transforms the world of outer space into a playground. Players imagine manipulating the spacecraft to explore interstellar space and search for beautiful planets. Players can control the spacecraft's movement and the arrangement of obstacles such as meteorites to find a planet suitable for human habitation in the other players region. The first player to find such a planet will win the game. In the game design, the card is placed in a straight splicing manner, which is similar to many current visual programming languages. This format helps children to establish the basis of writing code so that they can learn the concept of programming in the process of playing, including sequences, events, loops, conditionals, parallelism, names, operators and data [24].

Figure 1. Schematic of the Interstellar Explorer Tabletop Game

2.2.2 Brainwave Instrument (EEG)

The experimental tool in this study, a wearable brainwave instrument, is BrainLink Lite (Figure 2) (Baud rate is 57,600). The main function of the instrument is to measure the attention and meditation degree; the instrument includes the electrode positions of the prefrontal FP1, FP2, and 5 frequency planes (δ, θ, α, β and γ). It is a noninvasive brainwave-measuring instrument. The numerical data collection method for exploring the concentration and pressure of adolescents is the patented eSense algorithm developed by NeuroSky using the data parameter method. The specific value of 0-100 is used to express the degree of concentration and meditation of the subject [38]. Due to the analytical results of this tool, this study uses the data of participants' attention and meditation degree to perform analyses.

Figure 2. Image of the Brainwave Instrument

2.2.3 Association of Cognitive Goals with Games

Hou [28] proposed that the design of a tabletop game should consider cognitive analysis and that designers should check whether the content of the tabletop game corresponds to the cognitive goals of remembering, understanding, application, analysis, evaluation and creation. The relationship between these six cognitive goals and the game is shown in Figure 3.

2.3 Data Analysis

At the end of the experiment, we first calculated the brainwave signal through NeuroSky's eSense algorithm to calculate the degree of attention and meditation of each student (with the values of 0-100). Next, to understand the relationship between the behavior of students playing the Interstellar Explorer tabletop game and the brainwaves, the steps of the analysis of this research data were as follows:

Step 1. Mark the brainwave data for attention and meditation with the brainwave values of 70 or more and 30 or less and continuously rising or falling for 3 seconds. This value was of interest because the brainwaves of participants were mostly between 40 and 60, and for that reason, this study chose the upper and lower 30% of participants to conduct analyses in order to identify unique cognitive behaviors. In addition, this

Cognitive processing	Game content	Example of Interstellar Explorer
1. Remember	Game rules and situations can promote learners' recall and extraction of knowledge and strengthen learning motivation, helping learners to master and remember the knowledge content independently.	Look at the contents of some fixed pages of the manual.
2. Understand	Game rules and situations can help learners to review and remember and help them understand the content of knowledge; learners can understand the meaning of each knowledge point when operating games, reading and thinking.	Read the contents of the magic card.
3. Apply	Game rules and situations can help learners to apply what they have learned to the problem-solving tasks of the game. The success of these tasks depends on whether the learner can correctly apply the correct knowledge to solve the problem, select or arrange cards, and carry out the correct operation.	After the card is studied, the card is played.
4. Analyze	Game rules and situations can help learners compare, think or discuss; for example, the clues or information provided in each game must be classified and sorted before the task can be accomplished.	Look at the magic card and the fly card in hand, thinking about the order.
5. Evaluate	Game rules and situations help learners evaluate various scenarios or information and plan and diagnose strategies, such as listing various problem-solving strategies or solutions that can avoid risks.	Take away the big or small meteorite on the other party's board (magic card function).
6. Create	Improve game rules and situations, assist learners to extend new ideas and solutions and build their own products.	Move the meteorite card of various sizes that were already on the board (change their positions or take them away).

Figure 3. Association between cognitive goals and games

study used three consecutive seconds as a unit to better identify the brainwave values of participants. The entire game operation process and all activities were recorded, and we saved the recorded video file.

Step 2. Examine the videotape according to the marked data to identify the behavior of the continuous interval.

Step 3. Summarize the four categories of attention increase, attention decline, meditation increase and meditation decline, and according to the characteristics of behavior, analyze the meaning of behaviors.

Step 4. Summarize the behavioral implications and suggestions according to the behavior characteristics.

In Step 2 and Step 3, the videotapes from the field experiments and interviews were observed and analyzed by the research assistants, after which they discussed and summarized the results. In Step 4, the researcher and two research assistants discussed and summarized the results.

3 Results and Discussion

There were 6 groups in the study, and each group had 30 minutes of data collection time. There were 180 minutes of video analysis data. First, in terms of brainwave values, the average values of each group of attention and meditation were between 40 and 60 (Figure 4). According to the definition of the eSense algorithm, the average values of all six groups for both attention and meditation were normal. No special circumstances occurred.

Group	Attention	Meditation
G1-1	49.44	53.67
G1-2	44.30	51.03
G2-1	48.01	57.39
G2-2	46.16	54.25
G3-1	41.99	50.24
G3-2	48.12	54.66
G4-1	42.97	47.22
G4-2	47.35	61.84
G5-1	45.98	59.02
G5-2	51.50	50.45
G6-1	45.40	54.82
G6-2	53.33	52.61
Average	47.04	53.93

Fiugre 4. Average brainwave values for 6 groups

Next, we analyzed the changes in brainwaves. According to the screening conditions of data analysis, we have labeled brainwave data with brainwave attention and meditation values of 70 or more and 30 or less with continuous increase or decline for 3 seconds, among which continuous attention increased 179 times and declined 414 times, and continuous meditation increased 341 times and declined 162 times. Next, the research team conducted videotape inspection based on the marked data to identify the behavior of the continuous interval and summarized the features of the four categories of behaviors of continuous attention increase, continuous attention decline, continuous meditation increase and continuous meditation decline.

The behaviors and meanings of continuous attention increase are as shown in Figure 5. Three main behaviors can be summarized from the meanings of the behaviors, including understanding card content, strategy application and simulating route. First, in understanding the content of the card, students must think about the number of cards, coding logic arrangement, situation (size, meteorites, obstacles), magic points, etc., which is a problem at the level of knowledge and understanding according to the cognitive classification of Bloom's taxonomy [29-30]. In the strategy application part, students should think about how to make an overall arrangement. At this time, students need to integrate the function of coding logic with the current chessboard situation, which involves high-level cognitive processing of application and analysis. Finally, in the simulating route section, students must simulate the route of the spacecraft through simulations based on their own cards. This is a mental simulation process [39], which involves the cognitive processing of evaluation.

Behavior	Meaning
Put the used magic card and fly card into the discard pile	Focus on the number of cards
Collect the cards in your hand as a stack and use them to knock on the table	Unconscious movement when thinking
Move your magic points	Focus on the number of grids for the movement of magic points
Look at the magic card and the fly card in hand, thinking about the order	Think about sort order
Arrange meteorite cards of different sizes	Think about the layout
Read the contents of the magic card	Understand the contents of the card in the process of reading it
Move the meteorite cards of various sizes that were already on the board (change their positions or take them away)	Think about the layout
Hold a large or small meteorite card, looking at the chessboard and thinking about where to put it	Think about the layout
People moving position (front and back, left and right in the seat)	Unconscious movements while focusing/thinking
Look at the card with your fingers or body to simulate the direction in which the rocket will move	Think about the path of the flying ship
Look at each other's shuffle (magic card or fly card)	See if the other party has stolen cards or cheated
Take away the large or small meteorite on the other party's board (magic card function)	Think about which obstacle is more advantageous to remove

Figure 5. Behaviors and meanings of continuous attention increase

The behaviors and meanings of continuous attention decline are shown in Figure 6. The meanings of behaviors can be summarized into four main behaviors, including waiting, random and unanticipated actions, examining one's own cards but not thinking about strategy application and expecting to end soon. Waiting and expecting to end soon are the phenomena that occur in every kind of tabletop game; random and unanticipated actions and examining one's own cards but not thinking about strategy application are behaviors without any cognitive processing.

Behavior	Meaning
Chat with each other	The student is bored
Receive sound interference and look at the direction of the sound source	The student's thoughts are disturbed, and he or she looks at the interference source casually
Take a stack of cards and randomly take the required cards before putting them back (magic card or fly card)	The student is already familiar with the way to fill a hand and knows the number of cards he or she wants
Look at the other party shuffle (magic card or fly card) and shuffle one's own (magic card or fly card)	The student gets ready for his or her own card to play and looks at the other's shuffle casually
Look at the other party with glazed eyes	The student is waiting for the other party to play and is in a daze
Quickly browse the card that has just been picked up and put the card on the table (magic card or fly card)	It is not the student's own turn, so he or she simply waits for the other party to play
Collect the cards in one's hand and use them to knock the table	The student has already thought about what card to play and casually knocks the table with cards in hand
Move one's own magic points	The student has relaxed somewhat at the end of the round
Scratch one's head	A thoughtless action or habitual action

Figure 6. Behaviors and meanings of continuous attention decline

The behaviors and meanings of continuous meditation increase are shown in Figure 7. The meanings of behaviors can be summarized into four main behaviors, including self-confidence due to already knowing the strategy to be adopted, understanding the cards or being familiar with gameplay, looking at what the other side is doing in a round when it is not one's own turn and winning or being about to win. Among these behaviors, having self-confidence due to already knowing the strategy to be adopted and understanding the cards or being familiar with gameplay show that the students have reached the level of cognitive processing of knowledge and understanding. Looking at what the other side is doing in a round when it is not one's own turn and winning or being about to win do not involve not cognitive processing.

Behavior	Meaning
Draw the character card and look at its content	Already familiar with or understand the character card content
Arrange the meteorite cards of various sizes	Learning the meaning of how to arrange the meteorite of various size or have a strategy already
Move the meteorite cards of various sizes that were already on the board (change their position or take them away)	Already determined the location to be moved to
Study the magic card and fly card drawn	Watching the magic card and fly card without pressure, considering how to use it
Look at the other party's arranged magic card and fly card to be executed	The student has already arranged the card for the next round, waiting for the other party to perform the execution
After the card is studied, the card is played	Understands the contents of the card and know how to use it
Explain the content of the magic card	The student has studied the content and purely wants to talk to the other party
Shake the body	Is in a very good mood
Hold all the cards in one's own hand as a stack	The student already knows what to play
Randomly put the unused cards on any part of the desktop	Being sure to separate the cards unused or to be discarded
Mimic the card with one's own fingers or body to simulate the direction in which the rocket will move	Concentrating and being relaxed in simulating the path for flying ships
Pick a card from the discard area (magic card or fly card) and then put the used card in the discard area and draw the card immediately (magic card or fly card)	Already know the cards and the number of cards to be discarded or supplemented
After the flight ship starter card is pressed, move the rocket, and after the card is studied, put the card on the table (magic card or fly card)	Familiar and confident in executing card content
Read the direction of the fly card	Understand and know the direction of the fly card
Look at the other party's shuffle (magic card or fly card)	Treat it easily as none of one's own business
Shuffle by oneself (magic card or fly card)	A process with no need to think or make decisions
Look at the contents of some fixed pages of the manual, listen to the other party explain the content of the fly card and magic card arranged	Be very relaxed and stress free in listening to the other party to explain the contents of the card arranged
Move the card that was originally decided to be executed (reduce or increase the magic card or fly card, swap position of the magic card fly card, etc.)	Becoming very familiar with the game and free to change the card order
Open and look at the treasure card	Can finally open the treasure and be very happy

Figure 7. Behaviors and meanings of continuous meditation increase

Finally, the behaviors and meanings of continuous meditation decline are shown in Figure 8. The meaning of behaviors can be summarized into four main behaviors, including being unfamiliar with the contents of cards or forgetting which cards are one's own, anxiety about the strategy, drawing an unsuitable card, and loss of patience with the other party for taking too long to play. Regarding being unfamiliar with the contents of cards or forgetting which cards are one's own, it is necessary to strengthen the students' familiarity with the game mechanism and the card content, that is, to enhance the cognitive processing of knowledge and understanding. If there is anxiety in the strategy, then the student's application of strategy

needs to be strengthened, that is, to strengthen the ability of application and analysis. Finally, drawing an unsuitable card and having no patience with the other party taking too long to play are parts of the game and do not involve cognitive processing.

Behavior	Meaning
Arrange the meteorite cards of various sizes	The student feels anxious about the current situation and does not know where to put the cards
Organize the cards in the discard area (arrange them neatly or pile them up)	Feels pressure as classification cannot be wrong
Read out the steps (self-talk, magic card and fly card)	Cannot read the card content or is encountering bottlenecks
Take the covered card and quickly browse it and cover it again (magic card or fly card)	No card in the hand is wanted
Pick up the card that fell to the ground (magic card or fly card)	Feels a little nervous or embarrassed
Look at the other party with glazed eyes	Feels pressure about the card to be played by the other party, or the other party is about to find the treasure
Play with the cards in one's hands (moving them in circles, bending them, etc.)	It takes too long for the other party to play the card, and the student is losing patience
Look at the other party's cards and move the spaceship (magic card or fly card)	The other party is driving fast or better than oneself
Put unused cards in the discard area	There are no cards available, and the student is a little nervous

Figure 8. Behaviors and meanings of continuous meditation decline

After the experiment, we asked the students to share their thoughts on the game mechanics and learning outcomes. From the sharing of the students, we concluded that, first, the students believe that the familiarity of the card content and the game mechanics is very important. This finding is consistent with the results of our brainwave measurement. Students' familiarity with card content and game mechanics can increase focus and reduce anxiety during play. Second, the students believe that in order to improve the speed of winning, there are certain loops and functions in the game the can help them achieve the goal faster, and at this time, they can learn the content of the program logic.

4 Conclusions

To understand the extreme brainwave state and behavior of students in a tabletop game involving computational thinking to derive the relationship between behavioral meaning and cognitive processing, this study used the coding logical tabletop game Interstellar Explorer, which is played by 2 people. The study used the video and brainwave measurement to conduct behavior analysis and extreme brainwave signal comparison to find the extreme brainwave value. Then, the student's play behavior was examined for analysis, and the relevant behaviors, behavioral meanings and cognitive processing were summarized.

According to the research results, the continuous rise of attention and meditation showed low-level knowledge and understanding and high-level application, analysis and evaluation of cognitive processing, while the continuous decline of attention and meditation showed students' lack of knowledge and understanding level and the generation of behaviors irrelevant to cognitive processing.

From the meanings of the above behaviors and the understanding of Bloom's taxonomy, the continuous increase of attention included knowledge, understanding, analysis and evaluation; continuous attention decline lacked any behavior of cognitive processing; continuous rise of meditation contained the cognitive processing of knowledge and understanding; finally, the continuous decline of meditation indicated the need to strengthen the cognitive processing of knowledge and understanding. These results show this tabletop game can help students to achieve knowledge and understanding as well as analysis and evaluation of cognitive processing, but relative to other brainwave signals (such as continuous decline in attention and continuous rise in meditation), the number of instances of continuous attention rise was only 179 times, which was highly insufficient. In other parts of game play, where a significant increase or decrease took place, it was mostly due to insufficient knowledge and understanding of the card.

In response to the research findings and results, we summarized the following suggestions. First, it is recommended that the design of a tabletop game should consider how the content of the game is matched with the game mechanics, and game designers should check whether there is an application of cognitive processing according to Bloom's taxonomy so that students can learn knowledge in a natural environment through the game [15]. Second, to improve the cognitive ability of students playing tabletop games, it is recommended that tabletop games provide the ability to use contextual content and multiple strategies to enable students to practice the ability to apply, analyze and evaluate. The application of these strategies involves the application of a single strategy and a multistrategy and includes the player's change of the strategy application [17]. Finally, from the values of the brainwaves and the corresponding behaviors, the factors affecting meditation include the pressure of playing cards and the familiarity with the gameplay and cards. In terms of the pressure of playing cards, this is an inevitable pressure involved in educational tabletop games. Appropriate pressure can enhance students' cognitive thinking, but it is necessary to pay attention to whether students' prior knowledge and learning objectives are consistent; for the familiarity between the gameplay and the card, the teacher can release the pressure on the unfamiliar gameplay and card content by providing a long-term explanation and trial play [36, 40].

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References

[1] J. M. Wing, Computational thinking, *Communications of the ACM*, Vol. 49, No. 3, pp. 33-35, March, 2006.

[2] Google, Exploring Computational Thinking, 2010. [Online] Retrieved from https://www.google.com/edu/computational-thinking/

[3] S. Grover, R. Pea, Computational Thinking in K-12: A Review of the State of the Field, *Educational Researcher*, Vol. 42, No. 1, pp. 38-43, January, 2013.

[4] ACARA (Australian Curriculum, Assessment and Reporting Authority), *Draft Australian Curriculum: Technologies*, 2013. [Online] Retrieved from http://consultation.australiancurriculum.edu.au/Static/docs/Technologies/Draft%20Australian%20Curriculum%20Technologies%20-%20February%202013.pdf

[5] T. Brinda, H. Puhlmann, C. Schulte, Bridging ICT and CS: Educational standards for computer science in lower secondary education, *ACM SIGCSE Bulletin*, Vol. 41, No. 3, pp. 288-292, September, 2009.

[6] CSTA, CSTA K-12 Computer Science Standards, *The ACM K-12 Education Task Force*, 2011. [Online] Retrieved from http://www.csta.acm.org/Curriculum/sub/CurrFiles/CSTA_K-12_CSS.pdf

[7] N. C. Brown, S. Sentance, T. Crick, S. Humphreys, Restart: The resurgence of computer science in UK schools, *ACM Transactions on Computing Education (TOCE)*, Vol. 14, No. 2, pp. 1-22, June, 2014.

[8] N. Carlborg, M. Tyren, C. Heath, E. Eriksson, The scope of autonomy when teaching computational thinking in primary school, *International Journal of Child-Computer Interaction*, Vol. 21, pp. 130-139, September, 2019.

[9] L. Wu, C.-K. Looi, J. Multisilta, M.-L. How, H. Choi, T.-C. Hsu, P. Tuomi, Teacher's Perceptions and Readiness to Teach Coding Skills: A Comparative Study Between Finland, Mainland China, Singapore, Taiwan, and South Korea, *The Asia-Pacific Education Researcher*, Vol. 29, No. 1, pp. 21-34, February, 2020.

[10] D. Parmar, S. V. Babu, L. Lin, S. Jörg, N. D'Souza, A. E. Leonard, S. B. Daily, Can embodied interaction and virtual peer customization in a virtual programming environment enhance computational thinking?, *2016 Research on Equity and Sustained Participation in Engineering, Computing, and Technology (RESPECT)*, Atlanta, GA, USA, 2016, pp. 1-2.

[11] F. Buitrago Flórez, R. Casallas, M. Hernández, A. Reyes, S. Restrepo, G. Danies, Changing a generation's way of thinking: Teaching computational thinking through programming, *Review of Educational Research*, Vol. 87, No. 4, pp. 834-860, August, 2017.

[12] E. Costelloe, *Teaching Programming The State of the Art*, Department of Computing, Institute of Technology Tallaght, Dublin 24, CRITE Technical Report, 2004.

[13] K. Powers, S. Ecott, L. Hirshfield, Through the looking glass: teaching CS0 with Alice, *Proceedings of the 38th SIGCSE technical symposium on Computer science education*, Covington, Kentucky, USA, 2007, pp. 213-217.

[14] L. Mannila, M. Peltomäki, T. Salakoski, What about a simple language? Analyzing the difficulties in learning to program, *Computer science education*, Vol. 16, No. 3, pp. 211-227, February, 2006.

[15] Y.-H. Lai, S.-Y. Chen, C.-F. Lai, Y.-C. Chang, Y.-S. Su, Study on enhancing AIoT computational thinking skills by plot image-based VR, *Interactive Learning Environments*, pp. 1-14, February, 2019.

[16] W. Zhao, V. J. Shute, Can playing a video game foster computational thinking skills?, *Computers & Education*, Vol. 141, pp. 103633, November, 2019.

[17] Y.-S. Su, C.-L. Lin, S.-Y. Chen, C.-F. Lai, Bibliometric study of social network analysis literature, *Library Hi Tech*, Vol. 38, No. 2, pp. 420-433, December, 2019.

[18] R. E. Pattis, J. Roberts, M. Stehlik, *Karel the Robot: A Gentle Introduction to The Art of Programming*, John Wiley & Sons, 1995.

[19] P. Rich, S. F. Browning, Using Dr. Scratch as a Formative Feedback Tool to Assess Computational Thinking, in: J. Keengwe, P. Wachira (Eds.), *Handbook of Research on Integrating Computer Science and Computational Thinking in K-12 Education*, IGI Global, 2020, pp. 220-242.

[20] C. Angeli, N. Valanides, Developing young children's computational thinking with educational robotics: An interaction effect between gender and scaffolding strategy, *Computers in Human Behavior*, Vol. 105, pp. 105954, April, 2020.

[21] T. Bell, J. Alexander, I. Freeman, M. Grimley, Computer science unplugged: School students doing real computing without computers, *The New Zealand Journal of Applied Computing and Information Technology*, Vol. 13, No. 1, pp. 20-29, 2009.

[22] A. M. Piper, E. O'Brien, M. R. Morris, T. Winograd, SIDES: a cooperative tabletop computer game for social skills development, *Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work*, Banff, Alberta, Canada, 2006, pp. 1-10.

[23] S. Nicholson, Making gameplay matter: Designing modern educational tabletop games, *Knowledge Quest*, Vol. 40, No. 1, pp. 60-65, September/October, 2011.

[24] K. Brennan, M. Resnick, New frameworks for studying and assessing the development of computational thinking, *Proceedings of the 2012 annual meeting of the American educational research association*, Vancouver, Canada, 2012, pp. 1-25.

[25] L. Werner, J. Denner, S. Campe, D. C. Kawamoto, The fairy performance assessment: measuring computational thinking in middle school, *Proceedings of the 43rd ACM technical symposium on Computer Science Education*, Raleigh, North Carolina, United States, 2012, pp. 215-220.

[26] C. Selby, M. Dorling, J. Woollard, *Evidence of assessing computational thinking*, University of Southampton, December, 2014.

[27] F. Kalelioglu, Y. Gulbahar, V. Kukul, A framework for computational thinking based on a systematic research review, *Baltic Journal of Modern Computing*, Vol. 4, No. 3, pp. 583-596, May, 2016.

[28] H. T. Hou, *Game-based learning*, CommonWealth Magazine, Taipei, Taiwan, 2016.

[29] L. W. Anderson, D. R. Krathwohl, *A taxonomy for learning, teaching, and assessing: a revision of bloom's taxonomy of educational objectives*, Addison Wesley Longman, 2001.

[30] L. Anderson, *Revised Bloom's Taxonomy*, Paper presented at North Carolina Career and Technical Education Curriculum Development Training, Raleigh, NC, 2006.

[31] C. G. Johnson, U. Fuller, Is Bloom's taxonomy appropriate for computer science?, *Proceedings of the 6th Baltic Sea conference on Computing education research: Koli Calling 2006*, Uppsala, Sweden, 2006, pp. 120-123.

[32] E. Thompson, A. Luxton-Reilly, J. L. Whalley, M. Hu, P. Robbins, Bloom's taxonomy for CS assessment, *Proceedings of the tenth conference on Australasian Computing Education-Volume 78*, Wollongong, NSW, Australia, 2008, pp. 155-161.

[33] L. Haas, Hans Berger (1873-1941), Richard Caton (1842-1926), and electroencephalography, *Journal of Neurology, Neurosurgery & Psychiatry*, Vol. 74, No. 1, pp. 9-9, January, 2003.

[34] J. Huang, C. Yu, Y. Wang, Y. Zhao, S. Liu, C. Mo, J. Liu, L. Zhang, Y. Shi, FOCUS: Enhancing children's engagement in reading by using contextual BCI training sessions, *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Toronto, Ontario, Canada, 2014, pp. 1905-1908.

[35] I. L. Cheng, S. W. Chew, Y. Kang, W. Chang, N. S. Chen, Exploring the difference in brain activities under three distinct tasks: Listening to music, gaming, and learning, *2016 IEEE 16th International Conference on Advanced Learning Technologies (ICALT)*, Austin, TX, USA, 2016, pp. 493-497.

[36] Y.-S. Su, C.-H. Chou, Y.-L. Chu, Z.-F. Yang, A finger-worn device for exploring chinese printed text with using CNN algorithm on a micro IoT processor, *IEEE Access*, Vol. 7, pp. 116529-116541, August, 2019.

[37] S.-Y. Wu, J.-C. Fang, S.-M. Lian, Design a computational thinking board game based on programming elements, *International Conference on Computational Thinking Education 2018*, Hong Kong, 2018, pp. 19-20.

[38] S.-K. Tai, C.-Y. Liao, R.-C. Chen, Exploration of multi-brainwave system mainframe design, *ICIC Express Letters, Part B: Applications*, Vol. 8, No. 9, pp. 1307-1314, September, 2017.

[39] M. Hegarty, Mechanical reasoning by mental simulation, *Trends in cognitive sciences*, Vol. 8, No. 6, pp. 280-285, June, 2004.

[40] Y.-S. Su, C.-F. Ni, W.-C. Li, I.-H. Lee, C.-P. Lin, Applying deep learning algorithms to enhance simulations of large-scale groundwater flow in IoTs, *Applied Soft Computing*, Vol. 92, pp. 106298, July, 2020.

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