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How Unplugged Computational Thinking Shapes Students' Creative Thinking: Evidence From the Human Nervous and Endocrine Systems

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Abstract
This study offers a new and innovative perspective by examining the interaction between two important 21st-century skills—creative thinking and computational thinking (CT). Despite the growing body of research on CT and creativity, evidence regarding the effectiveness of unplugged CT activities in fostering students' creative thinking within science education remains limited. Therefore, the aim of this research is to examine the effect of the unplugged CT approach, implemented within the topic of "the human nervous and endocrine systems," on the creative thinking dispositions of 6th-grade middle school students. A quasi-experimental design with a pretest–posttest control group was employed. Students in the experimental group ($n=30$) participated in unplugged CT activities, while students in the control group ($n=30$) engaged in student-centered activities aligned with the current science curriculum. Results of the covariance analysis revealed a statistically significant difference in favor of the experimental group with respect to students' creative thinking dispositions. The observed increase in creative thinking dispositions in the experimental group can be attributed to the flexible and innovative learning environment provided during unplugged CT activities, where students developed their own games, designs, and models. In conclusion, this study provides concrete evidence that flexible, inquiry-based unplugged CT activities, in which students design and create their own products in science education, enhance their creativity.

Keywords Unplugged Computational Thinking · Creative Thinking · Human Nervous and Endocrine System · Middle School Students

Introduction

In the 21st century, the growing demand for innovative ways of thinking has brought creative thinking and computational thinking (CT) skills to the forefront of educational research (Bocconi et al., 2016; Israel-Fishelson & Hershkovitz, 2024). Computational thinking (CT) is defined as the process of structuring problems, designing solutions to these problems, and transforming these solutions into forms that can be executed by both humans and computer systems (Brennan & Resnick, 2012). Recent studies conceptualize CT as a holistic problem-solving approach consisting of complementary cognitive processes such as decomposition, pattern recognition, abstraction, and algorithmic thinking (Israel-Fishelson & Hershkovitz, 2022; Ocampo et al., 2024). Creative thinking, on the other hand, is defined as a cognitive process that enables individuals to generate original, meaningful, and valuable ideas, and consists of multidimensional components such as fluency, flexibility, originality, and elaboration (López Martínez et al., 2024). Current literature shows that the systematic and structured problem-solving nature of CT is closely related to creative thinking processes and that competencies such as approaching complex problems from different perspectives, developing alternative solution paths, and producing innovative ideas are jointly supported by both processes (Aytekin & Topçu, 2024; Israel-Fishelson & Hershkovitz, 2024). Therefore, numerous studies have indicated a strong relationship

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between CT and creative thinking (Israel-Fishelson & Hershkovitz, 2022).

CT enables individuals to move beyond being passive consumers of technology and instead become creative producers who actively use it to develop new products, projects, and solutions (Brennan, 2021; Korkmaz, Çakır & Özden, 2017; Mishra et al., 2013; Nagai et al., 2019; Strawhacker & Bers, 2019). Indeed, a review of the literature shows that using computational thinking skills through computers and programming can promote creative thinking (Knochel & Patton, 2015). In another study, Roque et al. (2016) demonstrated that the creative potential offered by programming environments involving computational thinking can serve as a catalyst for effective learning processes by supporting individuals' problem-solving, design thinking, and innovation skills. In a more recent study, it was also found that in self-directed computer programming learning environments, middle school students developed their creative thinking processes through the use of computational thinking skills (Brennan, 2021).

As the literature shows, the relationship between computational thinking (CT) skills and creative thinking has predominantly been examined in plugged learning environments that involve computer use and programming. Computer-assisted coding activities and technology-supported programming environments effectively support students' creative thinking alongside computational thinking development. Studies conducted in plugged CT environments indicate that creative programming experiences foster creativity through open-ended design tasks, iterative problem-solving processes, and the production of original digital artifacts (Romero et al., 2017). Similarly, research on robotics programming at the elementary school level has demonstrated that programming-based activities enhance students' originality, flexibility, and creative problem-solving through hands-on interaction and tangible feedback (Noh & Lee, 2020). Overall previous studies, these findings suggest that programming-based computational thinking environments provide a strong foundation for creativity across different educational levels. However, recent studies have also demonstrated that unplugged learning environments can enhance a variety of student learning outcomes (Peel et al., 2022). Among these outcomes, creative thinking stands out as one of the indispensable 21st-century skills. Given that CT and creative thinking are conceptually and mechanistically intertwined (Israel-Fishelson et al., 2022), and that the positive effects of plugged CT approaches on creativity are well documented (Bers et al., 2014; Brennan, 2021; Romero et al., 2017; Zaharin et al.,2018), there is a pressing need for empirical evidence regarding the impact of unplugged CT approaches on students' creativity.

Unplugged CT activities—such as paper-and-pencil tasks, role-playing, kinesthetic activities, games, arts-based tasks, and the use of simple materials—can be implemented by teachers in classrooms without requiring computers, programming, or technical expertise, making them particularly practical for science education. Previous studies have shown that many science topics can be effectively integrated into CT-based instruction (Aksit & Wiebe, 2020; Arık & Topçu, 2022; Aytekin & Topçu,2024; Peel et al., 2019a, b). Nevertheless, an important question remains as to which science topics are most suitable for CT integration. To address this gap, the present study investigates the applicability of unplugged CT to the topic of the human nervous and endocrine systems and examines its potential to foster students' creative thinking.

Despite the growing body of research on CT and creativity, evidence regarding the effectiveness of unplugged CT activities in fostering students' creative thinking within science education remains limited. Most existing studies have focused on plugged environments, leaving a gap in understanding how unplugged approaches can be integrated into specific science topics. To address this gap, the present study explores the implementation of unplugged CT activities in teaching the human nervous and endocrine systems. Specifically, it examines whether and how an unplugged CT approach can enhance students' creative thinking in the context of science classrooms. Thus, the primary purpose of this study is to investigate the effect of an unplugged CT approach on students' creative thinking dispositions within the context of science education, focusing specifically on the human nervous and endocrine systems. Therefore, the research question of the study is presented below:

What is the effect of the unplugged computational thinking approach on students' creative thinking dispositions in the context of learning the human nervous and endocrine systems?

Research Background

CT and CT Components

Computational Thinking (CT) is defined as a fundamental, human-centered thinking skill that involves the use of basic elements of computer science, supports individuals in problem-solving, and emphasizes personal understanding, competence, experience, and imagination (Wang et al., 2025). CT is recognized not only as skills for computer scientists but also as essential abilities for everyday life. Moreover, CT has been shown to facilitate the understanding of complex and abstract concepts, particularly in science

education, and to deepen the learning process (Peel et al., 2022). The complexity, abstract nature, and sequential processes involved in biology make it an ideal context for the integration of computational thinking. By using algorithms and abstraction—two key components of CT—students can make complex biological processes more meaningful. In the current study, the human nervous and endocrine systems were selected as the context, and students were asked to explain the interactions between the brain and organs using algorithms and by creating abstractions through computational thinking skills. In addition, students were guided to recognize, within the framework of CT components, that the process of hormone secretion—which plays a crucial role in maintaining the body's balance—follows a specific pattern and occurs in a repetitive manner.

In the existing literature, various analytical frameworks have been proposed to understand and analyze CT (Csizmadia et al., 2015; Shute et al., 2017; Wing, 2010). For example, while Shute et al. (2017) identify abstraction, decomposition, algorithms, debugging, and iteration as components of CT, Csizmadia et al. (2015) include algorithmic thinking, logical reasoning, abstraction, decomposition, generalization, and evaluation. In the present study, the CT analytical framework (See Table 1) taking into account the prominent standards (ISTE and CSTA, 2011) and the CT components widely accepted by researchers (Brennan & Resnick, 2012; Csizmadia et al., 2015; Dong et al., 2019; Fofang et al., 2020; Selby & Woollard, 2013; Valenzuela, 2020; Weintrop et al., 2016) was adopted. This framework contains CT components that best reflect the process of teaching the concepts and process of the human nervous and endocrine systems topic. Another reason for the selection of this framework is that the identified CT components. For example, the interaction between nerve cells can be explained in a more understandable and sequential manner through the process of *algorithmic thinking*, a CT component. The interaction

Table 1 CT components, their definitions, creative and unplugged CT activities integrated into the human nervous and endocrine system topic

CT Component	Definition	Creative unplugged CT activities integrated into the human nervous and endocrine system topic
Abstraction	This involves simplifying the instructional content by eliminating irrelevant details and focusing on the key concepts or processes of the subject.	- The students create a concept map summarizing the functions of the central nervous system organs (the brain and spinal cord) using paper, pencils, and colored cardboard.
Decomposition	This refers to dividing a complex and broad subject into smaller, more manageable and comprehensible components.	-The students design endocrine gland cards for five different endocrine glands. Each card includes the function of the corresponding gland.
Branching	This concept highlights that varying circumstances can result in different consequences.	- The students create cards that describe voluntary and involuntary responses of the body and use them to design a game. For example, if a student draws the card saying 'a needle pricks the hand' and correctly states that this response is controlled by the spinal cord, they earn a point. However, if they incorrectly say it is controlled by the brain, they lose the game.
Pattern Creation	Creation involves recognizing patterns, distinctions, and principles within events.	- The reflex mechanism creates a repeating pattern in response to sudden situations. The students participate in a role-playing activity where they simulate the process of a needle pricking their hand, including how sensory receptors receive the stimulus and transmit it to the nerves, how the nerves carry the stimulus to the spinal cord, how a response is generated in the spinal cord, and finally, how this response is transmitted to the relevant organ through the nerves.
Iteration	This refers to the repetitive cycle of a specific process occurring continuously.	- Students recognize that, in order to maintain internal balance (e.g., when blood sugar levels rise or fall, or in situations of fear and excitement), the relevant hormones are secreted again when similar situations are encountered repeatedly.
Algorithm Creation	It involves the representation of a process in a step-by-step order.	- Using colored cardboard and markers, the students create models of the nerve cells involved in a reflex arc and the organs of the central nervous system. They also design a stimulus card. Then, they choose classmates to act out the reflex mechanism, with each student representing a different part of the model.

between the brain and spinal cord, as part of the central nervous system, can be highlighted and visualized through *the abstraction process*, allowing for a better understanding of the underlying mechanisms of the nervous and endocrine systems.

CT and Creative Thinking

Creative thinking, like computational thinking, is a universal 21st-century skill, and its development should be nurtured from an early age. This skill is one of the essential skills needed not only in school but in all areas of life. Ellis Paul Torrance defined creativity as the process of being sensitive to problems, thinking about problems, and producing original and valuable products after solving problems in an innovative way (Torrance, 1965; 1974). Torrance explained creativity through four sub-dimensions: (1) fluency, (2) flexibility, (3) originality, and (4) elaboration. Fluency is defined as the ability to generate a large number of ideas and thoughts about a specific topic or problem, while flexibility is defined as the ability to produce ideas under different categories related to a given topic or problem. In addition, originality involves presenting unusual and unique ideas, whereas elaboration includes providing as much detail as possible about an existing idea.

The literature reveals a mutual, bidirectional relationship between -CT and creative thinking. Creative thinking skills act as a catalyst for solving algorithmic problems (Hershkovitz et al., 2019). A study conducted by Liu and Lu (2002) showed that creative thinking skills predicted undergraduate students' problem-solving abilities while programming computers. On the other hand, there are also studies showing that CT skills support creative thinking (Seo & Kim, 2016; Yadav & Cooper, 2017). For example, it is not very likely for a software engineer to write code and produce solutions to a problem without using creativity. Therefore, the literature has developed more in this direction, and the relationship between creativity and CT has mostly been discussed in the context of computer programming and game development. Although CT and creativity are universal skills, it is an undeniable fact that they gain meaning depending on the context (Hershkovitz et al., 2019). According to an engineer, creativity is producing an original design that solves a problem; for a scientist, creativity is proving a scientific claim through experiment and observation; and for a teacher, it is an extraordinary idea received from a student. Considering these circumstances, this study approached STEM education in general—and specifically the topic of the human nervous and endocrine systems from science education—as the context. Within this context, computational thinking was integrated, and the impact of this integration on middle school students' creativity skills was examined. The present study goes a step beyond merely exploring the relationship between these two important skills by conducting an experimental study and providing a contextual learning environment, thereby making a significant contribution to the literature.

The Integration of CT into the Topic of the Human Nervous and Endocrine Systems

The topic of the human nervous and endocrine systems is a subject in science/biology that is closely related to the functioning of many systems in our body (circulatory, respiratory, digestive, etc.) and is considered abstract and difficult to understand by students (Ağyürek & Köse, 2022; Kvello & Gericke, 2021; Zangerolamo et al., 2020). This topic consists of complex networks and biological processes that regulate the organism's responses to stimuli from the environment, play a role in maintaining internal balance (homeostasis), and shape various behaviors (Fabris et al., 2020). In particular, understanding the events that occur during the transmission of a stimulus in a nerve cell and how responses to this stimulus occur helps us realize how our body functions. It facilitates understanding how central nervous system organs such as the brain and spinal cord work in coordination with endocrine glands. In this regard, addressing this topic in science education provides important contributions to students' understanding of how the systems in our body work in harmony and interact with each other (Laelasari & Wakhidah, 2023; Zangerolamo et al., 2020). In this sense, teaching this topic is of great importance for students to understand the interrelationship between biological systems from a holistic perspective.

Previous research on students' learning of the nervous and endocrine systems has shown that these topics are challenging due to the abstract nature of neuronal transmission, hormone regulation, and homeostatic feedback loops. For example, Azzi et al. (2023) found that students had difficulty understanding the sequential steps of the reflex arc, while Rachidi et al. (2024) reported that many students struggled to conceptualize hormonal feedback mechanisms such as insulin–glucagon regulation. Similarly, Fabris et al. (2020) demonstrated that students tend to memorize individual structures without fully grasping the dynamic interactions between nervous system organs and endocrine glands. Studies also indicate that misconceptions—such as believing that hormones act instantaneously like nerve impulses or that all reflexes involve the brain—are common among middle school students (Zangerolamo et al., 2020). This body of literature highlights the need for instructional approaches that simplify, sequence, and visualize these mechanisms. Therefore, the present study aligns with previous research by addressing the complex nature of these systems and responding directly to the documented learning difficulties.

The integration of computational thinking skills in teaching the human nervous and endocrine systems provides various contributions to the teaching of this topic and helps make its abstract nature more concrete. For example, when dealing with a reflex event, creating an *algorithm* allows students to understand each step of the process, from the reception of the stimulus to its transmission through nerve cells to the central nervous system organ, and finally, how the response to the stimulus is formed. Alternatively, we can use the *branching component*, a CT element, to better understand how our body reacts in different situations. For example, *if* blood sugar drops, the hormone glucagon is released; *if* blood sugar rises, the hormone insulin is released. Through *the decomposition component*, students can learn the topic by breaking it down into smaller subparts. For example, the central nervous system can be taught more easily by dividing it into the brain and spinal cord, and the brain can be further divided into the forebrain, midbrain, and hindbrain. Under the *abstraction component*, they can focus on the main idea of the topic instead of getting caught up in unnecessary details. For example, the most noticeable effects of the hormone adrenaline on the body, such as an accelerated heartbeat, excitement, and feelings of fear, are emphasized. Recurring cyclical processes can become more understandable within the *patterning* and *iteration components*. The reflex mechanism, for example, creates a recurring pattern that follows a specific sequence of actions in sudden situations. More specifically, when a hot object is touched, sensory receptors detect the stimulus, and it is transmitted to the spinal cord via nerve cells. The response in the spinal cord is then transmitted by nerves to the relevant muscle or organ. This process demonstrates that the reflex occurs according to a specific pattern. Thus, the components of CT facilitate a clearer and more effective teaching of the human nervous and endocrine systems. Table 1 presents the definitions of CT components and provides examples of students' creative thinking activities within the framework of the activities conducted through the integration of CT components into the topic of the human nervous and endocrine systems.

Methods

Research design

In this study, a quasi-experimental design, one of the quantitative research methods, was used, and a pretest-posttest control group model was applied. The study included one experimental group and one control group. The groups were formed through random assignment measurements conducted before the experimental implementation. In the experimental group, the instruction was carried out using the unplugged CT approach, while in the control group, a student-centered approach based on the nationwide mandatory current 6th-grade science curriculum was used (Fig. 1). You can see implemented activities for each group in Table 2.

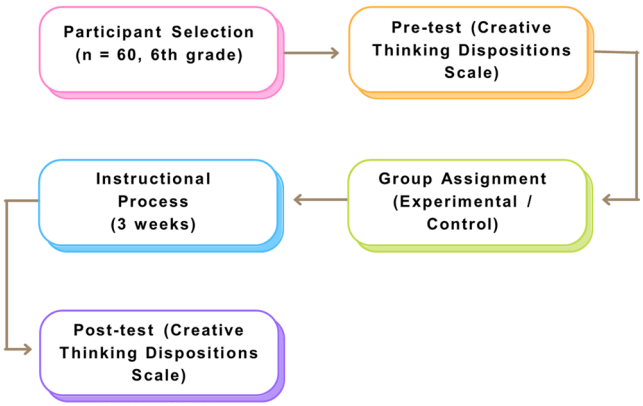


Fig. 1 Flow diagram of the research design and stages

Table 2 Experimental research design

Group name	Pre-test	Realised implementation	Post-test
Experimental	CTDS	Unplugged CT-based activities	CTDS
Control	CTDS	Student-centered activities based on the current 6th-grade science curriculum	CTDS

CTDS: Creative thinking dispositions scale

Participants

This study was conducted with 60 sixth-grade students attending a public middle school with moderate academic performance in a city located in the western region of Türkiye. Two sixth-grade classes from the school were selected based on the similarity of their academic performance in the previous semester. One of these classes was randomly assigned to the experimental group, and the other was randomly assigned to the control group. The experimental group consisted of 30 students (14 boys and 16 girls), while the control group also included 30 students (15 boys and 15 girls). The students participating in the study were between the ages of 12 and 13, had similar socioeconomic status (representing middle-class families), and all participated voluntarily. All students took part in the implementation over a period of three weeks.

Implementation Process in the Experimental Group

In the experimental group, the topic of the human nervous and endocrine systems was integrated with the unplugged computational thinking (CT) approach. It is important to

note that unplugged CT approach often inherently include hands-on, open-ended, and inquiry-based tasks. In line with this approach, students completed six different activities using tangible instructional materials (such as paper, colored pens, colored cardboard, glue, magnets, etc.) or through kinesthetic activities, games, and competitions.

In this process, CT skills were taught explicitly in the experimental group. Before each activity, the relevant CT component (e.g., abstraction, algorithm design, or pattern recognition) was clearly introduced to the students, its definition was explained, and the cognitive process involved was explicitly emphasized by the teacher during the activity. All activities, conducted with the active participation of the students, were completed over a period of three weeks, consisting of 12 class hours (each class hour being 40 min long) (See Table 3). Following the current science curriculum, students learned about the human nervous and endocrine systems within the context of these six different activities. The implementation was carried out in two stages. In the first stage, students learned computational thinking skills with the help of the unplugged coding game "Tospaa" (https://tospaa.org). In the second stage, they engaged in six different activities involving unplugged CT components. Each activity required the use of a different CT component integrated into the topic of the human nervous and endocrine systems. The integration of CT skill sub-dimensions with

Table 3 Application stages, durations, and activities in the experimental and control groups

Groups	Stages	Durations	Activities
Experimental	Stage 1 In the initial phase, students engage with computational thinking skills like algorithm creation, iterative, branching, abstraction, decomposition and pattern creation.	4 class hours (1 week)	By using the unplugged coding game Tospaa (https://tospaa.org), students develop their understanding of algorithm creation, iteration, branching, and pattern recognition through the use of direction, repetition, and condition cards. Additionally, they grasp the concepts of abstraction and decomposition by creating models and concept maps with colored cardboard and pencils.
	Stage 2 Students engaged in six separate activities developed according to the Unplugged Computational Thinking (CT) approach, utilizing a distinct CT component in each task. With the teacher's guidance, they determined how to apply the appropriate CT component during each activity.	8 class hours (2 week)	Students demonstrated their creativity by building models of neurons, the brain, the spinal cord, and endocrine glands using colored paper, colored pens, glue, and magnets as part of their practice with this CT component (abstraction). (2 lesson hours) They applied the reflex mechanism step by step through role-playing activities based on scenarios they designed themselves (algorithm creation). (2 class hours) Using colored cardboard, students created hormone cards and effect cards, which represented the organs influenced by hormones and their functions. They then matched the hormone cards with the corresponding glands and effect cards (decomposition) (1 class hour). Students created their own condition cards using colored cardboard and designed games based on events occurring in the body (e.g., a drop in blood sugar) by using these condition cards (branching) (1 lesson hour). Students animated the sequence and repetition involved in the transmission of a stimulus by employing the models of neurons, muscles, and sensory organs they had created (Pattern creation) (1 class hours). Students repeatedly selected the same hormone (adrenaline) card when they encountered the same situation card (e.g., fear or excitement) (Iteration (1 class hours).
Control	Stage 1 Preparatory work was carried out to prepare for the topic.	2 lesson hours (Half a week)	Students individually researched questions such as "What changes occur in our body when we are scared or excited? What could be the causes of these changes? Our body has many systems. What role might the brain play in ensuring these systems work together?" They used the internet, textbooks, and class videos for their research. They presented their findings through creative products such as presentations, models, posters, and so on.
	Stage 2 The topic was taught by following the textbook.	10 lesson hours (2.5 weeks)	Students read the textbook and watched the lesson videos. During this process, they completed the activities included in the textbook. In these activities, students were asked to write a story about "what you would experience as a neuron for a day" and to participate in the "How Fast Are You?" activity, where they reenacted the reflex process (7 lesson hours). As part of the end-of-unit activities, students actively participated in exercises such as true-false questions, fill-in-the-blanks, concept matching, and answering open-ended questions. For example, they wrote the names and functions of the organs on the central nervous system model provided in the textbook, matched hormones with the endocrine glands that secrete them, and identified the names and functions of modeled endocrine glands (3 lesson hours).

the human nervous and endocrine systems activities is presented in Table 4, which provides a clear overview of the CT framework, along with the brief content and instructional purpose of each activity. In each activity, students were informed in advance which CT component they would use, and they were encouraged to consciously apply this component while completing the task. Thus, students did not use CT skills implicitly; rather, they were made aware of the specific CT processes involved in each activity.

In every activity, students used a different CT component while applying their creativity. For example, in an activity requiring the use of the algorithm creation component, students first decided whether to use concrete materials, kinesthetic activities, games, or role-play methods to develop an algorithm. Then, using their creativity, they constructed an algorithm related to the human nervous and endocrine systems. During this process, students could consult the teacher about how to create an algorithm, but the algorithms they developed were products of their own creativity. Thus, while the teacher acted as a guide during the implementation process, the students actively carried out the activities. Similarly, before the brain model–building activity,

Table 4 Integration of CT Skill Sub-Dimensions with Human Nervous and Endocrine Systems Activities

Activity	Science Topic	Brief Description	CT Sub-Components	Instructional Objective	Duration
1	Nervous System	Students built models of neurons, the brain, spinal cord, and endocrine glands using colored paper, colored pens, glue, and magnets	Abstraction	Explains the functions of the central and peripheral nervous systems on the model.	2 class hours
2	Nervous System	Students applied the reflex mechanism step by step through role-playing activities based on scenarios they designed	Algorithm Creation	Explains how the reflex mechanism works.	2 class hours
3	Endocrine System	Students created hormone cards and effect cards representing their functions using colored cardboard, then matched the hormone cards with the corresponding glands and effect cards	Decomposition	Students learn the hormones secreted by the endocrine glands.	1 class hour
4	Endocrine/ Nervous System	Students created condition cards using colored cardboard and designed games based on body events (e.g., drop in blood sugar)	Branching	Students understand the regulatory processes that maintain the body's internal balance (homeostasis).	1 class hour
5	Nervous System	Students used the models of neurons, muscles, and sensory organs they had created to animate the steps and patterns involved in impulse transmission	Pattern Creation	Students explain the fundamental processes that occur during the transmission of a nerve impulse within a neural network.	1 class hour
6	Endocrine System	Students use concrete materials such as condition cards (e.g., fear, excitement, danger) and hormone cards (adrenaline) made from colored cardboard. Each time a condition card representing fear or excitement is drawn, students repeatedly raise the adrenaline card. This repetition helps students model how adrenaline is secreted repeatedly as long as the stimulus continues, without using any digital tools.	Repetition	Students recognize that hormones secreted to maintain the body's internal balance in different situations are released again when the same situations are encountered repeatedly.	1 class hour

the concept of abstraction was explicitly explained to the students. They were informed that the modeling process required representing only the essential structures and functions of the brain that were relevant to the learning objectives, rather than all anatomical details. During the activity, students were explicitly reminded that the model they were constructing was an example of abstraction, and they were encouraged to reflect on this process.

An example of an unplugged CT activity integrated into the nervous and endocrine systems is provided in Appendix 1.

Implementation Process in the Control Group

In the control group, a student-centered approach based on the current nationwade mandatory 6th-grade science curriculum was applied the topic of the human nervous and endocrine systems. In the control group, students engaged in student-centered activities and completed tasks similar to those in the experimental group, such as hands-on, open-ended, and inquiry-based tasks; however, CT components were not integrated into these activities in the control group. Similar to the experimental group, the activities in the control group were carried out over a period of 3 weeks and 12 class hours.

During the instructional process, the textbook was used. The activities in the textbook related to the human nervous and endocrine systems were implemented with the active participation of the students. In the textbook, there are preparatory tasks, two main activities, and end-of-unit exercises for students. As part of the preparatory tasks, the textbook includes research questions and discussion activities. While searching for answers to the research questions, students individually investigate the topic using the internet, the textbook, and lesson videos. They present their findings using creative products such as presentations, models, or posters. The models created in the control group were developed as scientific models in accordance with the objectives of the science curriculum and aimed to represent the anatomical structures and functions of the nervous and endocrine systems in a detailed manner. Unlike the abstraction-focused modeling activities in the experimental group, students in the control group were not instructed to simplify or deliberately omit details, nor were they informed that they were engaging in an abstraction process. Therefore, these modeling activities were not framed as CT-based abstraction tasks.

Afterwards, they carry out the activities included in the textbook. In these activities, students are asked to write a story about "what you would experience as a neuron for a day" and to complete the activity titled "how fast are you?" Although the story-writing activity may appear sequential on the surface, students were not guided to construct step-by-step procedures, decision points, or ordered rules. The story did not require an explicit, structured, or systematic sequence of steps; therefore, it was not designed or implemented as an algorithmic activity, and no references to algorithm design or computational thinking were made during instruction.

Finally, in the end-of-unit section, students actively participate in activities such as true-false exercises, fill-in-the-blanks, concept matching, answering open-ended questions, and model building. In all of these activities, students actively participate using their creativity, while the teacher acts as a guide throughout the process. Throughout the entire instructional process in the control group, CT components were neither explicitly introduced nor intentionally emphasized. As a result, although students engaged in creative and student-centered activities, they were not made aware of, nor systematically engaged in, computational thinking processes (See Table 3).

An example of an activity used in the control group is provided in Appendix 2 (Fig. 2).

The instructional practices carried out in the experimental and control groups are explained in detail in Table 3.

Data Collection Tool

In this study, the Creative Thinking Dispositions Scale, developed by Özgenel and Çetin (2017), was used to measure students' creative thinking dispositions before and after the experimental practices. The validity and reliability of the scale were established by Özgenel and Çetin (2017). Detailed information regarding the development, validity, and reliability of the scale can be accessed in the original study (https://doi.org/10.15285/maruaebd.335087). This scale is a self-assessment (self-report) scale. Likert-type instrument, consists of 6 factors (self-discipline, seeking innovation, courage, curiosity, skepticism, and flexibility) and 25 items. The items of the scale are grouped under six sub-dimensions as follows: Items 1, 6, 7, 15, and 23 belong to *self-discipline*; Items 2, 5, 8, 12, 17, 19, 22, and 24 to seeking *innovation*; Items 9, 11, 14, and 25 to *courage*; Items 3, 10, and 21 to *curiosity*; Items 4 and 16 to *skepticism*; and Items 13, 18, and 20 to *flexibility*.

Sample items representing each of these six factors are presented in order as follows. For example, a sample item for the **self-discipline** sub-dimension is *"I work in a disciplined manner to create an idea or a product."* For **seeking innovation**, *"I design a new idea, product, or solution by using my imagination."* For **courage**, *"I express my feelings and thoughts, even if they are different from others', without fear."* For **curiosity**, *"I enjoy dealing with events, situations, or tasks that I am curious about or interested in."* For **skepticism**, *"I accept that an event or a problem may*

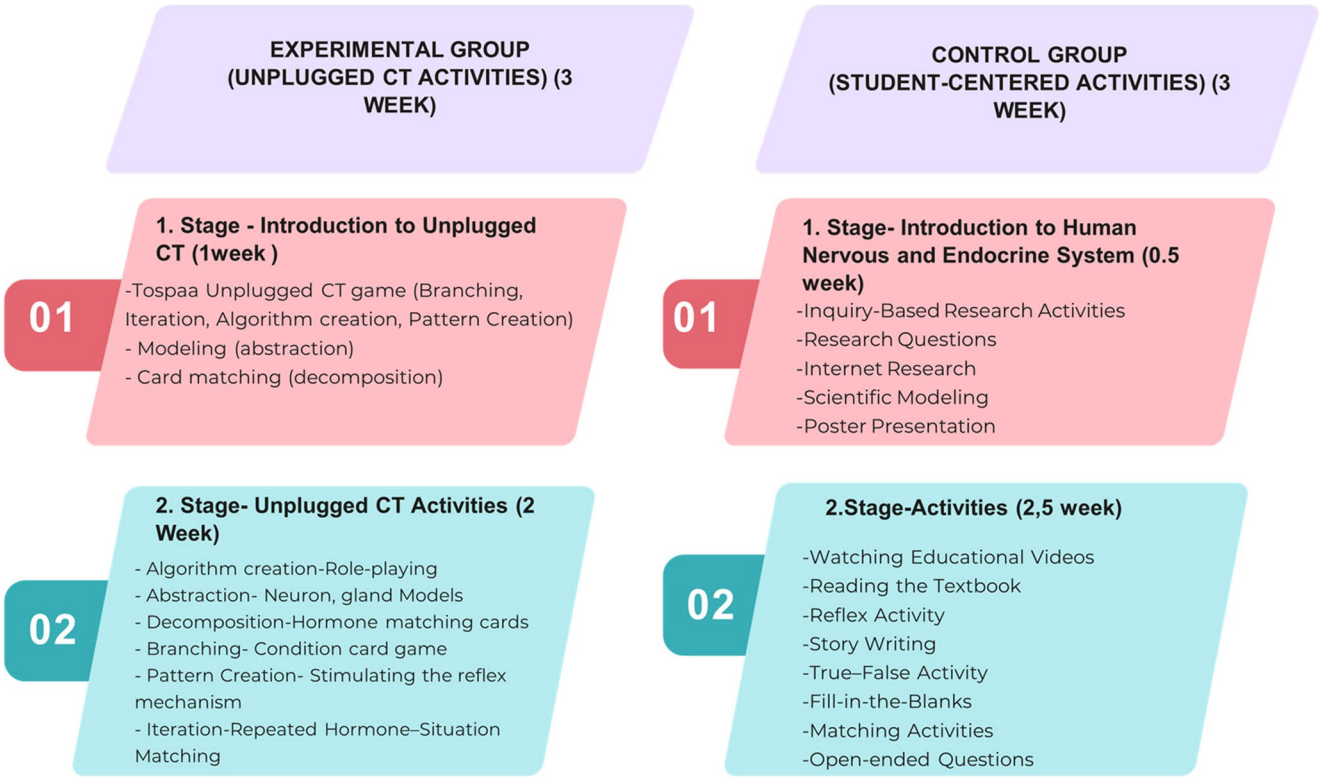


Fig. 2 Learning Activity Flowchart for Experimental and Control Groups

have more than one cause." For **flexibility**, *"I try to look at events from different perspectives."*

It can be stated that the sub-dimensions of the scale are related to CT. For example, seeking innovation enhances creative problem-solving; courage enables trial-and-error and iterative problem-solving processes; curiosity activates CT processes such as questioning problems, recognizing patterns, and exploration.

Data Analysis

The responses given in the Likert-type scale used to measure students' creative thinking dispositions were scored as follows: "Always (5), Generally (4), Occasionally (3), Rarely (2), Never (1)." Accordingly, the lowest possible score on the scale is 25, and the highest score is 125. To determine whether there was a difference in the creative thinking dispositions of the students in the experimental and control groups, a one-way analysis of covariance (ANCOVA) was conducted. In this analysis, the independent variable was the experimental and control groups, while the pre-test scores of the Creative Thinking Dispositions Scale (CTDS) were considered as the covariate, and the post-test scores of both groups were the dependent variable. ANCOVA is an inferential analysis method used to reduce the Type 1 error probability in multiple comparisons (Pallant, 2020). In this context, ANCOVA was preferred to control for pre-test score differences between groups, reduce the Type 1 error risk, and more clearly assess the change between the pre-test and post-test.

Findings

Before the ANCOVA analysis, the necessary statistical assumptions (Pallant, 2020) were checked, and it was determined that all assumptions were met. First, a normality analysis was conducted on the pre-test and post-test scores of the experimental and control groups regarding their creative thinking dispositions. According to the Shapiro-Wilk normality test results presented in Table 4, the p-values for the pre-test and post-test scores of the experimental and control groups are above the 0.05 level. Additionally, the skewness and kurtosis coefficients of the pre-test and post-test scores of both groups fall within the range of −1.5 to +1.5 (Tabachnick et al., 2013), indicating that these scores follow a normal distribution.

To check if the variances between groups are equal, a Levene's test was conducted. The p-value obtained from the test being greater than 0.05 indicates that the variances between the groups are equal [$F(1,58) = 0.166$, $p > .05$]. Additionally, the scatter plot was used to examine whether there is a linear relationship between the CTDS pre-test

Table 5 Normality analysis of the data obtained from the CTDS

Tests	Groups	Shapiro-Wilk	Skewness	Kurtosis	Distribution
Pre-tests	Experiment	0.088	0.638	−0.145	Normal
	Control	0.124	−0.645	−0.341	Normal
Post-tests	Experiment	0.546	−0.401	−0.386	Normal
	Control	0.778	−0.120	−0.589	Normal

Table 6 Post-Test Means, Adjusted Means, Standard Deviations, and Standard Errors of the Groups for CTDS

Groups	Means	Adjusted Means	Standard Deviations	Standard Error
Experiment	100.70	100.72	13.58	2.58
Control	88.40	88.44	14.48	2.58

and post-test scores, and a linear relationship was found. Finally, it was tested whether the slopes of the regression lines between the group and the pre-test scores were different. The p-value obtained being greater than 0.05 indicates that the slopes do not significantly differ between groups [$F(1,56) = 0.905$, $p > .05$]. This indicates that the slopes of the regression lines for CTDS are homogeneous. After ensuring all these assumptions, the ANCOVA analysis for the CTDS scores was conducted (Table 5).

The ANCOVA results for the CTDS are presented in Tables 6 and 7.

When Table 6 is examined, it is seen that the adjusted post-test mean of the experimental group ($M = 100.72$, $SD = 13.58$) is higher than that of the control group ($M = 88.44$, $SD = 14.48$). This finding indicates that the creative thinking dispositions of the students in the experimental group improved by approximately 12 points more than those in the control group during the implementation process.

To determine whether this difference between the groups was statistically significant, an ANCOVA analysis was conducted. According to the results presented in Table 7, when the CTDS pre-test scores were controlled, a significant difference was found between the groups' adjusted post-test scores [$F(1,56) = 11.265$, $p < .05$, $\eta p^2 = 0.467$]. This finding indicates that the observed difference was not due to chance and that the unplugged CT approach applied in the experimental group significantly improved creative thinking dispositions.

In terms of effect size, the obtained ηp^2 value is 0.467. This value indicates that approximately 47% of the total variance in creative thinking dispositions is explained by the experimental intervention. In the context of educational research, this ratio is considered quite high and represents a strong effect size close to the medium level according to Cohen's (2013) classification. In other words, nearly half of the improvement in students' creative thinking dispositions can be attributed to the unplugged CT approach applied.

Discussion and Implications

In the current study, students' creative thinking dispositions showed a statistically significant difference in favor of the experimental group. The reason why students' creative thinking dispositions developed more in the experimental group may be that the students in the experimental group were provided with a freer and more creative environment in their designs with concrete materials while performing unplugged CT activities. Students showcased their creativity in designing their own products, particularly by utilizing various materials such as colored cardboard, colored markers, scissors, and glue. For example, during an unplugged CT activity, the design of endocrine glands and hormone cards may have supported and developed their creative thinking abilities. In the experimental group, students were provided with a flexible and open working environment, and their curiosity and courage were guided in a way that triggered their creative thinking. As a result, the students in the experimental group had access to a richer variety of materials compared to the control group, which provided them with flexibility during the product development process and encouraged them to develop different perspectives by stimulating their creative thinking processes. Learning environments that integrate unplugged CT components and provide flexibility, allowing students to introduce innovations, can support the development of students' creative thinking dispositions. The richness of materials also encourages students to adopt an exploratory approach rather than thinking in a limited manner (Batlolona et al., 2019). Offering them more options can help them experiment, make mistakes, and learn from those mistakes, thereby increasing their potential to generate more innovative and original ideas. In contrast, the limited variety of materials used in the control group might have led to less development of creative thinking dispositions compared to the experimental group.

Table 7 ANCOVA Results of the Groups Regarding CTDS Scores

Source	SS	df	MS	F	*p*	Partial η2
Pre-tests	8.452	1	8.452	0.042	0.838	0.001
Groups	2263.259	1	2263.259	11.265	0.001	0.467
Error	11250.652	56	200.904			
Total	550085.000	60				

The use of specific teaching tools such as the textbook, lesson videos, discussions, and end-of-chapter activities in the control group may have restricted the use of different materials and flexible learning environments, thus limiting the development of creative thinking.

Another reason for the higher creative thinking dispositions in the experimental group may be related to the use of computational thinking skills. For example, in the experimental group, students were asked to create an algorithm for the transmission of a stimulus along the reflex arc and to design this algorithm themselves. The students constructed the algorithm either by role-playing or by using various materials such as paper and pencils. This process may have encouraged them to organize their original ideas and arrange them in an algorithmic sequence. Similarly, the use of the *branching component* by the students in the experimental group during the process of learning about hormones secreted in the body under certain conditions may have enabled the generation of new and alternative ideas by allowing different options and possibilities to be considered. Additionally, allowing students to have freedom in their designs while modeling the central and peripheral nervous systems and endocrine glands within the scope of *abstraction* (such as choosing which color cardboard and pencils to use, or deciding what kind of model to create in 3D, 2D, etc.) may have supported their creative thinking dispositions. Designing games related to hormone secretion mechanisms by using students' *patterning* and *iteration* skills may have further strengthened their creative thinking dispositions and enabled them to view things from different perspectives.

The lack of the use of computational thinking skills in the control group can be considered one of the reasons why creative thinking dispositions did not develop sufficiently. When examining studies on this topic, Peteranetz et al. (2018) stated that the use of computational thinking skills had a positive impact on students' creative thinking processes in a study they conducted with university students. In a different study, Suherman and Vidákovich (2024a, b) identified a positive relationship between computational thinking skills and creative thinking, and found that computational thinking is a predictor of creativity in an experimental study conducted with 896 middle school students. In another study, Xu et al. (2022) found a significant relationship between computational thinking (CT) and creative thinking in 5–6 year-old children. Research has revealed that computational thinking skills support and develop students' creative thinking dispositions. The findings obtained in the current study also confirm this situation. However, another reason for not observing a significant improvement in the creative thinking dispositions of the students in the control group may be that the students in the control group mostly relied on models, presentations, and posters that are readily available on the internet when presenting the information they acquired during the activities. Instead of producing original content, students preferred to use readily available visual and written materials, which may have limited the creative production process. For example, when students in the control group were asked to create a nervous system model, they made use of sources such as the internet and mostly tended to imitate scientific models created by others. In contrast, the modeling process in the experimental group, which emphasized abstraction, enabled students to simplify complex representations. The lack of ready-made content and the freedom to work with diverse materials encouraged students to generate innovative ideas and solutions related to the abstract and complex processes of the human nervous and endocrine systems. For example, when modeling a reflex action, students applied abstraction by reducing the complex neural processes of the human nervous system to core functional components (e.g., stimulus, sensory neuron, control center, motor neuron, and response), enabling them to represent reflex pathways through simplified, student-generated models. By applying abstraction in modeling reflex actions, students were freed from reproducing biologically detailed diagrams and instead encouraged to generate original representations using self-selected symbols and materials, thereby fostering creative thinking through increased fluency and originality. As a result, this orientation toward such ready-made materials may have prevented students from expressing their own thoughts, developing original ideas, and presenting different perspectives. In addition, the largely directive nature of the activities and end-of-chapter exercises in the textbook can be considered another factor limiting students' creative thinking processes. These directives may have prevented students from freeing their thoughts and hindered the emergence of their creativity. Therefore, it can be said that more flexible, exploration-based, and production-oriented learning environments are needed for students to create original products and develop their creative thinking skills.

A review of the literature indicates that learning environments integrating unplugged CT can support students' creative thinking skills. However, most existing studies have primarily focused on computer programming and coding, with limited research examining the integration of unplugged CT within specific science topics. Unlike these studies, the present study addresses this gap by applying unplugged CT in the context of science education, specifically to the human nervous and endocrine systems, and investigating its impact on students' creative thinking. Previous research has shown that activities such as games, competitions, role-playing, and other hands-on tasks can enhance creativity by keeping students' minds actively

engaged (Aytekin & Topçu, 2024; Israel-Fishelson et al., 2021; Hufad et al., 2021; Tsarava et al., 2019; Wang et al., 2021; Bulut et al., 2015). Consistent with these findings, the present study demonstrates that incorporating similar elements into unplugged CT activities provides a practical and effective approach to fostering creativity in science classrooms. Therefore, this study contributes to the literature by offering empirical evidence that unplugged CT can not only support computational thinking skills but also enhance students' creative thinking dispositions in the context of middle school science education, highlighting the potential of flexible, game- and activity-based learning environments for promoting 21st-century skills.

Conclusion

This study, unlike the existing literature, demonstrates that unplugged learning environments, rather than computer-based settings, can be effectively used to enhance students' creative thinking dispositions. Through unplugged activities, students employed computational thinking skills to develop their own games, designs, and models, gaining opportunities to generate original ideas and explore alternative solutions. This finding indicates that creative thinking can be supported not only through technology but also in flexible, inquiry-based learning environments where students actively participate and create their own products. Therefore, the study provides concrete evidence for the applicability of the unplugged CT approach in education and its contribution to the development of students' creativity. Given the positive effects of computational thinking skills on creative thinking dispositions, it is crucial to create learning environments where students can experience these skills, particularly through unplugged activities. In this regard, it is suggested that flexible environments be provided that encourage students to design their own games, stories, or physical models, promoting the generation of original ideas. Additionally, offering students the opportunity to design their own unplugged activities and share them with their peers, rather than merely applying pre-designed activities, will support the development of both computational thinking and creative thinking dispositions.

Limitations

The sample group in this study was limited to 60 sixth-grade students attending a single public school located in the city center with a moderate level of academic achievement. In future studies, similar effects can be observed by conducting research with larger sample groups and in schools with different levels of academic achievement or in rural areas. Another limitation of this study is that the assessment of students' creative thinking dispositions relied primarily on self-report instruments. In addition, only quantitative analysis was used in this study, and future research can be supported with qualitative data as well. Future research could include the triangulation of quantitative data with qualitative evidence, such as concrete examples of student work, project outcomes, or observations of engagement in creative tasks, to provide a more comprehensive understanding of how unplugged CT supports creativity. In future studies, in addition to investigating the impact of integrating unplugged CT activities into various science topics on creative thinking skills, the effects on other 21st-century skills, such as analytical thinking, problem-solving, and systems thinking, can also be explored, not just creative thinking skills. In addition, while the current study was conducted with middle school students to examine the development of creativity skills, future studies could investigate the impact of unplugged CT activities on the development of creative thinking skills, which is a crucial ability for younger age groups, by applying these activities to primary school and preschool students.

Appendix

Appendix 1. An example activity from the experimental group.

6.6.1.1. Objective: Explains the functions of the central and peripheral nervous systems on the model.

Duration:2 class hours (each class hour is 40 minutes)

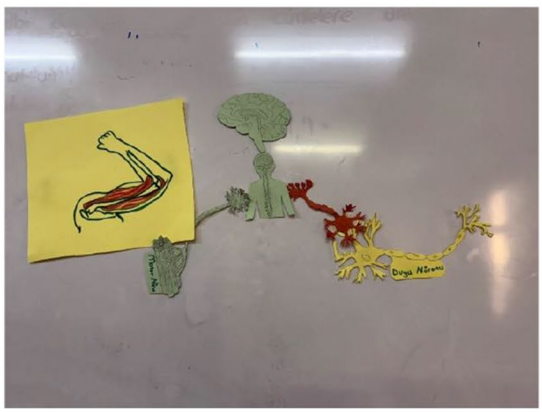
Computational Thinking Component: Algorithm Creation

Activity Name: Stimulus Algorithm

Materials: Colored cardboard, colored markers, felt-tip pens, glue, magnets, string.

Application Process: Students design two-dimensional models representing the brain, spinal cord, sensory and motor neurons, sense organs, and muscles involved in the reflex process (within one class period). During this process, they create their own original visuals using various materials such as colored cardboard, felt-tip pens, colored pencils, and scissors. They place their models on the board using magnets. The model creation stages and the students' final works can be seen in detail in the four visuals below.



Then, students are asked to use their creativity to create an algorithm that represents the process of receiving a stimulus in the neural network, transmitting it to the central nervous system, and then carrying it to the response organ. Students decide for themselves how to construct the algorithm. They express that they want to simulate a reflex process. Volunteer students in the class choose any model displayed on the board. (see the image below)

a



Students line up according to their models to simulate neural transmission. They connect to each other with a long piece of string, and another student hands a stimulus card made from colored paper (e.g., "a needle pricked the hand") to the student playing the role of the sensory neuron. The student acting as the sensory neuron takes the card and reads it aloud to the class. Then, to represent the transmission of the signal, this student pulls the string to send the message to the student acting as the spinal cord. The spinal cord student examines the incoming card and writes an appropriate response on a colored piece of paper. Using the string, they send this response to the student playing the role of the motor neuron. The motor neuron student then passes the response, again via the string, to the student playing the muscle. The student acting as the muscle performs the response received from the spinal cord, completing the process.This step-by-step, algorithm-like sequence is carefully observed by other students and is re-enacted with different volunteers. The algorithm developed by the students during this process is presented in detail in the visuals below.



Appendix 2. An example activity from the control group.

6.6.1.1. Objective: Explains the functions of the central and peripheral nervous systems on the model.

Duration:1 class hours (each class hour is 40 minutes)

Activity Name: If I Were a Neuron for One Day

Materials: Paper, pen

Application Process: Students learn about the organs of the central and peripheral nervous systems from the textbook. The following questions are asked to the students:

- How is information transmitted in our body?
- How does your brain send the "pull!" command to your hand?
- Have you ever thought like a nerve cell?

Then, a simple explanation is given:

"Neurons are the information carriers in our body. Like wires, they carry information through electrical signals. Imagine this: Today, you are a neuron! Maybe you're in the brain, maybe in the spinal cord, or a nerve cell in your hand. What would you experience throughout the day? Who would you communicate with? What tasks would you perform? What dangers might you face? Students are asked to write a short story describing what they would feel. Then, students read their stories to their classmates, and the most liked stories are displayed on the board. The visuals of the activity are provided below.".



Author Contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by first author. The first draft of the manuscript was written by first author and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability The author confirms that all data generated or analysed during this study are included in this published article.

Declarations

Consent to Participate Written informed consent was obtained from the parents.

Consent to Publish The authors affirm that human research participants provided informed consent for publication of the images in Appendix 1 and 2.

Ethics Approval All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and national research. Approval was obtained from the Yıldız Technical University ethics committee for the process and all documents to be applied in the study.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Statement Regarding Research Involving Human Participants and/or Animals Approval was obtained from the ethics committee of University Yıldız Technical. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Competing Interests The authors have no competing interests to declare that are relevant to the content of this article.

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