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More than words: Conceptualizing narrative computational thinking based on a multicase study

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ABSTRACT

This paper presents an investigation that compares and analyzes the interactions of three groups of pre-and-primary school children with three different storytelling systems. We identify emerging patterns through which they engaged in what we refer to as narrative computational thinking. The latter describes broadened aspects of narrative literacy practices that are linked to computational thinking. By applying a multicase study approach and through various vignettes, we illustrate how children applied computational thinking to understand and influence the narrative possibilities offered by the different tools. Our results illustrate circumstances under which digital storytelling activities provide a favorable basis for narrative computational thinking, and that when computational thinking functions as a scaffold for story creation, it encourages a blend of creativity and computational thinking, providing a compelling approach to introducing emerging digital literacies to young children in a narrative context.

1. Introduction

Today, computational thinking (CT) is emerging as a fundamental skill for young learners, expanding beyond its original associations with computer science and into broader educational domains. At the same time, there is a need to link conventional literacy domains, such as narrative thinking, with emerging digital literacies, including media literacy, data literacy, and artificial intelligence (AI) literacy, as these are becoming integral parts of students' everyday interactions with technology. This paper explores the intersection of narrative and computational thinking to assess the potential for new approaches to introducing emerging digital literacies at an early age.

Computational thinking (CT) involves thinking at different levels of abstraction that help humans solve problems in a creative and imaginative way, combining and complementing mathematical and engineering thinking (Wing, 2006). With "learning to code" agendas entering schools worldwide (Williamson, Rensfeldt, Player-Koro, & Selwyn, 2018), initiatives for CT have mostly been associated with block-based visual programming and educational robotics kits typically introduced alongside STEM subjects at a secondary level, i.e. around the age of 12 years. More recently there has also been an effort for introducing CT at pre- and primary school level (ages 5–10) through visual programming languages, such as Scratch and Scratch junior. A positive vs. negative attitude towards the acquisition of computing concepts already starts developing at the beginning of primary school. This impacts subsequent gaps and disparities, in particular for young girls (Szabo, Sheard, Luxton-Reilly, Simon, Becker et al., 2019). Therefore, teaching CT at a younger age raises both pedagogical challenges and opportunities at the same time. Recent investigations suggest that such challenges could be overcome by relying more on an activity that is a fundamental part of the early education curriculum and cognition generally, i.e. storytelling (Herman, 2003).

Considering storytelling to teach CT concepts, most programming environments and CT tools require basic reading and writing skills, highlighting a gap for approaches that promote literacy and CT. As Dietz et al. (2021, 2) remark:

> "Children's stories, like code, are told in logical sequences, often leverage repetition (i.e., loops), and have components (e.g., characters and locations) that can be changed, reused, or replaced (i.e., data or variables). Stories are also built on top of abstractions (e.g., a standard story structure) and are logically organized using decomposition (e.g., scenes or chapters)".

Wing (2006) argues that computational thinking is a "universally applicable attitude and skill set" for everyone and not just for computer scientists, a characteristic that is also shared with narrative thought.

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Much like computational thinking, Bruner (1991) illustrates how narratives operate as an instrument of mind through features such as "narrative diachronicity", i.e. events are ordered in a temporal sequence, "context sensitivity" and "normativeness" in everyday life. In relation to this, Herman (2003) highlights how narrative is used as a problem-solving strategy in many contexts and acts as a general resource for thought, as it can structure "any time-based pattern into a resource of consciousness" (Herman, 2003, 170). May (1984) highlights that stories offer a "memory framework", namely, the ability to remember and effortlessly analyze new stories, providing anticipation of information, which helps children to understand new stories and retell them, which in turn encourages to construct meaning, and facilitates the creation of new stories (Morrow, 2001). Consequently, narratives can also act as a cognitive instrument to develop ideas of CT among young learners.

In this context, technological authoring tools and interactive storytelling for children not only offer forms of creativity and learning that are not fully explored yet (Garzotto, 2014; Hall, 2012), but also enable new pedagogical approaches that take advantage of the similarities between interactive stories and computer programs (Letonsaari et al., 2021). This knowledge has two important consequences that we discuss in this paper. First, technological authoring tools can extend the domain of CT initiatives from STEM-based subjects towards activities that are typically pursued in primary school next to early "unplugged" activities. Secondly, CT itself can be extended in response to criticism of one-sided "learning to code" agendas entering schools worldwide (Williamson et al., 2018).

The investigation presented here aims at contributing to the body of knowledge on this subject, by investigating the following research question: *How can interactive digitally enhanced narrative exploration expand the realm of computational thinking initiatives in primary classroom settings?* In this context, with digitally enhanced narrative exploration we refer to the use of digital authoring tools that scaffold creative storytelling.

2. Theoretical framework

2.1. Computational thinking

Discussing the origins of the CT principles, Lodi and Martini (2021) observe that today's school practice is a step behind an original constructionist understanding of computational thinking which argues that "only a social and affective involvement of students into the technical content will make programming an interdisciplinary tool for learning (also) other disciplines". The engagement with and the creation of interactive media provides opportunities for the development of CT in a broader sense, encompassing not only the understanding of concepts and widely accepted CT elements, but also the engagement in new practices, such as testing or remixing, and the adoption of new perspectives on the surrounding world (Brennan & Resnick, 2012). According to Grover and Pea (2013, 39-40), computational thinking is generally acknowledged to include these aspects:

- Abstractions and pattern generalizations (including models and simulations)
- Systematic processing of information
- Symbol systems and representations
- Algorithmic notions of flow of control
- Structured problem decomposition (modularizing)
- Iterative, recursive, and parallel thinking
- Conditional logic
- Efficiency and performance constraints
- Debugging and systematic error detection

2.2. Interactive storytelling and storytelling systems

One way to take advantage of the possible combination of CT and storytelling is through digital tools that enhance pedagogical options and expressive affordances. The major role that stories play in the development of social skills, cognition, and emotions, has been widely acknowledged (Hutto & Ravenscroft, 2021; Paley, 2004; Speaker, Taylor, & Kamen, 2004). Creating narratives helps children to organize their experience (Bruner, 2004), sustaining the development of emotions, such as empathy (Baron-Cohen, 1995). Since early examples such as POGO (Decortis & Rizzo, 2002) there have been numerous efforts to design learning environments which blend material and digital elements that facilitate storytelling for younger learners. The presence of mobile devices in classrooms has expanded the possibilities for exploring new approaches both for learning and teaching.

Nevertheless, in between technological tools that are open-ended and those which host predefined narrative structures, there is a gap for interactive storytelling tools that guide the storytelling process towards the creation of stories that enable further classroom activities for specific learning goals, such as computational thinking. Recent developments in this area include "Telling board" (Powell, Gyory, Roque, & Bruns, 2018), a device that combines pre-illustrated cards with cards drawn by children to support storyboarding and oral narration, or "Communics" (Rutta, Schiavo, Zancanaro, & Rubegni, 2020), which promotes comic-based storytelling for reflection on conflicts on the basis of a library of texts and images. "StoryCoder" (Dietz et al., 2021) presents a voice-based app that encourages the use of computational thinking concepts such as sequences, loops, events and variables to manipulate stories. "CyberPLAYce" uses tangible programming via icon cards to let children reconstruct or create their own story and accompany story segments with electrical input/output effects (Soleimani, Herro, & Green, 2019). The study presented here reports findings from a multicase study carried out with three different authoring tools, namely, Touch–Organize–Create (Sylla, Coutinho, Branco, & Müller, 2015), Mobeybou (Sylla et al., 2019), and Fantastinomio (Schlauch, 2022). The findings emerged from the observation of children's interaction with the tools in different contexts and provide insights on the potential of storytelling authoring tools to foster young children's computational thinking, and how particular interactions performed during the storytelling process may provide insights about broader literacy aspects of computational thinking.

2.3. Computational thinking through narrative exploration

It is possible to derive conceptual overlaps between computational thinking and a narrative mode of thinking. This can be done by observing and analyzing in detail literacy events where children apply forms of computational thinking. As such, literacy events are defined as any occasions where encoded meanings, such as written text, are "integral to the nature of the participants' interactions and their interpretative processes" (Heath, 1982, 50), whereas literacy practices refer to "the broader cultural conception of particular ways of thinking about and doing reading and writing in cultural contexts" (Street, 2017, 26).

For several of the narrative aspects formulated by Bruner (1991) and the characteristics of computational thinking listed earlier, we can hypothesize links between the broader skills of computational thinking and the narrative features it affords when applied to the expression of experiences or stories. Specifically, narrative features such as referentiality, hermeneutic composability, narrative diachronicity or normativeness (Bruner, 1991) may require some form of systematic processing of information, recursivity, conditional logic and other aspects during the use of interactive systems.

Therefore, assuming that computational thinking skills can be applied in particular literacy events as part of broader literacy practices, we posit a working definition of *narrative computational thinking* as *expanded computational thinking aspects that support or enhance narrative features within literacy practices*.

3. Methodology

The study we present here is conceived as a multicase study (Stake, 2005), and aims at discussing how children apply aspects of computational thinking when using digital and tangible authoring tools for storytelling. Although the planning of each study was not identical to the original proposal provided by Stake (2005), the presented cases are collected to inform about a common phenomenon (Stake, 2005, 4), and a cross-case analytical procedure is conducted. The intent of this research is to understand if and how the interactions performed by children during the exploration of digital and tangible authoring tools and the storytelling process mediated by them support *narrative computational thinking*. To do so we present three case studies that were carried out with three storytelling interfaces. As it is expected in a multicase study, the single studies with different interfaces that comprise this collection of cases share a common characteristic. Namely, all of them were designed to improve the understanding of the potentialities and difficulties of the use of storytelling authoring tools aimed at young children. In specific, this was done with respect to three aspects, namely (1) how the system's functions support storytelling, (2) how children experience constraints and affordances and (3) shared processes of meaning-making among children.

To select the cases, we followed the three main criteria proposed by Stake (2005, 23), that is, their relevance to the wider phenomenon, their diversity across contexts, and the opportunities they provide to learn about complexity and contexts. For that, it was possible to characterize different types of (1) authoring tools (i.e, Touch–Organize–Create (TOK), Mobeybou (MBB), and Fantastinomio (FNT)); (2) contexts of observation (i.e., free play, semi-oriented activity, and oriented activity); and (3) age-span (i.e., 4–5 years-old, 6–10 years-old). However, to analyze all 18 combinations of them would be excessive for the purpose of this article. Therefore, based on the qualitative data that has been collected during the fieldwork and in accordance with the multicase approach, a purposive sample of cases has been selected according to the research question. Looking at multiple studies increases variety and generates opportunities for intensive study. Thus, we selected three cases with the following configuration: (1) case I: authoring tool 1, free play with 4–5 year-old children; (2) case II: authoring tool 2, semi-oriented activity with 5 year-old children; and (3) case III: authoring tool 3, oriented activity with 6–10 year-old children. Each case originates from its own complex situation, which will be briefly described in the next section.

For the cross-case analysis, we followed the procedure described by Stake (2005, 51) aimed at generating theme-based assertions from separate case findings. During this process, we started by reviewing each case report and identifying the prominence of themes, which are directly related to the common research goals of the different studies (Stake, 2005, 43). In this case, the cross-cutting themes are connected to the 3 research goals mentioned above:

- Theme A: functions of the system
- Theme B: childrens' position in relation to rules and constraints
- Theme C: childrens' interactions and shared meaning making

We further developed the themes based on the relevance of the case descriptions. During the analysis, each interaction, as it is situated in its special context, provides additional aspects for the development of the theoretical themes. Triangulation occurred along the way, for instance, during the data collection (i.e., recordings, notes, photos), during the analysis of each case (i.e., using different data, such as notes, interviews, transcriptions) and while organizing and writing the results (i.e., considering different case reports). Finally, we were able to list a number of assertions about the investigated phenomenon, which we organized in a framework.

3.1. The case studies and tools

The three authoring tools used in our studies were designed based on the notion that children are "players rather than spectators" (Bruner, 1966, 95), and that the creation of narratives should be centered on the playful character of language and the pleasure in dealing with words through playful experimentation. Its development was also based on social constructivist theories of learning embedded within a social context and generated through the interaction with others (Lave & Wenger, 1991). All studies were presented to the children's parents and their teachers. All parents gave their informed consent and signed a statement of agreement. The children were informed that they were free to withdraw from the activity at any time. We have translated children's verbalizations from Portuguese, German and Italian into English, thereby we have tried to be as faithful as possible to the original language. In this section, we describe the three cases and present the authoring tools used in each of them.

3.1.1. Case study I

Case I was carried out with the tool Touch–Organize–Create (TOK) involving 24 pairs of pre-schoolers aged four and five (five pairs of girls, seven pairs of boys and 12 mixed pairs) from two parallel classes in a Portuguese pre-school. The investigation followed an exploratory approach. The researchers wanted to gather information on how children handle the interface, whether it was intuitive to use and engaging (or if children would lose interest after the novelty disappeared) and if it could involve children in meaningful activities, promoting the development of oral language and emergent literacy.

The study took place during a period of four months, and was carried out in the classroom during children's free-play time. Free-play time is an integral part of the preschool activities, and takes place every day after lunch for around 45 min. During free-play time children can choose between four different "activity areas" (house, constructions, library and computer) to play without the teacher's intervention. Each of the two participant classes had a TOK, which was placed in the computer area. The children could use the tool in pairs as long as they wanted (within the 45 min of the free-play time period); after finishing, another pair could use it. These procedures were part of the guidelines for multimedia use during free-play time in both classes. Two times a week on a regular basis a researcher visited the classes and collected the data using a video camera discreetly placed behind the interface. To better capture children's verbalizations a microphone was connected to the camera and placed on the table between the children and the interface. The researcher stood at the back of the room, observing and taking notes. To avoid any bias caused by the novelty of the digital artifact, the collection of the data began some weeks after children started using the tool. Besides video recordings the data was collected using direct observation techniques and field notes. The average interaction time of each pair was 16.64 min, whereby 75% of the children verbalized the wish to play longer.

Touch–organize–create. TOK was used during this case study. The tool is composed of an electronic platform, and a set of 23 physical blocks (see Fig. 1). The surface of the electronic platform has slots for placing the blocks. Both the backside of the blocks and the electronic platform have magnets on their surface that correctly snap the blocks to the platform, making it easy to place the blocks, while simultaneously ensuring a stable contact between the blocks and the platform. Each block has a sticker with a picture of the respective digital representation on the upper side and a conductive pattern on the backside that is detected by capacitive sensors on the platform, providing the system its identification. Placing a block on the platform displays the corresponding digital content on the computer screen, creating a direct mapping between input and output; the sequence of blocks placed on the platform unfolds a narrative.

Fig. 1. Touch–Organize–Create (TOK).

The blocks represent classical scenarios and actants from children's narratives (heroes and opponents), comprising characters, magical objects and nature elements (the moon). The familiarity of the characters allows recreating narratives (e.g. the three little pigs), variations from the original stories, or simply to create completely new stories. Five different scenarios (a castle landscape, a forest, a desert, the woods and a circus) allow locating the stories in different settings, and a block with the moon allows transforming the day into night or the other way around. When children place the blocks on the electronic board, corresponding images and animations are triggered and displayed on the computer. Children can freely verbalize their narratives while interacting with the tool.

3.1.2. Case study II

Case II was carried out with the tool Mobeybou (MBB), for seven weeks at a primary school in Portugal with a class of 21 first graders aged six and seven. The study followed an exploratory approach. All the sessions took place during regular classes and were planned in collaboration with the teacher. During this period the teacher used the MBB for promoting the acquisition of storytelling competences.

The last two sessions were entirely dedicated to the storytelling mediated by the MBB, and took place at the school's gymnasium. The room was equipped with two tables and five chairs. The tool was set on a table with the blocks scattered on both sides of the board. The other table was placed away from the interaction table and used by one researcher for taking notes. The data was collected by two researchers through observation and written notes. Researcher A. was close to the students, interacting with them, while researcher B. was observing and taking notes. The children came to the room in pairs (one pair at a time) and started by freely exploring the tool. Following the exploratory phase, one researcher proposed to each pair to tell a story. Given that the children were asked to tell a story, this was a semi-oriented activity but there were no strict steps to be followed. Each pair interacted with the tool for around 20 min.

Mobeybou. Mobeybou was used during this case study. This tool evolved from TOK as a result of the participatory design process that was carried out with the children (Sylla et al., 2019) (see Fig. 2). The difference between the two tools are (1) number of blocks, (2) type of connection, (3) content embedded on the blocks. Namely, authoring tool 2 presents a total of 60 blocks, which gives children more options to create their stories, also there are five atmospheric blocks; the blocks connect with each other through magnets placed on the sides and communicate with a computer device via Bluetooth, which allows connecting more blocks together; and the story elements represent various world cultures, promoting storytelling within an intercultural context.

In both tools (TOK and MBB) the tangible objects are building blocks of the narrative, representing story elements, and manipulators-of-what-is-represented (Sylla, Gil, & Pereira, 2022). Each block represents a story element and is a multimodal container that stores an animated image, ambient sounds and/or music. Together the blocks contain all the codified narrative information that defines the interactions between the narrative elements (i.e. landscapes, antagonists, protagonists, magical objects, instruments and atmospheric blocks), which are modeled based on Propps' structure of traditional narratives (Propp, 1968). The story world in both tools is modeled using behavior trees (BTs), therefore different combinations of blocks result in the creation of a myriad of original narratives. Except for the landscapes, (which set the stage for the narrative) and the atmospheric-blocks (rain, snow, wind, rainbow, night), all the elements behave according to a set of rules and constraints that define their actions and the relations to the other active elements. In their story creation with the tools, the children are incentivized to find creative solutions for the situations that unfold by attending to these constraints, which they therefore must infer and understand.

Fig. 2. Mobeybou.

Fig. 3. Fantastinomio.

3.1.3. Case study III

Case III was carried out with the tool Fantastinomio (FNT) (see Fig. 3) over the course of two months with mixed-aged groups of children between 6–10 years old. The study took place in the bilingual region of South-Tyrol, therefore there were children who spoke German and Italian. This study followed an exploratory approach. As a part of a larger design-based research project (Schlauch, 2023), the purpose was to test the feasibility of the tool in a real educational context and gain insights about (1) design adaptations to make to the tool for the next iteration cycle and to gather (2) recommendations on how the tool can be best used in an education context to stimulate reflection on a certain subject. The intervention took place in a school inspired by Montessori principles. This meant that children autonomously decided whether to take part in the project on a weekly basis. Each week, a group of 3–4 children registered for participation at the "media workshop" conducted by a researcher, consisting of two sessions on different days. In the first session, the children would be prompted by the researcher to talk about their media usage before being introduced to the authoring tool. Taking turns and inventing stories along the way, the children generated and narrated 3–6 image sequences in each workshop, proceeding to develop one story further as a written text. In the next session, children used the tool more autonomously, worked on another text and then had the possibility to draw or photograph story elements to add to the tool. The gathered data consists of audio recordings of the sessions, webcam video and screen recordings during the interaction with the tool, scans of children's drawings and story products as well as generated image sequences as pdf and different versions of texts written by the children.

Fantastinomio. FNT distinguishes itself from TOK and MBB by offering educators the possibility to configure and curate available story elements to prepare learning activities for specific learning outcomes. Its focus lies specifically on the guidance of collaborative narrative creation. The story idea can then be told in class or processed as a written text or be enriched with multi-media content via third-party tools. The tool was created with the open-source tool Twine and custom code to enable data importation, and it is accessed through a browser-window. It is modeled on established creative storytelling techniques that engage children playfully with random word-pairs and corresponding images ("binomio fantastico") to construct interesting narratives (Rodari, 1973). Similar storytelling tools often use categories such as "characters", "items" and "scenarios" (Powell et al., 2018; Prada, Machado, & Paiva, 2000; Sylla et al., 2019) and echo typical narrative archetypes (Propp, 1968). Here, the story elements are grouped in categories that are not predefined but customizable. The elements can be created by the children or the educator and edited by the latter. To create their stories, the children undergo multiple steps. In each step, the system displays the name of three story elements that are randomly selected under the constraint that each has to belong to a different category. As the child chooses and clicks on one of these elements, it is transformed into the respective picture or drawing. The children then repeat this process until they obtain a visual story sequence resembling a storyboard. This resulting image sequence acts as a scaffold for the oral/written or theatrical production of a story that can be created either individually or as a group-based activity. In between the actions, the interface structures and guides the narrative process using multimodal representation, visuals, audio and animated transitions. As the pool of story elements can be adapted to a specific learning outcome or topic to discuss, the tool acts as a device that enables the use of storytelling for a wide range of subjects.

4. Cross-case analysis

This multicase study aimed at discussing how children apply aspects of computational thinking when using digital and tangible authoring tools for storytelling. According to the multicase methodology (Stake, 2005), we have identified three cross-cutting themes across the three cases (functions of the system, childrens' position in relation to rules and constraints as well as childrens' interactions and shared meaning-making), which are investigated in relation to the occurrence of narrative computational thinking.

In a later step, the themes guided the construction of a matrix for generating theme-based assertions from the case findings. In what follows, we present a qualitative analysis of each theme, illustrated with vignettes from the three cases. The selected cases are representative of the patterns identified during the analysis. Finally, elaborating on the themes illustrated in the vignettes, we further elaborate on the findings to address the researched phenomenon.

4.1. Theme 1: Functions of the system

Here we present vignettes related to Theme 1 "Functions of the system".

Case I. In case study I, one finding was highly related to this theme, namely: Children discovered the rules of the system by trial and error. The vignette below is related to it.

> Vignette 1: J. and F. (5-year-old) are telling a story using A1: F. "And now comes the superhero [the knight]. And now we will kill the wolf, and the witch too! However, the knight loses the fight. J. wonders why and how the knight lost. So he reconstructs all the story sequences again to find out why that happened.

Vignette 1 illustrates how the children identified something that they were not expecting and how they took a step back to reconstruct the story sequence, try again, and analyze what happened in order to understand it. In other words, they practiced *debugging and systematic error detection* in order to 'correct' an unforeseen outcome of a story. The vignette also contains the narrative aspect of *canonicity and breach*. According to Bruner (1991, 11) a "prescription for a canonical behavior in a culturally defined situation" is a defining aspect of a story that often is "breached, violated, or deviated from" to drive a story forward. In this case, the knight, seen as the strong hero of the story, is unexpectedly killed by a wolf and a witch. Thus, the children identified a breach of an expected canonical behavior. In this case, this breach is interpreted as a 'system error' to which children applied a strategy of debugging and systematic error detection in order to understand the cultural prescriptions of the system.

Case II. In case II, the same finding was identified and highly related to this theme. The following vignette illustrates it.

> Vignette 2: A. and S. (7-year-old boy and girl) are using MBB and exploring the tool. They start placing animals and antagonists to watch the conflicts, selecting various animals. A. looks at the screen and says "the fire dragon is afraid, I think it is because there are too many possible opponents", so he starts to remove some animals to see what happens.

This vignette illustrates children making a hypothesis and how they discovered the rules of the system by exploring the interactions between the elements. They try different combinations to understand how the interactions are programmed to happen. By varying one character at a time, they exercise *conditional logic* in order to find out if there is a pattern behind who wins and who loses. On a narrative plane, regarding *context sensitivity and negotiability* the children adjusted their interpretation of the events to the context of the conditional logic expressed by the narrative system. Thus, the children form an hypothesis (the fire dragon was afraid since there were multiple opponents present in the scene), and verified if it was true, by removing other elements from the scene, one by one. This vignette highlights how narrative accounts depend on the context, but also how the rules behind the narrative tool constitute part of that context. Thus, when engaging with a computational system for storytelling children apply conditional logic. This enables them to negotiate meanings that are context sensitive.

Fig. 4. Output of session in case study III: "prince, very kind, flowers, mermaid, treehorse, book, in love, magic stick" , 5 out of 8 elements were invented by the children.

Case III. There have been occasions where children tweaked the tool beyond the anticipated use case. Normally, via a click on the previously selected picture, it is possible to turn back and remove the already selected story element in order to be able to choose a new one. Here, in this transcript based on video data and observational notes, we look at the behavior of a child S (9-year-old boy), whose mother tongue is Italian, and who used the tool individually:

> Vignette 3, using FNT: ...after selecting the story elements of "prince", "kind", "flowers", "mermaid" S selected "school", but was unhappy about it and asked the instructor to turn back, he then proceeded by selecting "fairy of the lake", turning back by himself, and selecting "alien". After a small laugh he revoked "alien" as well. The same happened with "algorithm". He finally settled for "treehorse" as the fifth story element. He continued the next step by selecting "robot", already commenting that later he would cancel it. After two more removals the sixth element chosen was "book". For the seventh element, S cycles through the process of reading the options, selection and cancelling 9 times, dedicating 5 min before finding the element "being in love". Shortly after that, he finishes the story sequence with a visible relief, calling the instructor to retell it.

The child then continued to put the story into written form with the help of a word processing software. The result resembles an intentional variation of Hans Christian Andersen's tale "The little mermaid", where the prince, instead of the mermaid, is transformed:

> The mermaid: Once upon a time there was a very kind prince who had a bouquet of flowers for a mermaid. He rode on his treehorse [a story element invented by the children], he also had a novel for her under his arm. When he arrived at the lake, she had a magic wand and turned him into a merman. (translated from Italian)

While the tool has been conceived for the creation of new stories based on prepared story elements, it is less adapted for the visualization of already invented stories. It is not possible to account for the precise moment when the child decided to retell his own version of "the little mermaid". Yet, in order to do so, he had to have a clear understanding of the random selection mechanism at the beginning of each step, knowing that it is statistically possible to "browse" through them and find a desired element. Vignette 3 shows how regarding computational thinking aspects, the student applied *iterative, recursive and parallel thinking*. Thus he decomposed the task of narration in a structured and patient manner, through recursive steps. At the same time, the child was keen on positioning the desired story elements in a certain order (see Fig. 4). Bruner (1991) refers to this characteristic of narrative as *narrative diachronicity*, a performed temporal order. In other words, the child has to construct narrative diachronicity out of given frames, events or story elements, which can require iterative, recursive and parallel thinking in order to grasp the relationship of elements that are not yet aligned.

4.2. Theme 2: Children's position in relation to rules and constraints

Here we present vignettes related to Theme 2.

Case i. Case 1 exemplifies how children adapted their story according to the constraints of the system.

> Vignette 4: A., B., and C. (5-year-old girls) are using TOK, they start placing a landscape, the three little pigs and also want to put their houses. However, as the platform only has 6 slots they start a conversation about which block they should remove to be able to put the missing house. A. says "we take the landscape", B. says "but we need a landscape", A. replies: "doesn't matter, the three little pigs are having a party in the sidereal space" (without the landscape, the background of the screen turns gray).

Vignette 4 shows how the children were able to creatively adapt their story according to the constraints of the system, which only allows for placing 6 blocks simultaneously. By removing the landscape they moved the location of the party to the sidereal space, which they imagined as being empty and gray. Thus the functional constraints of the system (limited amount of slots) influenced the narrative stance of the characters.

Case II. Case 2 exemplifies how children reflected (orally) about their impressions about the content and the tool. The vignette below illustrates this finding.

> Vignette 5: A. (7-year-old boy) is using MBB, he inserts the Chinese dragon and the Panda. He watches the conflict between the characters and gets happy when the panda wins. The researcher asks why he celebrates. A. answers that he wanted the panda to win "because there are few pandas alive in the world". Some moments later, while planning his narrative, A. thinks aloud "I've been twice in Germany, and twice in Turkey, now I'm going to China". The researcher asks "Have you ever been to these countries?". A. answers "Not in real life, just here with Mobeybou".

Vignette 5 shows how the boy engaged with the character at a personal level, and reflected consciously about the story's content. This vignette highlights the relevance of the storyworld's content to engage children in the activity. Through it, children get the opportunity to compare the algorithmic rules of the system with their own ethical considerations and values. *Referentiality* expresses the fact that narratives are never entirely fictional, but they are grounded in genres and patterns that "predispose us to use our minds and sensibilities in particular ways" (Bruner, 1991). A. introduced the reference to endangered species and travel reports. To do this, it is also necessary to *systematically process* information given by the story system.

Case III. In another storytelling session in case study 3, a group of children (7–9-year-old) using FNT, expressed a critical account of technology use in everyday life. From the output of the story element selections in Fig. 5 one of the children provided this oral summary:

> Vignette 6: There were the children who watch TV all the time, TV and smartphones. There was a stick insect who also played with the smartphone. A microchip exits the smartphone and projects a cat who plays on the computer. (translated from Italian)

Vignette 6 shows how children were able to reflect critically about the role of technology in their own life. In this case the children have narrated a one-sided use of TV, smartphone and computers through loosely connected events, expanding the criticized habits to the animal world. They also used a custom story element, the "stick insect", which was added to the storytelling system by another child (see Fig. 5). This relates the story to the common environment of the children, in this case a biology project done at school. The children were keen on using technological story elements. Thus, they had to understand

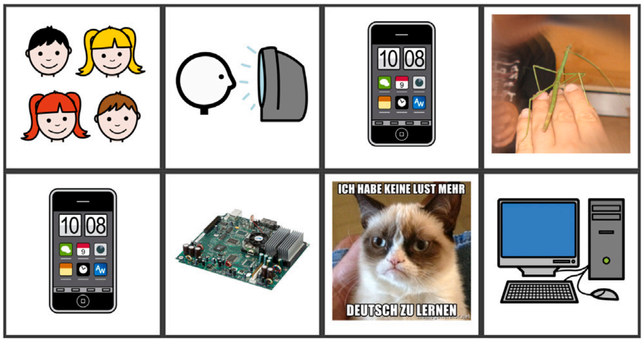

Fig. 5. Output of session in case study 3: "friends, TV, smart phone, stick insect, computer chip, meme, computer", the element "stick insect" has been photographed by another child.

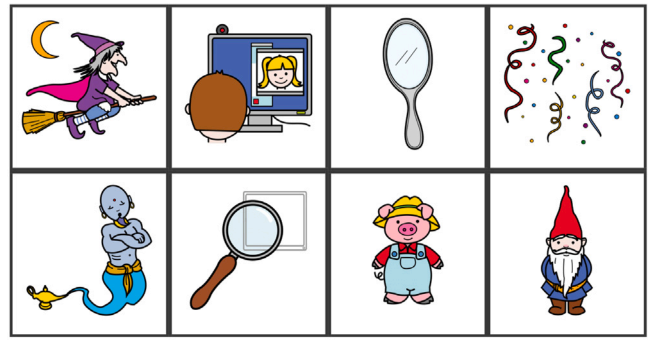

Fig. 6. Output of "an online party during covid": "witch, video conference, magic mirror, celebrate, magic lamp, search on the internet, little pig, dwarf".

the algorithmic *flow of control* in order to be able to select story elements of the category "media" exclusively. According to Bruner (1991), narratives entail *intentional states*, i.e. beliefs, desires, theories and values of protagonists, that are affected by narrative events. In this case, all of the characters mirrored the group's fascination for video games.

4.3. Theme 3: Children's interactions and shared meaning-making

Here we present vignettes related to Theme 3.

Case I. Case 1 exemplifies how children made innovative use of the system, and how they collaborated with each other.

> Vignette 7: F. and G. (5-year-old boys) using TOK, try to knock down the princess with the caldron, as it does not work F. justifies saying that the princess makes magic. G. keeps trying, but F. tells him: "only the bad ones can be knocked down with it. Now we try with the angry man, wait, wait… 1,2,3, now! Oh, we failed! G. asks: "is he bad?" F".: I think so, he has an angry face… F. continues thinking: "is he maybe good?" and tries again. And as again the caldron does not knock down the character, G. concludes saying: "No he is good!". After finding out that the cauldron does not knock down the "good characters", both children put their efforts in trying to knock down the antagonists (witch, wolf) with the cauldron. After several experiments, they observed that both characters always meet at a certain place on the screen, so they placed the mouse of the computer there and let the caldron fall when both characters were nearby, managing to knock down the witch and the wolf simultaneously with just one placing of the caldron.

Vignette 7 shows how children were able to discover the rules of the system, through exploration and experimentation as well as their creativity and collaboration to solve a problem and achieve a common goal. The caldron was programmed to knock down the antagonists (wolf, witch), and to always appear and fall on the same place. When the caldron block was added to the system, it appeared on the top-middle of the screen, and quickly fell down with a vertical trajectory, only knocking down the characters that intersected its trajectory in that fraction of time. The characters would enter the screen on the bottom left or right and then walk towards the other end of the screen in a loop. Thus, knocking down two characters simultaneously via placing only one caldron required collaboration and good coordination between the two children, so that the timing and positioning of the three elements converged simultaneously in the right position. In order to do that, children had to understand the *conditional logic* behind the cauldron and to anticipate its trajectory. At the same time, the "bad" characters are defined as bad in relation to the rules and logic of the cauldron's behavior, which additionaly highlights the *context sensitivity* of narrative.

Case II. Case 2 exemplifies children's engagement with the tools.

> Vignette 8: M.L. (7-years-old girl) and R. (7-years-old boy) using MBB, started planning the story before telling it. M.L. separated and ordered the blocks that she and R. wanted to use. As both discuss the story, they organize the blocks without connecting them to trigger the animation on the screen. They were only ready to tell their story after having finished the planning the story with the physical support of the blocks.

Vignette 8 illustrates how children engaged with the story elements and how they used the physical blocks to plan their narratives. This planning required a level of abstraction which does not depend on the screen animations. It also illustrates the collaboration among the two children to achieve a common goal.

The children exhibited a strategy of *structured problem decomposition*, as they decomposed their decision-making process with the help of the blocks. With *hermeneutic composability* Bruner (1991) refers to how the reader extracts meaning from a text. In this case, the meaning of the blocks are determined by the children's prior experiences with the storytelling system.

Case III. In this vignette a group of 4 children aged between 8 and 11 years used the tool (FNT) for the first time after an initial introduction. At each step, the children turned the mouse over to the next child who would have to click on the chosen story element. The only instruction given was that the children had to discuss and communicate the motivation of their choice, in order to enable the others to understand the unfolding of the story and continue the narration. At the end of the selection, the children were asked to recount the story and provided this oral account:

> Vignette 9:
>
> W: Well, once upon a time there was a witch...
>
> M: ...she makes a video conference, with the magic mirror.
>
> W: ...with the magic mirror, they make a celebration.
>
> C: ...she invites mhm... she invites everyone
>
> W: and the magic lamp comes too, and they celebrate on the internet because there's Covid
>
> C: and then the butcher does it
>
> M: the butcher beats the pig so they can eat it (translated from German)

Vignette 9 shows how the children integrated the story elements of "video conference" and "internet research" among typical fairy tale elements to narrate a story that resembles the experience they had during Covid-related lockdowns and homeschooling a few months before (see Fig. 6). This reflects the role of technology in their recent experience as an enabler for social interaction, but they also abstracted and introduced contradictions worth discussing, such as substituting the dwarf with a butcher who brings a pig to the feast. While using the tool, children introduce causal relations between the elements by introducing the additional context of lockdowns. Thus, both the *context sensitivity* of narrative as well as the *conditional logic* behind the supply of story elements contribute to the unfolding of the narrative.

5. Merged findings

Table 1 displays the final step of the cross-case analysis. Here, we can see how different types of narrative computational thinking emerged in relation to the cross-cutting themes initially given.

Our investigation confirms that digitally enhanced narrative exploration can expand the realm of computational thinking initiatives in primary classroom settings. This can be encouraged by introducing and anticipating these connections in the design of digital and tangible tools with regard to (i) affordances and playful exploration of features; (ii) constraints and their implications for narrative as well as (iii) with regard to collaboration and shared meaning-making.

Designing especially *for* narrative computational thinking comprises:

(1) with regard to the main functions (theme A): providing opportunities for combining debugging and systematic error detection, conditional logic, iterative, recursive and parallel thinking to narrative constructs such as canonicity and breach, context sensitivity and negotiability as well as narrative diachronicity. In terms of interface design, this could entail providing narrative elements that behave differently based on specific conditions and combinations the child chooses. The storytelling system could encourage children to explore "what-if" scenarios, such as what happens if a social norm is violated (breach) or to alter contextual variables, e.g. the place, weather or time, accompanied by visual or auditory cues.

(2) with regard to meaning-making constraints and rules (theme B): providing opportunities for combining systematic processing of information and algorithmic notions of flow of control with narrative features such as referentiality and intentional state entailments. In terms of the design of authoring tools, this could entail enabling children to choose and organize story elements according to clearly defined categories, ensuring that children understand the function of each element. Depending on age, the authoring system may also limit the number of choices or story elements available at one time. Additionally, the system could include the possibility to modify the internal state of characters, which motivates turning points in the story.

(3) with regard to children's shared meaning making (theme C): providing opportunities for combining conditional logic and structured problem decomposition with the narrative aspects of context sensitivity and negotiability and hermeneutic composability. In terms of conducting structured storytelling activities, this means including open-ended story elements that can be interpreted in different ways, allowing children to collaboratively shape the meanings. Teachers or educators can provide reflective prompts for children to ask themselves about the motives for their character's actions. Storytelling activities that break down narrative tasks into smaller steps, such as selecting characters, sequencing actions, and adding background details, expand opportunities for peer collaboration.

In addition to the design guidelines for Technology and Interfaces for narrative computational thinking outlined, other critical design considerations include:

i Story World: The more children can personally connect with the story world, the more engaged they become in the task. This engagement fosters intrinsic learning as they adapt new information, compare it with what they already know, and creatively "make something new with it, play with it, build with it" (Papert, 1993, 120).

ii Supporting Classroom Activities: Interactive storytelling tools should be designed to guide the creation of stories that align with specific learning objectives, such as promoting computational thinking, and enable subsequent classroom activities.

iii Designing for Collaboration: Processes like reflexivity, curiosity about computational relationships, modular engagement, exploring system transparency, and adapting designs often unfold in tandem or in response to prompts from peers, highlighting the importance of collaborative learning (Sylla, Gil, Menegazzi, & Landoni, 2024).

5.1. Narrative computational thinking as social interaction and literacy

Based on our findings, we can state that narrative construction mediated by technology can facilitate computational thinking. The social dimension of computational thinking has long been disregarded, which has contributed to the aforementioned criticisms of CT as a mere individual learning effort. Yet, as we have seen, processes connected to reflexivity, gaining curiosity about computational relationships, modular engagement, uncovering the more or less transparent functions of a system, and the adaptability of designs and products often happen together or in reaction to a prompt given by another child. This social aspect, which is entailed in *narrative computational thinking* places it into the proximity of digital literacy and play concepts. If we assume the notion of literacies as "socially recognized ways in which people generate, communicate, and negotiate meanings, as members of Discourses, through the medium of encoded texts" (Lankshear & Knobel, 2011, 33), then it becomes clear that this kind of narrative computational thinking achieves a form of literacy that facilitates children's participation in computational discourses. Encoded text, in this regard, would also include coded systems that can be designed or deconstructed. As we have seen, digital authoring tools can function as coded systems where children explore both narrative and computational rules and relate them to one another. Computational discourses are what Wing (2006) has characterized as a form of thinking with an increasing importance in all aspects of life. Therefore, it allows us to think of CT in a way that is not limited to STEM-subjects, but to make it relevant for other educational domains as well. It is no coincidence that there is already a long tradition of scholarship that advocates the promotion of critical literacy as a form of empowerment (Freire & Macedo, 1987). What has changed is the introduction of digital environments as something that mediates communication and meaning-making. This idea can be further investigated in sight of these new findings. Looking at smaller children, specific forms of digital play, such as "transgressive play", where children "contest, resist and/or transgress expected norms, rules and perceived restrictions in both digital and non-digital contexts" (Marsh, Plowman, Yamada-Rice, Bishop, & Scott, 2016, 9), involve aspects of deconstruction and construction that educators can employ in order to stimulate reflection about technology. Exploration of computational systems and narrative constructs enable children to transgress those rules in order to provoke an error, obtain an alternative functioning, or even create stories that breach canonical expectations.

Thus, as narrative construction mediated by technology can facilitate computational thinking, it is warranted to think of *narrative computational thinking* as a connection point between CT and numerous other educational domains which are also increasingly influenced by digital technologies. It also extends the notion that computational literacies are intertwined with students' other literacies, as has been

Table 1
Matrix of findings: according to the procedure given by Stake (2005, 59), emergence of narrative computational thinking in the sample.

Merged findings	From cases	Themes		
		Functions	Position	Interactions
debugging and systematic error detection, canonicity and breach	1	X		
conditional logic, context sensitivity and negotiability	2, 1, 3	X		X
iterative, recursive and parallel thinking, narrative diachronicity	3	X		
systematic processing of information, referentiality	2		X	
algorithmic notions of flow of control, intentional state entailment	1, 3		X	
structured problem decomposition, hermeneutic composability	2			X

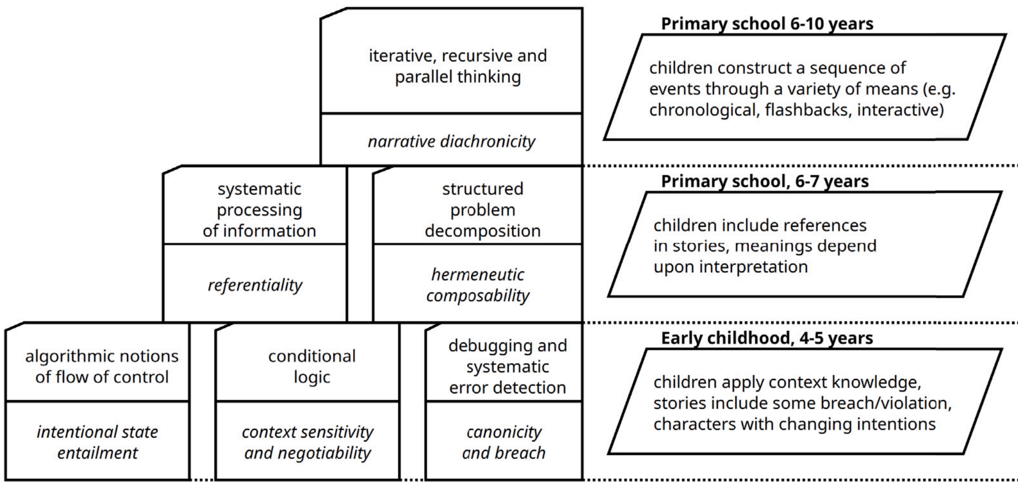

Fig. 7. Occurrences of computational and narrative thinking aspects in studies with different age groups.

observed previously with the bilingual students's translanguaging practices in computer science education (Vogel, Hoadley, Ascenzi-Moreno, & Menken, 2019).

Social interaction however is always rooted and shaped by the culture in which it is situated, creating shared knowledge that guides thought and behavior (Vygotsky, 1978). Learning is mediated by culture and language, meaning that narrative construction mediated by technology can facilitate narrative computational thinking more readily when it is presented through culturally meaningful stories. Narrative storytelling tools that are sensitive to cultural differences enable children to connect CT concepts with their own experiences, supporting both cognitive and cultural development in computational thinking. In the design of our tools, we have tried to accommodate users from different cultures, by incorporating narrative elements, symbols, and themes from a range of cultures, including Angola, China, Portugal, Germany, Cape Verde, Turkey, India, and Brazil. This variety of story elements allows children to engage with and recognize aspects of their own and others' cultural backgrounds, making it engaging and meaningful to children from varied cultural backgrounds (Sylla et al., 2019).

5.2. Narrative computational thinking in early childhood

Given that the three studies involved a range of children of different ages, it is now possible to comment on the emergent literacy aspects of narrative computational thinking. While Case Study I involved children aged 4–5, Case II involved children in the first year of primary school, and Case Study 3 involved primary school children up to the age of 10. In Fig. 7, we see how certain aspects of computational thinking and features of narrative emerged in this study corresponding to the school level.

At age 4–5, children begin to experiment with narrative elements and computational rules through trial and error. For example, they test story sequences and character interactions to understand how elements such as antagonists behave in certain contexts, and they engage in trial-and-error debugging. If a dragon is placed in a scene with a knight, children might systematically experiment with outcomes (e.g., "Does the knight win?"), reflecting their increasing ability to process and organize information in a narrative flow. The child's ability to recognize and apply conditional logic comes from understanding the specific context surrounding the character's actions. Children also start to grasp that a character's internal state drives their actions, which in turn affects the flow of the story. This understanding of intentionality creates a sense of the logical progression of cause and effect in the story and prepares them for the algorithmic notion of control flow.

By the beginning of elementary school, children recognize patterns in stories and systematically process how different elements such as characters, settings, and conflicts relate to one another. At this stage, children begin to organize narrative events more logically. For example, they may plan the sequence of a story in advance to ensure that characters appear in a structured order.

At this stage, references to real-life experiences or familiar cultural symbols become more common in their stories. This is an important leap in literacy as children begin to understand that stories are not isolated - they can be influenced by or refer to things outside the story itself. For example, in Vignette 5, we saw a child celebrating the panda's victory because he knows that pandas are endangered. By incorporating their background knowledge, children are asked to process information systematically. Children begin to realize that their stories can have different meanings depending on how the audience or they themselves interpret them. For example, a dragon might be seen as a villain in one scenario but as a misunderstood creature in another. Children explore how small changes in narrative elements (such as character actions or choices) lead to different interpretations. They understand that the meaning of the story is constructed through interaction, which prepares them to deconstruct the story structure if it does not have the desired effect on the audience. As a result, they become more familiar with the processes of structured problem decomposition.

Further on in primary school up to age 10, children develop the ability to iterate their stories, recursively revisit elements, and manage multiple narrative threads simultaneously, engaging in parallel thinking. This refers to their ability to structure events in a temporal sequence and to engage in more complex forms of storytelling that involve multiple storylines or levels occurring simultaneously. Recursion involves repeating elements within a story, often embedding stories within stories or returning to earlier narrative points to add depth or complexity. Children at this stage may introduce flashbacks or stories-within-stories, revisiting earlier plot points or actions to add layers of meaning. They may also tweak storytelling systems in unexpected ways, such as reconstructing a familiar fairy tale to change the outcome.

These findings add to earlier results obtained by Critten, Hagon, and Messer (2022) for early childhood contexts. Among the skills that children were first to learn, was debugging by correcting picture codes to navigate an educational robot. They also exhibited context sensitivity by choosing the right equipment for a given scenario (Critten et al., 2022, 978). While more advanced tasks involving logic, sequencing, algorithms required 1–1 support in that study, narrative engagement offers an alternative frame of reference for introducing computational thinking in early childhood education. When children engage with interactive storytelling systems, they not only learn to develop stories, but also strengthen their emergent computational thinking skills by learning to logically sequence events, understand abstract concepts, and apply problem-solving strategies. This process fosters their understanding of both narrative structure and computational thinking, as they learn to logically arrange story components, explore cause-and-effect relationships, and solve problems within the context of their stories. As a result, they develop a rich foundation for a digital literacy that blends creative expression with computational thinking.

6. Limitations

This study has several limitations that may affect the generalizability of the findings. First, the studies took place in selected European classrooms that were open to research with experimental storytelling tools. The findings may not fully apply to different cultural or socioeconomic contexts, which could affect how students engage with CT and digital literacy tools. Additionally, the applicability of literacy concepts, particularly those related to storytelling and narrative structures, may vary across cultures. Given the occurrences and the age-range of children analyzed during the study, not all computational literacy aspects (Grover & Pea, 2013) and not all features of narrative thinking (Bruner, 1991) initially portrayed have been covered. Also, certain storytelling traditions or cultural norms around technology use could affect how students interpret and interact with digital authoring tools, potentially leading to different outcomes than those observed in this study. The use of three particular digital authoring tools may have introduced technological biases, as the outcomes were dependent on the usability and design of these tools. The specifics of each study, as well as differences in familiarity with technology among the participants may have further impacted their ability to use the tools effectively. Based on the findings, there is a need for further research on technological adaptations of storytelling tools that specifically promote narrative computational thinking in a variety of classrooms at different age levels.

7. Conclusion

The complementary nature of computational thinking and features of narrative as a mode of thought has been suggested various times in the past. In this paper, we compared and analyzed the interactions of three cohorts of children with ages ranging from 4 to 10 that interacted with three different storytelling systems and the emerging patterns through which children engaged in narrative computational thinking, which we defined as broadened aspects of narrative literacy practices that are linked to computational thinking. With a multicase study approach (Stake, 2005) and through various vignettes, we have illustrated how children apply computational thinking to understand and manipulate the narrative possibilities offered by different tools. Up to now, there are only a few storytelling tools that are specifically tailored for computational thinking (Dietz et al., 2021; Soleimani et al., 2019). As we move forward, it is imperative to consider how these tools can be further refined to support not just the development of computational skills, but also to enrich the narrative experiences of children. By fostering an environment that intertwines aspects of computational thinking with aspects of narrative construction, it will be possible to facilitate computational thinking in a broader range of literacy domains, and thus make it more appealing to a wider range of students, e.g., younger students or students with different interests, also challenging gender stereotypes.

The connection between storytelling and computational thinking in education has profound implications in the context of broader digital literacies. Storytelling is a natural and intuitive way for humans to communicate and learn, and when combined with computational concepts, it can demystify complex ideas, making them more accessible and interesting. This approach can motivate students by showing the practical and creative applications of computational thinking in narrative contexts they are familiar with. Paired with computational thinking, it challenges students to apply logical reasoning, pattern recognition, and problem-solving strategies to create and understand stories. This dual focus can enhance students' ability to approach problems both creatively and analytically, fostering a more comprehensive form of critical thinking.

This objective, however, requires further study on the pedagogical strategies to adopt and on feasible teacher education programs to propagate CT in activities that involve technological objects. In this paper, we illustrated circumstances under which digital storytelling activities provide a favorable basis for narrative computational thinking. When computational thinking functions as a scaffold for story creation, it encourages a blend of creativity and computational thinking, providing a compelling approach to introducing computational concepts in a narrative context. In future work, we are particularly interested in investigating how to support teachers to integrate digital storytelling activities in their pedagogical practice.

CRediT authorship contribution statement

Michael Schlauch: Writing – original draft, Visualization, Investigation, Formal analysis, Data curation, Conceptualization. **Cristina Sylla:** Writing – review & editing, Investigation. **Maitê Gil:** Writing – review & editing, Methodology, Investigation.

Selection and participation

Before initiating the study, we sought and obtained approval from school authorities and secured ethical approval for the research. All consent forms, study protocols, and questionnaires were reviewed to ensure compliance with ethical guidelines for research involving children. After receiving ethical approval, participants were recruited by engaging with school coordinators and teachers, presenting the storytelling tools, and explaining the study design and procedures.

Parental informed consent forms were distributed, which included a detailed overview of the studies along with requests for approval of the children to participate, as well as permission for photos and video recordings. Parents were also informed about the confidentiality of the data and secure storage used solely for research purposes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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