DIGITAL STORYTELLING AS AN EFFECTIVE FRAMEWORK FOR
THE DEVELOPMENT OF COMPUTATIONAL THINKING SKILLS

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Abstract

Computational Thinking (CT) is widely recognized as a way of thinking—including a set of essential thinking skills—that should be mastered by the whole literate population, through compulsory education along with reading, writing and mathematics. CT is described as a set of significant aspects such as abstraction, algorithmic problem solving, data representation and data analysis. Diverse studies have been conducted in order to find effective educational practices and frameworks to help K-12 students to develop their computational thinking skills and many proposals have been formed. Despite this fact, a proposal identifying Digital Storytelling (DST) as a framework for the development of CT skills by K-12 level students has not yet been reported. This is the contribution of this paper. In fact, by analyzing secondary data emerging from the literature regarding CT and DST, a specific framework highlighting the relationship between the abilities of CT and the skills cultivated in DST for each stage of digital story development are proposed. It is worth mentioning that DST has emerged as a powerful teaching and learning tool across all disciplines by providing various direct and indirect advantages for the learners. Thus, the purpose of this paper is to clarify the contribution of digital storytelling (DST) as an effective educational framework to the development of specific aspects of computational thinking at K-12 level students.

Keywords: Computational thinking, digital storytelling, K-12 education.

1 INTRODUCTION

As technology becomes an integral part of our lives understanding basic computing structures and practices turns into basic knowledge that is required in the 21st century ([1]). Nevertheless, it has been widely recognized that digital literacy is important in our present day information society ([2]). In addition, developing students’ 21st century skills, such as creativity, critical thinking and problem solving abilities has been prevailing concern in our society ([3]).

J. M. Wing was first in 2006 that introduced the term CT in order to describe a set of skills and approaches that are integral to solving complex problems and widely appropriate for our lives ([4]). She pointed out that CT will be a fundamental skill used by everyone in the world by the middle of 21st century ([5]). She argues that CT represents a universally applicable attitude and skill set for everyone—not just for computer scientists. Thus, she proposes CT to be added to every child’s analytical ability, similarly to reading, writing, and arithmetic ([4], [5]).

CT has become a subject of worldwide attention during the last decade as part of multiple efforts to bring computer science and its concepts into K-12 education ([6]). In fact, many attempts have been conducted with the intent to promote new ways of CT-acquisition by K-12 students across all scientific fields, not only STEM. In fact, based on our literature review ([7])—after searching ten large electronic databases for the last decade (2006-2016) - 60 papers have been found presenting empirical data related to the CT’s cultivation by primary level education students. Forty-three of these papers use programming as a context to introduce children to CT concepts. From the remaining papers, CT-concepts have been developed and assessed through: (a) the design of puzzle-based algorithm games ([8], [9]), (b) modules designed to teach the binary number system ([10]), (c) interactive galleries in order students to construct and categorize fractals in Mathematics ([11]), (d) game-play with no programming environments ([12], [13], [14], [15]), (e) the use of tangible technologies ([16], [17]), (f) students’ participation in competitions such as Bedras contest ([18], [19], [20]) or RoboCupJunior competition ([21]). Finally, test tools have been created in order to evaluate students’ (a) knowledge before encountering a CT-based curriculum ([22]), (b) computational literacy ([23]), and (c) understanding and application of CT patterns to novel situations ([24]). Despite the above, a
proposal identifying Digital Storytelling (DST) as a framework for the development of CT skills by K-12 level students has not yet been reported.

It is worth mentioning that DST has been emerged as a powerful teaching and learning tool that engages both students and their teachers to work in authentic learning tasks ([25]) in order to make a digital story by exploiting the diverse multimedia systems and the Internet ([26]). Several studies have been conducted in order students to develop a digital story, an animation even a game working with programming environments, such as Scratch or Alice. It would be important, however, to highlight the CT benefits of students when they develop a DST on a digital environment (e.g. MovieMaker, Pixton, Cartoon Story Maker) that do not utilize a programming language.

Therefore, it would have a great interest to examine how DST development by K-12 students in diverse subjects can cultivate specific CT skills and abilities. Thus, the aim of this study is to identify possible bridges between the acquisition of CT-competences and the skills cultivated through DST activities through each stage of a digital story development using non programming environments. This is the contribution of this paper.

Although we could not find studies with the same goal, some papers with similarities have been reported. Specifically, Lee et al. (2014) discuss how digital storytelling can be used to incorporate CT across the K-8 curriculum ([27]). However, they present an example of using the Scratch programming environment for DST in language arts and history classes by middle school level students. L’Heureux et al. (2012) also reported a scenario designed to cultivate CT in information technology education at the college level, where students were asked to use the ‘Alice’ programming environment to make an animation in order to complete a given story ([28]). In addition, Morales-Díaz and Gaytán-Lugo (2016) outlined the general idea of using programming environments like Scratch, Alice and Kodu, to teach computer animation instead of computer programming as a vehicle for teaching CT in a more effective way to young learners ([29]). Waite et al. (2016) were also drew on their personal classroom experience trying to illustrate how common classroom activities such as using labelled diagrams, concept maps and storyboards are aligned to features of abstraction ([30]). As students plan writing and develop a storyboard, they have to decide what must be included, and what they can ignore. Moreover, Zhong et al. (2015; 2016) aimed to explore the impact of two social factors (gender and partnership) on pair programming as well as to integrate three dimensions (directionality, openness and process) into the design of effective assessment tasks and to assess comprehensively the three dimension (3D) of CT including computational concepts, practices and perspectives. To do so -in a primary school setting- they developed a school-based curriculum entitled “learning to storytelling by programming” ([31], [32]). They used “Alice” as educational tool, based on the 3-Dimensions framework of CT proposed by Brennan and Resnick ([33]). Soleimani et al. (2016) examined the potential of linking tangibles, playful storytelling, and theories of knowledge construction with CT for children, developing for designing a tangible learning tool that would engage children in playful activity while enhancing their learning and storytelling experience ([16]).

It is hoped that this paper would contribute in the discussion of CT-skills development that is carried out by the educational research community by appropriately integrating DST in the teaching practice so that students can cultivate various CT skills even in disciplines not related to STEM fields. The rest of this paper is organized as follows: In Section 2, it is discussed the term of CT and its dimensions, as well as the practice of DST in education in Section 3. In Section 4 it is presented an initial framework between the DST’s development and the CT’s skill cultivation for each stage followed by the conclusions and our future work plans (Section 5).

2 COMPUTATIONAL THINKING

CT has been defined in various ways and it has encompassed broad discussions in order a general CT’s operational definition to be suggested, as well as the skills that compose the concept of CT to be determined.

In fact, Wing (2006) described that CT is a term which involves “solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science”([4]) (p. 33). She argued that CT is a set of essential thinking skills such as data abstraction and data representation, algorithmic thinking, logical thinking, problem composition and decomposition, data analysis, recursion, sorting and search, handling of intractability, representing data as code and code as data, reduction, embedding, transformation, debugging, caching, pipelining, concurrency and parallelization of the processes, simulation, automation, generalization of
dimensional analysis and modularization, judging a program for correctness, efficiency and aesthetics, as well as planning, learning and scheduling in the presence of uncertainty ([4], [5]).

Wing (2011) changed her initial definition arguing that “CT is the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent” ([34]). She described CT as the mental activity in formulating a problem to admit a computational solution, which can be carried out by a human or a machine, or more generally, by combinations of humans and machines. Thus, CT overlaps with logical thinking and systems thinking. It includes algorithmic and parallel thinking, which in turn engage other kinds of thought processes, such as compositional reasoning, pattern matching, procedural thinking, and recursive thinking. CT is used in the design and analysis of problems and their solutions, broadly interpreted ([34]).

Recognizing the value of CT in K-12 education, the International Society for Technology in Education and the Computer Science Teachers Association, the summer of 2009- collaborated with leaders from higher education, industry, and K–12 education to develop an operational definition of CT which was described as a problem-solving process that includes the following dimensions ([35]): (a) formulating problems in a way that enables us to use a computer and other tools to help solve them, (b) logically organizing and analysing data, (c) representing data through abstractions such as models and simulations, (d) automating solutions through algorithmic thinking, (e) identifying, analysing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources, and (f) generalizing and transferring this problem-solving process to a wide variety of problems.

Discussing the work of the abovementioned computer science community, Barr & Stephenson (2011) proposed a CT-definition for all K-12 education. They focus on CT as an approach for solving problems in a way that can be implemented with a computer, where students have the role of tool builders. They focused on CT as a problem-solving methodology that can be automated, transferred and applied across various subjects. They also, provided a list of CT concepts (data collection, data analysis, data representation, problem decomposition, abstraction, algorithms and procedures, automation, parallelization, simulation) mapping them onto diverse school subjects (e.g. computer science, maths, science, social studies, language arts) presenting a specific example of what a concept could look like in different lessons ([36]).

Aho (2012), also simplified the term considering CT as “the thought process involved in formulating problems so their solutions can be represented as computational steps and algorithms” ([37]).

However, a different operational definition of CT came from Brennan & Resnick (2012) who proposed a CT framework -in particular programming interactive media- consisting of three dimensions: computational concepts (e.g. sequences, loops, conditionals), computational practices (e.g. being incremental and iterative) and computational perspectives (e.g. expressive, connecting, questioning) and provide guidelines on how to assess CT across the diverse ways it can be used ([33]).

Furthermore, Mishra & Yadav (2013) articulated that CT goes beyond typical human computer interactions, since human creativity can be developed using CT by allowing students to not only be consumers of technology, but also build tools that can have significant impact on society ([38]).

Based on the above, it seems that CT is a concept that extends over diverse dimensions. The findings of various studies all over the world continually offer new features to this concept. Thus, this study attempts to highlight some features of CT’s concept, identifying specific CT’s skills and dimensions that can be cultivated via DST development by K-12 students. Therefore, the next section presents the main benefits of DST use in education.

3 DIGITAL STORYTELLING IN EDUCATION

Everyone has a story to tell and every day we hear from other people talking about their experiences in the form of stories ([39], [40]). Stories and storytelling are powerful strategies for teaching and learning ([41]). Storytelling is widely used in K-12 classrooms to enrich the learning experience, since it is a natural method of human communication and is prevalent in all aspects of human social interaction ([39]).

In modern society, with the rapid development of technology, a new potential of storytelling has been raised namely “Digital Storytelling”. Digital Storytelling Association (2002) describes DST a “the modern expression of the ancient art of storytelling. Throughout history, storytelling has been used to
DST has been already used in multiple ways and in different subjects in order to help students of all educational levels to develop diverse learning skills and abilities. Specifically, DST has been used in stories. Specifically, they cultivate a set of literacy skills, including: (a) problem-solving skills, (b) writing skills, (c) organization skills, (d) technology skills, (e) presentation skills, (f) interview skills, (g) interpersonal skills, (h) problem-solving skills, and (i) assessment skills.

Robin (2006) classifies digital stories into three categories: personal narratives, stories that examine historical events and stories that are primarily used to inform or instruct ([44]). In any category, DST can be integrated in teaching practice in multiple ways. In fact, four main teaching approaches are proposed [45]: (a) case-based, (b) narrative-based, (c) scenario-based, and (d) problem-based. Each approach presents learners with a Digital story that shows an ordered sequence of information and employs an attention-focusing mechanism. (a) **Case-based instruction**: In case-based digital storytelling instruction, the problem and the solution are fixed and the learner is positioned as an outside observer and is asked by the instructor to concentrate on the story, find its basic and significant events and also make appropriate interpretations and explanations, and (b) **Narrative-based instruction**: In narrative-based digital storytelling instruction the problem and solution are also fixed but the learner is positioned within the narrator’s context and control of information and could express their own emotions about the story in various ways (e.g. by talking, drawing, signing, playing roles, etc.).

(c) **Scenario-based instruction**: In scenario-based digital storytelling instruction the problem is characterized by fixed solution criteria and the learner is positioned in an interactive, real-time experience that allows for a variety of solution paths. In fact, students could interact with the content of the digital story at hand by making their own transformations and extensions. In fact, they could combine their understanding of content knowledge and their own personal experiences to tell a new story, and (d) **Problem-based instruction**: In problem-based digital storytelling instruction the problem is ill structured with no preformed solution criteria or parameters and the learner is positioned as the director of learning activities and could take create their own stories that at their opinion could solve the problem that is described in the digital story they observed. Students could act individually or collaboratively in all the teaching approaches described above. Teachers can also ask their students to develop digital stories: (a) instead of delivering presentations or writing essays, (b) to teach others about a particular concept or topic, (c) to summarize a lesson or unit or set of readings, (d) to illustrate their understanding of how theory applies to their professional work, (e) to explore their conceptions as well as their misconceptions of a complex topic prior to working on a unit/module or project, and (f) to empower them to creatively express their ideas and perspective in an engaging evocative way ([41]).

While students making a digital story, perform various tasks as researchers, playwrights, designers, media producers and educators. They explore diverse topics of significance, compose a narrative, develop computer images, record a personal voiceover, apply contextual knowledge, and analyze ways in which information and mood effectively convey a story ([46]).

The creation of a digital story offers a range of direct and indirect educational benefits to students [47]. The direct educational benefits of DST recognized its potential to: (a) create student engagement in their learning, (b) support the acquisition of multiple literacies such as: digital literacy, global literacy, technology literacy, visual literacy and information literacy ([25], [44]), (c) encourage cooperation between students, (d) create learner motivation, (e) improve the ‘flow’ situation, (f) create personalized learning experiences, (g) enhance learners’ communication skills, (h) encourage critical thinking and problem solving skills, (i) improve data organization abilities, and (g) foster creativity and innovation. Among the indirect educational benefits of student involvement in the creation of digital stories included the possibilities for: (a) creation of professional behavior, (b) emergence of new talents, (c) creation of improved relationships between educators and students, (d) participation of the family and the wider community, (e) a critical view of self, (f) adopting creative viewpoints about various situations and things, (g) integration in the classroom society and also in multicultural environments, and (h) enhancing a global citizenship. Gils (2005) also suggested that DST could: (a) provide more variation than traditional practicing methods, (b) make explanation or the practising of certain topics more compelling, (c) create real life situations in an easy and cheaper way, and (d) improve the involvement of students in the process of learning ([48]). Robin (2006) also summarizes the benefits of students when they are actively involved in the process of designing, creating and presenting their own digital stories. Specifically, they cultivate a set of literacy skills, including ([44]): (a) research skills, (b) writing skills, (c) organization skills, (d) technology skills, (e) presentation skills, (f) interview skills, (g) interpersonal skills, (h) problem-solving skills, and (i) assessment skills.

DST has been already used in multiple ways and in different subjects in order to help students of all educational levels to develop diverse learning skills and abilities. Specifically, DST has been used in...
mathematics for teaching algorithms and problem solving [(49)], as well as for teaching computer
science and programming [(50)]. Moreover, DST has been effectively used to enhance elementary
school students’ science learning in terms of motivation, problem-solving competence, and learning
achievement [(51)]. Campbell (2012), also, examined the effects of introducing multimedia digital
technology on students’ engagement and writing achievement in primary school [(52)]. Furthermore,
DST has been used for children with special needs and disabilities in order to enhance their
communicative and social skills [(53), [54]]. In addition, Xu et al. (2011) have suggested the
formulation of DST in virtual worlds with open-ended, edutainment elements, in order to teach writing
[(39)]. Students and teachers also involved in collaboratively creation of multimedia stories using
“PoliCultura”; a large-scale DST initiative (20,000 students aged 5-18 years old), that combines formal
and informal education [(55)]. Finally, Signes (2014) analysed 50 samples of digital stories produced
by secondary school students showing that: (a) students develop full awareness of the issue chosen
for their story (e.g. violence, war, racism), and (b) DST can help the promotion of critical thinking and
self/group reflection by bringing school and society together and making students cast a critical view
on the world they live in [(56)].

4 RELATIONSHIP BETWEEN COMPUTATIONAL THINKING AND DIGITAL
STORYTELLING

To address possible relationships between DST development and CT-skills cultivation by the students,
the following analysis was realized. Firstly, the process of DST creation was considered as a four
basic stage procedure while a set of tasks appropriate for the successful realization of each stage
were mentioned (see Table 1; column 1). This analysis was based on a synthesis and enrichment of
the work of other researchers regarding DST formation [(46), [57], [58], [59]]. Secondly, in
correspondence to each task falling in the aforementioned stages, an appropriate set of CT-skills
which could be cultivated by the students was presented (see Table 1; column 2).

In fact, this framework constitutes an initial attempt to depict the aforementioned relationship during
DST construction through the following stages: (a) setting the stage, (b) design of the story, (c) digital
story development, and (d) assessment of the digital story. Specifically:

Setting the stage: Initially, given a general DST topic by the teacher, each student should analyze it
(data analysis) in order to select one of its sub-topics (decision making) according to their preferences—
so that they form their digital story around that topic and they become engaged to the task at hand.
Students should also identify the target audience in order to ensure that their digital story is
appropriate for it, by analysing (data analysis) some specific characteristics such as its age, gender,
educational and social level, cognitive background, cultural environment and country of origin.
Moreover, students individually and in groups have to analyze some essential aspects related to the
context of their DST development (data analysis), such as [(59): (a) the available resources (e.g.
computers, software features, cameras, voice-recorders), (b) the time they have at their disposal until
they complete their tasks, and (c) the capabilities and experiences of their team-members, in order to
share their ideas and set their goals. The above elements are crucial in order for each team to
perceive in a critical and logical way (critical and logical thinking) all the elements that emerged from
their analysis and select a subject from a set of topics or a dimension of a theme that is close to the
general topic and their interests (sorting).

Design of the story: Subsequently, students have to explore various sources (research skills) such as
the internet or various books and keep the relevant information (caching) in order to gain a deeper
knowledge of the selected subject of their digital story. After that, they should distinguish their topic
into sub-themes according to the collected material (data analysis, problem-decomposition,
abstraction, reduction, caching and modularization), in order to better understand the subject they are
working on. Then, students have to underline (critical thinking) and highlight the basic information that
is necessary to be briefly presented on their digital story (abstraction, reduction, sorting). After
selecting and defining the appropriate information, students have to write the script of their story.
Script writing is a difficult task because students have to think in a logical and critical way (logical and
critical thinking) how they can separate the topics’ dimensions in an proper way (problem
decomposition) and then they have to compose the elements (problem composition) in an appropriate
sequence (algorithmic thinking) so that the interest of the audience is kept focused. Next, students
have to decide on the materials that their story should include (critical thinking), searching the web or
other sources of information (research skills) to find appropriate parts such as photos and images
(sorting) to represent and support the plot of the story (data representation), and organize them in
appropriate folders they have created (data organization, modularization, caching). Once the script has been accomplished, students have to create the storyboard. A storyboard is considered as an algorithm which constitutes a set of parts and events of the story that could help students visualize their script. They should split the script in sequences (algorithmic thinking, logical and critical thinking, transformation, problem composition and decomposition) and put together the words, the images, videos and audios (parallelization, data representation, pipelining) that they will use in the digital story development using an appropriate software at the next stage. Throughout the script’s and storyboard’s creation, students should check on how their digital story can be more beneficial by adding or removing specific items (critical thinking, transformation, debugging, pipelining, aesthetic skills).

**Digital story development:** When students complete their storyboard, they should proceed to the production stage. After importing their files in the software program within the proper folders (data organization), then they have to “combine them together” taking into account the storyboard they have created in the previous stage (data representation, parallelization, sorting, caching, debugging, aesthetic skills). Throughout this process, students should ([57], [58], [59]): (a) add titles and captions on the appropriate slides of the story (parallelization) and think about their effects (aesthetic skills), (b) record themselves according to their script and save their narratives (aesthetic skills, caching), (c) think about additional multimedia elements (e.g. meaningful audios, images and videos) that they could find or create in order to enrich their DST (critical thinking, data representation, transformation, research skills, aesthetic skills), (d) consider about adding special effects to the slides that the software provides (aesthetic skills, critical thinking, transformation), (e) check and modify the elements of the story so that they become more advantageous (critical thinking, transformation, debugging, pipelining, aesthetic skills). When students complete the editing, they have to save the final version of their digital story in different file formats (caching), so that they have the flexibility to upload their story on a website, a blog, even turn it into a PowerPoint presentation ([57]).

**Assessment of the digital story:** When students generate their digital stories, they should know about the criteria based on which their stories will be evaluated. Therefore, these criteria should be given at the same time students are producing their stories ([46]). Thus, throughout the entire process students should have a rubric consisting of guidelines with specific elements comprising an effective digital story. Such a rubric can also be used as a peer- evaluation tool ([57]) (critical thinking, debugging), as well as for the assessment of the digital stories of other teams (critical thinking, debugging). Evaluation is important in DST development, since students share their ideas with their peers and get feedback from both their team-mates and the whole class.

**Table 1. Stages of DST creation and CT-skills possible development**

<table>
<thead>
<tr>
<th>Stages of DST creation</th>
<th>CT-skills cultivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting the stage</td>
<td></td>
</tr>
<tr>
<td>• setting the aim of the story by each student</td>
<td>data analysis</td>
</tr>
<tr>
<td>• audience's analysis</td>
<td>data analysis</td>
</tr>
<tr>
<td>• analysis of the context of DST development (resources and time available, team-members’ characteristics)</td>
<td>data analysis</td>
</tr>
<tr>
<td>• topic's selection according to team's interests, knowledge and experiences</td>
<td>critical thinking, logical thinking, sorting</td>
</tr>
<tr>
<td>Design of the story</td>
<td></td>
</tr>
<tr>
<td>• data and information research for better understanding of the selected topic</td>
<td>research skills, caching</td>
</tr>
<tr>
<td>• topic's analysis into sub-themes and selection of the information relevant to the story</td>
<td>data analysis, problem decomposition, abstraction, reduction, caching, modularization</td>
</tr>
<tr>
<td>• highlight of the basic information</td>
<td>abstraction, critical thinking, sorting, reduction</td>
</tr>
<tr>
<td>• script writing</td>
<td>logical thinking, critical thinking, algorithmic thinking, problem composition and decomposition</td>
</tr>
<tr>
<td>• decision of the materials to be included</td>
<td>critical thinking</td>
</tr>
<tr>
<td>• DST materials' collection and organization (e.g. in folders)</td>
<td>research skills, critical thinking, data representation, sorting, data organization, modularization, caching</td>
</tr>
</tbody>
</table>
As it is shown in Table 1, there seems to be a relationship between DST development and CT-skills cultivation, since in each stage, students could nurture diverse CT-abilities. Therefore, DST creation is a teaching practice that could offer new learning opportunities to K-12 level students in order to develop their CT skills and abilities working within a different context than the ones within which CT has been cultivated so far. After analysing the benefits of DST creation by all students, it was noticed that there are several CT-skills that could be developed during the students’ engagement with DST-development.

5 CONCLUSIONS AND FUTURE WORK

This paper has examined the potential of DST development as an effective framework for the cultivation of specific CT skills by K-12 level students. In fact, this paper proposes an initial framework consisting of a 4-stage DST-creation process. Each stage includes a set of general tasks and their correspondent CT-competences which could be cultivated -using non programming environments- by the students. This framework was based on the analysis of secondary data presented in the literature. It was highlighted that, students engaging on DST-creation tasks could develop diverse CT skills such as data abstraction, data representation, algorithmic thinking, logical thinking, problem composition and decomposition, data analysis, sorting and search, reduction, debugging, caching, concurrency and parallelization of the processes, transformation, modularization, pipelining, and aesthetic skills.

However, the present study has some limitations due to the fact that, it is an initial attempt to clarify the contribution of DST as an effective educational framework to develop CT skills by K-12 level students. Therefore, it would have a great interest to examine to a greater extent how CT-skills can be cultivated via DST creation, as well as the ways that CT-skills could be measured through the use of this framework.

Thus, our future plans are to develop a methodology with specific tasks for each stage of DST creation that students should follow in order to create their digital stories developing their CT skills at the same time. This methodology would also serve as an assessment method about the level of each CT-skill acquired by the students. It is also our hope to provide more useful and important elements to the educational community after implementing this methodology to K-12 students.
REFERENCES


