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Design-Based Digital Story Program: Enhancing Coding and Computational Thinking Skills in Early Childhood Education

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Abstract
The domain of early childhood education has witnessed an increasing emphasis on developing coding and computational thinking (CT) abilities. Scholarly investigations have delved into appropriate approaches for enhancing these proficiencies within early childhood classrooms. The present study aims to investigate the impact of a digital story design program, or Design-Based Digital Story Program (DBDS), on the coding and CT skills of 5-year-old children. Specifically designed for children aged 3–6, the DBDS program aligns with constructivism principles, which promote experiential learning. Employing a case–control quasi-experimental design, the study employed pre-intervention and post-intervention assessments and a follow-up retest after one month. The intervention involved implementing the digital story design program over 11 weeks, with three sessions per week, each lasting between 60 to 90 min, targeting five-year-old participants. The findings reveal that the DBDS program significantly enhances CT and coding skills compared to a control group. Moreover, female participants exhibited more significant improvements in CT skills post-intervention than their male counterparts, while no significant gender-based effects were observed in coding skills. These findings suggest that the DBDS program effectively supports the cultivation of coding and CT abilities among young children, warranting further exploration in diverse educational settings and across various grade levels.

Keywords Early years education · Twenty-first century abilities · Improving classroom teaching · Design-based learning · Computational thinking

Introduction

The rapid proliferation of 21st-century technologies requires new educational practices. Fullan (2001) stated that the primary purpose of education was to "make a positive difference in children's lives and enable them to become citizens who live and work productively in increasingly complex societies." Papert (1990) proposed that children learn best through design with technological tools. Papert's research showed that children gain metacognitive thinking and investigative skills such as problem-solving, questioning, and mathematic reasoning when learning to code. Learning by design (LBD) has emerged as a pedagogical model that can help every child learn and develop in the twenty-first century (Li et al., 2019).

Children are arguably born engineers. They have a curiosity about their environment, a desire to explore new situations and places, and a great enthusiasm for manipulating and experimenting with new objects and materials (Bairaktarova et al., 2011; Cunningham, 2009; Davis et al., 2017). Therefore, engineering is an essential practice for children to engage in by building and producing artifacts using various materials. Learning through

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design has gained several advocates in recent years. Harel (1988) states that children learn best when they use, manipulate, and create objects and share what they produce with others. Kolodner et al. (2003) argue that design-based learning is essential in development. They believe engaging in design can help students acquire the foundational science principles they need to be successful thinkers, learners, and decision-makers throughout their lives and thrive in the modern world.

With the increased emphasis on LBD, attempts to find effective ways of teaching engineering design skills have increased at all levels of education (Dym et al., 2005). Additionally, it has become increasingly crucial that LBD starts in preschool and is integrated into studies of technology, coding, and Computational Thinking (CT) (Dym et al., 2005). We have developed a collaborative, technology-supported, design-based program integrated with the preschool education program in early childhood education. The present study investigates the effects of this design-based digital story creation educational program on the computational thinking and coding skills of 5-year-old children.

Review of the Literature

Foundations of Design-Based Learning for Children

Humans have been using design to improve their environments since the beginning (Gero, 1990; Kouprie & Visser, 2009). Design is an approach to defining and solving a problem in the man-made world (Li et al., 2019). The design process is defined as a creative and iterative process that begins with identifying a problem, brainstorming, planning, creating, and developing solutions (Honebein, 1996; Koh et al., 2015; National Research Council, 2010; NAE & NRC, 2009; Smith, 1997; Wolf, 1998).

An understanding of how children learn from design experiences is based on the constructivist views of Pestalozzi, Montessori, Dewey, and Piaget. Piaget's theory of cognitive development created a framework for understanding how children think and learn at different developmental stages (Ackermann, 2001). Piaget proposed that children do not learn best by receiving knowledge passively but by actively constructing knowledge (Piaget, 1973). This theory fundamentally affected education.

Papert facilitated children's learning by design by following Piaget's teachings and creating the Logo programming language to support children's mathematical skills (Ackermann, 2001). Papert (1990) took the concept of constructionism a step further than constructivism by stating that the key to learning is expressing one's feelings and thoughts with technological tools and sharing them with others. He paved the way for LBD by emphasizing that expressing ideas makes them concrete and shareable, enabling ideas to be shaped and sharpened (Ackermann, 2001; Papert & Harel, 1991). According to Piaget (1973) and Papert (1994), knowledge is not only a commodity to be transferred, codified, stored, and reapplied but also a personal experience to be constructed. He emphasized that an excellent way to support the construction of knowledge in one's mind is to build things in one's mind. Papert argued that when children use technological tools to design and create content, the interaction changes from a passive to an active, personally guided environment. He also argued that children's use of tangible technologies to acquire knowledge reinforces their natural tendency to produce while learning by doing (Papert, 1980). Harel (1988) stated that children learn best when they use, manipulate, and produce objects and share what they produce with others. Kolodner et al. (2003) stated that learning through design is a process that involves a classroom culture in which teachers and students engage in highly collaborative, learner-centered, inquiry-oriented, and design-based activities.

Design-based Learning in Early Childhood Education

Design and design thinking are vital for creativity and innovation. Its integration into education is increasingly important in developing and implementing integrated STEM education (Johansson-Sköldberg et al., 2013; Li et al., 2019;). Design thinking is sometimes called engineering design, design-based learning, and designerly thinking (Johansson-Sköldberg et al., 2013).

Design is often taught as part of the engineering component of STEM education (Brophy et al., 2008; Bybee, 2011). Although design thinking as a cognitive model is essential for every student to develop and possess in the twenty-first century, studies on design thinking have focused mainly on the cognitive approaches of professional designers and engineers. Studies on the use of design in education that are not specific to engineering and technology are still limited (Li et al., 2019). The first studies on design in education started to be used in technology education in the UK. After 1975, it was added to the national program as an achievement goal, and students were expected to design and produce (Lewis, 2006). Papert (1990) came to the fore with his view that children can learn anything through design and his work on mathematics skills with Logos (Harel & Papert, 1990; Papert, 1980).

In the design-based learning process, students must learn the knowledge and skills to design and plan a solution, make practical applications, and test and evaluate solutions (NRC, 2013). Li et al. (2019) state that design is a term usually used by professionals in architecture, fashion, technology, and engineering and is not widely used in education. However, Wright and Wrigley (2019) state that 21st-century citizens must develop the necessary technological skills and design thinking to succeed in various professions and engage in lifelong learning.

The engineering design process often requires working in a group to design, test, optimize, and communicate a solution to a problem, as many researchers and theorists in the engineering field have put forward (Strimel et al., 2018). Honebein (1996) states that the design process involves problem-posing, brainstorming, planning, creating, and developing. Brooks and Brooks (1993) state that it is a process in which children can use cognitive terminology such as creating, classifying, analyzing, predicting, and creating meanings through social interactions. Design activities include a series of design events that occur from the initial comprehension of a design problem to the concretization of the solution to this problem (Koh et al., 2015). The design process in early childhood is used to identify the problem, imagine the solution, plan for the solution, and transform the solution into a product through the process called producing or creating, testing or developing (Bagiati, 2011; Bagiati & Evangelou, 2016; Bers, 2022; Davis et al., 2017; Lottero-Perdue et al., 2016). Bers (2022) stated that "sharing" the solution obtained from the design process is an essential step in design-based thinking for young children.

The design process provides important opportunities for children to develop science and mathematical reasoning skills, collaborative sense-making, reasoning with evidence, and evaluating knowledge (English, 2018; Kelley & Sung, 2017; Kelly & Cunningham, 2019). The engineering design process can improve children's executive function (Bustamante et al., 2017, 2018a, b; Nayfeld et al., 2013; Strimel et al., 2018). Stone-MacDonald and Douglass (2015) argue that the engineering design process supports different thinking skills, such as curiosity, continuous, flexible, reflective, and collaborative thinking. Kafai and Peppler (2011) report that the metacognitive aspects of learning are vital in the design-based learning process, and in this process, children learn a meta-design language that enables them to plan to solve problems and solve these problems.

In early childhood, science and engineering are often taught through hands-on and interactive activities in which children investigate, plan, execute, or solve problems rather than memorize facts (Davis et al., 2017). The design process has also become a gateway to children's understanding of scientific concepts (Benenson, 2001; Crismond, 2001; Kolodner, 2002). The design process, which is vital for early childhood creativity and innovation as it encourages different perspectives and approaches to solving problems (Li & Schoenfeld, 2019), provides children with engineering habits of mind, such as working as a team and the values of teamwork, persisting with a failed design, and making evidence-based decisions (Hadzigeorgiou, 2016; Lottero-Perdue, 2019).

The engineering practices and performance indicators in the NGSS start with kindergarten and indicate many ways for young children to identify problems and then design solutions to those problems (Lottero-Perdue et al., 2016). Although Lippard et al. (2019) stated that children often encounter design or engineering problems daily, these opportunities are not emphasized in preschool classrooms. Lippard et al. (2017) revealed in their review that 24 studies had been conducted on children's design skills. This suggests that efforts and studies on design-based learning (DBL) have increased in early childhood years.

It can be readily appreciated that studies on DBL are gaining momentum. Several reviews of studies in this field have been published recently (Bagiati et al., 2010; Cunningham et al., 2018; Lippard et al., 2017). Research in this area covers several different areas of focus, including:

- Studies with a focus on environment, activities, and teachers' behaviors for engineering design skills in early childhood classrooms (Bagiati & Evangelou, 2016; Bairaktarova et al., 2011; Brophy & Evangelou, 2007; Evangelou et al., 2010; Gold et al., 2015; Lippard et al., 2018; Van Meeteren & Zan, 2010),
- Studies emphasizing program development (such as Ata Aktürk, 2019; Bagiati, 2011; Bagiati & Evangelou, 2015; Davis et al., 2017),
- Studies integrating DBL into the educational process and classroom practices (Bers & Portsmore, 2005; Bustamante et al., 2018a, b; Gold & Elicker, 2020; Gunning et al., 2016; Lottero-Perdue et al., 2016; Malone et al., 2018; Pantoya et al., 2015; Raven et al., 2018)
- Studies supporting children's developmental domains, including problem-solving (e.g., John et al., 2018; Pattison et al., 2020), children's spatial and math (Keren et al., 2012; Keren & Fridin, 2014; Verdine et al., 2014), literacy, social (McDonald & Howell, 2012), and motor skills (Christenson & James, 2015; Davis et al., 2017).

Studies centering on teachers and families (such as Ata-Aktürk & Demircan, 2021; Bers et al., 2013). It is seen that the engineering design process, which is one of the STEM skills, has started to be studied for coding and CT skills, which are the concepts of computer science.

Digital Story

Kelly and Cunningham (2019) state that design practices that enter educational environments require using epistemic tools, defined as physical, symbolic, and discursive artifacts that facilitate the construction of knowledge and design solutions (objects, systems, and processes). These artifacts allow for knowledge to be tangible and visible. Stories are one of the epistemic tools defined as symbolic and/or discursive artifacts. The literature shows that stories, which are ubiquitous in human experience, are an essential pedagogical tool that can significantly enhance learning and teaching outcomes (Lowenthal & Dunlap, 2010; Novak, 2015; Xu et al., 2011). Story-enriched learning enables children to understand the information presented using various visual, auditory, and linguistic inputs. This process activates working memory by enabling children to distinguish between necessary and unnecessary information (Stevens & Bavelier, 2012). Kervin and Mantei (2017) state that children develop essential knowledge about language, vocabulary, and story schemas through their stories and that sharing their own stories allows them to develop and communicate their perspectives and interpretations. For this reason, the story-based learning approach has been seen as an essential tool in learning in recent years.

The Story-Based Learning Approach, a teaching method, uses a creative approach for students to realize meaningful learning through topics. When planning a Story-Based Learning Approach, the teacher uses the story tool to contextualize and focus teaching and learning on a particular topic. The most important aspect of this method is that it is a process that starts with what the student already knows and builds new knowledge by strengthening students' knowledge and skills through carefully prepared questions and activities (Harkness, 1993; Omand, 2014).

Digital storytelling involves the author utilizing a series of technical tools to create a personal story using images, graphics, music, and sound, akin to oral storytelling (Porter, 2004). Digital story-making permits children to become active producers rather than passive multimedia consumers (Leinonen & Sintonen, 2014; Ohler, 2006). Bruner (1990) refers to the stories developed by children as a different form of reasoning, a construction process, and a narrative mode of thinking. Children can produce digital stories that promote learning through technologies and mobile devices (McGee, 2014). These stories allow children to explore and construct knowledge, design, learn deeply, reflect, apply, and evaluate their learning (Boase, 2008; Cole et al., 2012; Raven & O'Donnell, 2010). Research has shown that stories have numerous benefits for children's development and that there is a positive relationship between computational thinking (CT) skills and using stories as a learning tool (Kordaki & Kakavas, 2017; Psomos & Kordaki, 2016). Similarly, children's creation of digital stories in early childhood supports computational thinking and coding skills (Fleer, 2013; García-Peñalvo & Cruz-Benito, 2016; Maureen et al., 2018; Moradi & Chen, 2019; Portelance et al., 2016). Digital stories in education have been proposed as a potentially effective way to develop children's coding and computational thinking skills. This is mainly due to the process of digital story creation, which involves children choosing and analyzing a story topic, creating a sequence of events, and transferring the story to a digital format (Burke & Kafai, 2012; Hytönen et al., 2011; Kordaki & Kakavas, 2017; Robin & McNeil, 2012; Wang & Zhan, 2010; Werby, 2012).

Bruner (1990) describes stories developed by children as a different form of reasoning, a construction process, and a narrative mode of thinking. The story-based learning approach with a constructivist perspective, as in the design process, includes a basic structure (Yang & Wu, 2012), and the digital story process requires following project creation steps to generate content (Ohler, 2006, 2008; Yang & Wu, 2012). The essence of a story includes the stages of 1) pre-production, 2) production, 3) post-production, and 4) distribution (Ohler, 2006; Robin, 2006; Yang & Wu, 2012). This creation process also involves planning and developing a story using elements such as setting, characters, time, and problem situation (Harkness, 1997; Harkness & Creswell, 1997; Omand, 2014). Morra (2013) expresses the digital story as a cyclical process. Like the design process, which is cyclical, the digital story creation process includes starting with a problem/idea, continuing with research and exploration related to the problem, writing the story, preparing the storyboard, creating the digital story using multimedia tools, sharing the story and feedback, and finally writing the story (Robin, 2008; Robin & Pierson, 2005; Jakes & Brennan, 2005; Morra, 2013). Although the engineering design process and digital storytelling are traditionally seen as different disciplines, the digital story creation process is considered a design process because it includes the steps of project creation, planning, and development.

Digital stories offer the opportunity to integrate technology into storytelling. This technology enables children to participate in the process of active learning and also helps them develop various skills such as problem-solving, critical thinking, knowledge construction, design, and evaluation (Ballard & Haroldson, 2022; Brennan & Resnick, 2012; Dogan, 2011; Hytönen et al., 2011; Jenkins & Gravestock, 2009; Ohler, 2006). Therefore, the experiences in the digital story creation process, which is a design process, include children's computational thinking and coding skills and are an essential way to support these skills.

Coding and Computational Thinking

Some consider coding and computational thinking skills a new 21st-century literacy that all individuals should acquire in the early years. (Korkmaz et al., 2018; Manches & Plowman, 2017; Popat & Starkey, 2019; Román-González et al., 2017; Wing, 2006, 2008). Coding and computational thinking skills include the basic skills of computer science and are seen as closely related. Wing (2006) emphasizes that children are exposed to IS during programming, and Smith et al. (2000) state that programming languages are seen as the primary way to develop computational thinking, although they do not have the same scope as IS. However, some researchers argue that children will have better coding performance when they acquire IC skills (Davies, 2008).

Although there are different opinions on which skills are included in CID and coding, which have shared skills, recent studies (Angeli & Valanides, 2020; Angeli et al., 2016; Barr & Stephenson, 2011; Bers et al. 2022a, b; Futschek, 2006; Futschek & Moschitz, 2011; Gibson, 2012; Lee & Junoh, 2019; Mittermeir 2013; Relkin et al., 2020; Relkin & Bers, 2021; Selby & Woollard, 2013; Shute et al., 2017) and organizations such as ISTE (2016, 2017, 2019), CSTA (2016, 2019) and NAEYC (2012) have put forward ICT and coding skills by taking into account the developmental characteristics of children in early childhood. Computational thinking skills and coding skills include algorithms (sequencing), modularity (breaking large tasks into small parts), control structures (recognizing cause and effect), design process (understanding the cyclical nature of creative processes), debugging (identifying and solving problems), creating functions, and building loops (Bers, 2018; Relkin & Bers, 2019).

Study Overview

The current scholarly discourse has indicated a growing trend in applying coding and computational thinking skills. In this regard, Wang et al. (2022) explored the relationship between DBL and CT, asserting that DBL can provide a tangible and visual framework for the acquisition of CT skills. Additionally, they suggest that the iterative nature of the design process is particularly beneficial in mastering CT skills. Furthermore, the creation of digital stories, which incorporates the design process, is an effective means of developing CT skills and conveying CT-related concepts (Kelleher et al., 2007; Kordaki & Kakavas, 2017; Lee et al., 2014; Mishra et al. 2013; Robin & McNeil, 2012; Saritepeci, 2020; Yildiz Durak 2018; Wang & Zhan, 2010; Werby, 2012).

The literature reveals various approaches to teaching coding and computational thinking at the K-12 level, including constructivist, design-based, game-based, digital story, scaffolding, and collaborative strategies (Tikva & Tambouris, 2021). Studies focusing on early childhood education have employed block-based applications such as Scratch, Alice, and robotics, incorporating design and digital story creation strategies. This study explores the potential benefits of a pilot implementation of the DBDS program, which engages children in a collaborative process to design and illustrate their own stories and share them in a digital environment. The DBDS program is intended to serve as a scaffold to support children's computational thinking and coding skills. Specifically, the study seeks to answer the following hypotheses:

- How does the developmentally appropriate DBDS program impact children's coding and computational thinking skills?
- To what extent does the DBDS program have a differential effect on gender?

Method

Research Design

This study aims to evaluate the effect of a design-based digital story creation program on the development of coding and computational thinking skills of 5-year-old children. The study used a quasi-experimental design with a pre-test/post-test/retest control group (2 × 3 split plot). The data were collected with "CodingTest 2" (Metin et al., 2023) and "TechCheck-K," which was adapted into Turkish by Metin et al. (2024)

Study Group

The study group comprised 64 children (35 girls and 29 boys) who were five years of age and from low-income households. The participants attended kindergarten classrooms that were part of the Provincial Directorate of National Education in Turkey, especially children from families with low socio-economic status. The experimental group consisted of 35 children (18 girls, 17 boys), and 29 children (17 girls, 12 boys) were in the control group.

Data Collection Tools

CodingTest 2 Developed by Kalyenci et al. (2022), "CodingTest 2" is an assessment tool designed to evaluate the coding and robotic coding skills of children aged 5–7. It comprises two forms: CodingTest-A measures unplugged coding skills, while CodingTest-B assesses robotic coding skills. The reliability results for the test were KR-20 = 0.973 > 0.70 for Form A and KR-20 = 0.978 > 0.70 for Form B. The test consists of a coding sheet (comprising 9 × 9 squares), marker cards, and visual cards depicting stories, allowing children to engage with visual materials during the application. The application is conducted individually with each child and takes 25 min. To facilitate ease for practitioners due to the extended time required for the application of CodingTest and the procurement of materials, Metin et al. (2023) developed "CodingTest 2," a short form of "CodingTest" to assess coding skills in children aged 5–7. The reliability results for the test were found to be KR-20 = 0.967 > 0.70. This study also used "CodingTest 2," the short form of "CodingTest," to measure children's coding skills quickly and easily. In "CodingTest 2," the stories from "CodingTest" have been abbreviated, and three visual response options to evaluate each skill have been added. The answer options consist of 6 × 6 squares. For each question, the story is read to the child, and they are expected to choose or show the correct response out of the three options. "CodingTest 2" can be administered via tablet, computer, or A4 paper. The test contains two samples and eleven main questions, each with brief stories. The first ten questions are multiple-choice with three visual response options, with only one correct option. In the test scoring, a child selecting the correct option receives 1 point, while a wrong choice results in 0 points. The 11th question measures the child's programming skills and is presented as an open-ended question where the child is expected to draw their program. If the child creates and draws their program, they receive 1 point; otherwise, if they cannot program or draw, they get 0 points. The total score of the test is 11 points.

TechCheck-K Metin et al. (2024) adapted "TechCheck-K" and conducted validity and reliability studies measuring the computational thinking skills of 5–6-year-old children. TechCheck-K (Relkin et al. 2021) is based on developmentally appropriate computational thinking concepts and is a multiple-choice "unplugged" assessment that allows it to be administered to whole classes or online settings in less than 15 min. The assessment covers algorithms, modularity, control structures, representation, hardware/software, and debugging skills. There are 15 multiple-choice questions and three visual options for each. These questions assess tasks such as sorting difficulties, shortest path puzzles, missing symbol series, object sorting, obstacle mazes, symbol-shape puzzles, identifying technological concepts, and symmetry problems. In the test's scoring, a child gets 1 point for the correct answer and 0 points for the wrong answer. The KR-20 reliability coefficient of the Turkish version of TechCheck-K was found to be 0.87, indicating that it is a valid and reliable measurement tool for Turkish children.

Design-Based Digital Story Program

In the DBDS program, two significant teaching approaches have been utilized to provide meaningful experiences for children and support their coding and STEAM (Science, Technology, Engineering, Arts, and Mathematics) skills. Design-based learning that contributes to all developmental domains while children create meaningful works is based on a story-based learning approach encompassing a specific structure and stages (setting, characters, trigger event, problem, solution/end) and simple narrative elements (Bell, 2009; Güney, 2019; Letschert et al., 2006; Mandler & Johnson, 1977; Omand, 2014). Essentially, these two approaches reflect constructivist perspectives. Therefore, in utilizing these approaches, the DBDS program draws from the strong ideas of three constructivist theorists. It relies on Piaget's experiential learning, Vygotsky's interaction with adults and peers, and scaffolding, along with Papert's (1986) views on technology and producing meaningful products.

Both approaches start with a problem and offer children multiple experiences while cyclically solving the problem. Throughout the program, children grasp the cyclical structure of a narrative, utilizing coding and STEAM skills while designing their digital stories.

The DBDS program creates a collaborative learning environment facilitating child-child, teacher–child, and child-object interactions as children engage in the design process. Moreover, the design process necessitates communication through epistemic tools such as verbal, written, and symbolic modes. According to Kelly and Cunningham (2019), these tools are epistemic, aiding knowledge construction and serving as scaffolds for DBDS.

Within the DBDS program, eight stories authored by the primary writer serve as epistemic tools. These stories are structured to include narrative elements (place, time, characters, problem, solution, outcome) and align with the design process. Throughout the program, technology plays a prominent role. For instance, children were encouraged to use the "Wordwall" from Web 2.0 tools to select groups and gather information about story characters and events using computers. Children transferred their designed stories to the "e-BookCreator" program, took pictures of their drawings, transferred them to computers, and presented some stories using presentations.

The DBDS program operates in harmony with the achievements and indicators in early childhood education programs. The program comprises three stages:

Stage 1: Ohler (2006) emphasizes that to harness the potential power of digital storytelling, one should focus on the story first and then on the digital medium. He highlights that as technology becomes powerful, the strength of the stories weakens, with some students being more interested in the tools rather than the message, producing a technical event rather than a story. Therefore, it is intended for children first to develop skills related to how a story is designed before creating a digital story. This program's initial stage focuses on a story's design and structure.

Comprising six activities to impart skills in structuring and designing a story, lasting three weeks. In this stage, "story mapping" (Fig. 1) and "my story map" (Fig. 2) notebooks were used to illustrate the design process of a story. After each story, children, individually or in groups, used story maps to reveal the elements of the story. Sample activities implemented in this stage are outlined below:

In the initial activity, the practitioner narrated a story ("Activity 1: Will the Baby Bird Fly?") to the children, claiming to be the story's author. It was explained that the story had no pictures, and the children would draw these pictures. The practitioner commenced the story, pausing to ask the children to draw the setting, time, character, event, and problem from the story (Figs. 3 and 4). After completing the story and the children's drawings, each child combined their book. All children named their stories and drew a cover picture (Fig. 5). Children examined each other's storybooks and provided feedback. They took their stories home to share with their families.

On the second day (Activity 2: The Washing Machine), various symbols were examined, and their meanings were discussed with the children. It was indicated that research would be conducted on symbols around us, and the children went on a symbol hunt (Fig. 6). Equipped with a pen and a post-it, the children explored other areas of the school, drew the symbols they observed, and returned to the classroom.

The practitioner placed a "story map" on the wall before reading the story. They directed the children's attention to the symbols on the story map, discussing what each symbol represented and conveyed in the story. After discussing each symbol (character, place, time, prob-

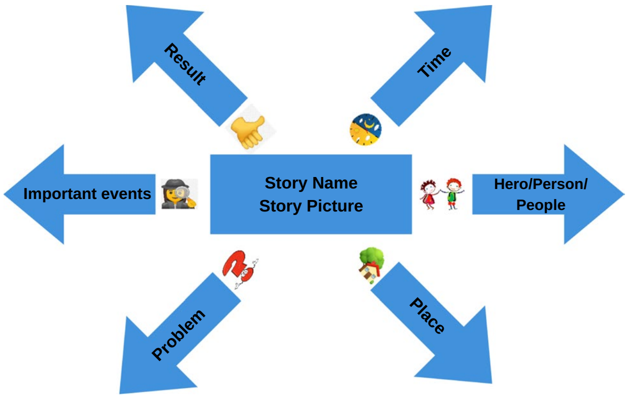

Fig. 1 Story Map

lem, solution), the practitioner began reading the story. After a while, they paused the story and asked who the main character was. They requested a child to draw this character and stick it next to the relevant symbol. The practitioner guided them in drawing and sticking all story elements on the wall. After finishing the story, a map displaying the story's elements emerged on the wall (Fig. 7).

Stage 2 consists of twelve activities where children attempt to write their own stories. Sample activities conducted during this process are outlined below:

The practitioner began interactively narrating the story "The Boatman." The practitioner and children sat down, mimicking rowing movements like holding oars. Throughout the story, the practitioner and children acted out the story together (For instance, the practitioner said, "It was boiling. The boatman decided to make himself a hat," and the children made a hat using paper and newspaper. Then, the story continued). Towards the end of the story, the children were divided into groups to determine what happened. Each group decided the story's ending, drew the processes of the story, and created a story map. All the children shared their stories. Groups examined each other's story maps and explained how they concluded the story (Figs. 8 and 9).

The next day, the practitioner introduced the story "Little Koala." After explaining the problem in the story, they paused and asked the children, "How do you think this problem will be solved?" After gathering the children's opinions, they divided the children into groups. Each group started designing their Koalas (color, habitat, costume) using Web 2.0 tools. Following this design process, groups determined the continuation of the story and created a story map (Fig. 10).

Stage 3: In this stage, lasting for 10 days, children begin designing a story as a group and continuously improve their stories throughout the process. Children designed, drew, digitized, and narrated their stories, presenting them to classmates, families, and other children at school. They reconstructed their stories after receiving feedback. Some activities during this process are outlined below:

In Activity 12, the practitioner hangs the story map on the wall (Fig. 11) and pastes the elements of the story on it. The practitioner divides the children into groups and asks them

Fig. 2 My Story Map

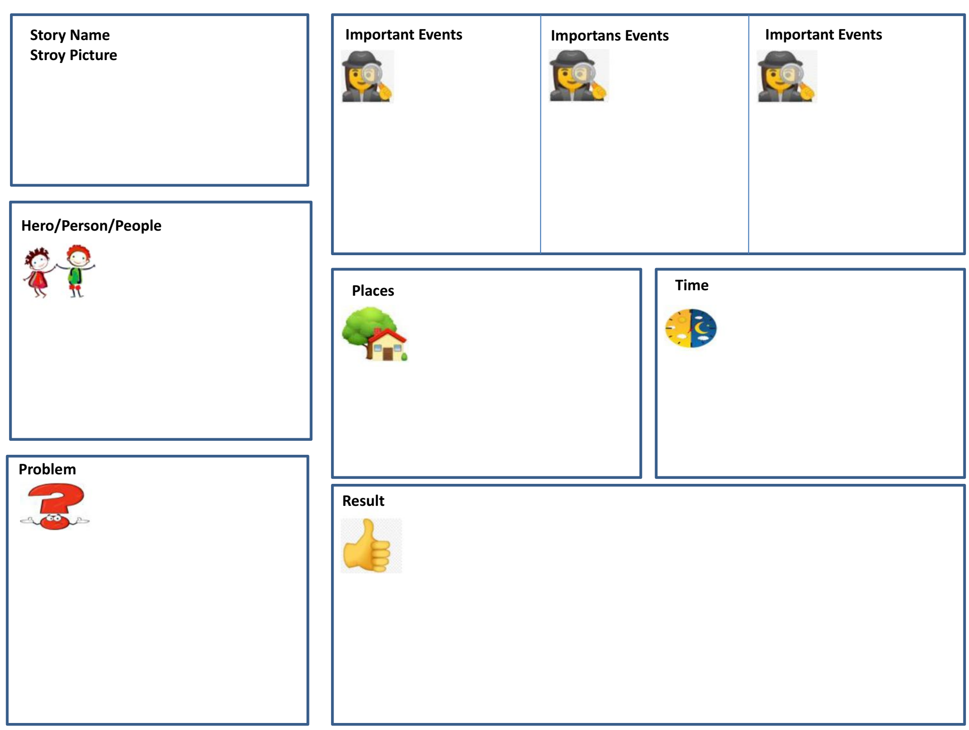

Fig. 3 Hero Image

Fig. 4 Story Problem Image

Fig. 5 Cover Image

to analyses the story map. The groups designed and drew their stories based on the visuals.

In the last stage of the program, children designed their own stories for 8 days and created them using the E-Bookcreator application. Children developed the first draft of the story through a cyclical process. During this process, the children presented the results to their classmates, families, and peers at school and received feedback. Based on each feedback, they made changes and additions to the story and drawings. After completing the story, they took photos of their drawings and transferred them to the computer. Following the algorithm of the story, they transferred their drawings to the "E-Bookcreator" application. The groups shared their stories (Fig. 12) with the community.

Process

This study examines the impact of the DBDS program on the coding and computational thinking skills of 5-year-old children continuing in preschool education. The program aimed to enhance children's coding and computational thinking skills. Implemented by the second researcher, the experimental group underwent 22 activities twice weekly for 11 weeks. The control group continued with normal educational programs and participated in class teacher-led story activities. Before and after the program implementation, both control and experimental groups underwent assessment tools called "TechCheck-K" and "CodingTest 2." Assessment tools were re-administered to the experimental group one month after the program's completion to evaluate the sustainability of learning. Computers were used throughout the activity process. Tablets were not utilized for children for two reasons: primarily due to the lack of resources for both children and the school, and secondly, because only a few children in Turkey, especially children from families with low socio-economic status have access to tablets. The program was implemented using computers to ensure accessibility for all children. However, teachers can also implement the program using tablets.

Before the implementation of the activity program, an informative meeting was held with the class teacher and parents of the children in the experimental group about the purpose, content, and implementation of the "Design-Based Digital Story Creation Training Program." This meeting introduced the program, including its activities, methods, and techniques. Parents were told of the program's potential contributions to their child's vital coding and CT skills acquisition. In addition, to increase the study's effectiveness, parents were advised to integrate some of the activities in the program into their child's life at home. Parents provided feedback on the program by filling out the family participation forms that were sent to them. They were also asked to send their child to school so that absenteeism would not

Fig. 6 Symbol Hunt

Fig. 7 Map of Elements of a Story

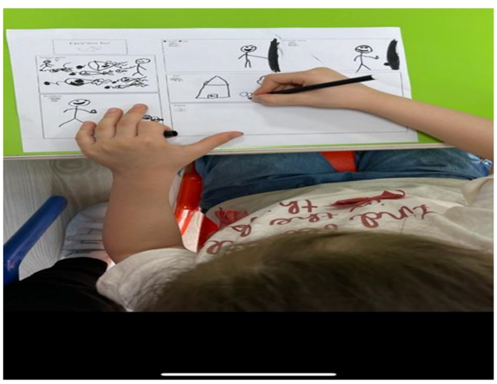

Fig. 8 Children's Drawings of My Story Map

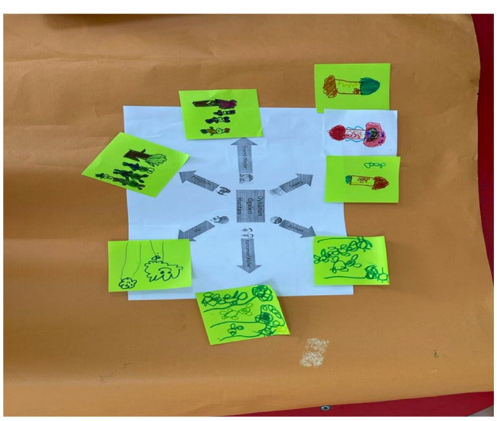

Fig. 9 Groups' Drawings of Story Elements

affect the research. The control group students participated in business as usual without learning coding, computational thinking, or design over the same 11-week period.

Data Analysis

The statistical package program was used for the SPPS 25 (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.). Descriptive statistics (mean, standard deviation, median, maximum value, minimum value, number, and percentile) were used for categorical and continuous variables. In addition, the homogeneity of variances, one of the prerequisites of parametric tests, was checked using the "Levene" test. The normality assumption was checked with the "Shapiro–Wilk" test. When the differences between the two groups were evaluated, "Independent Sample T-Tests" were used. When the prerequisites for parametric tests were met, "The Mann Whitney-U tests" were used. When parametric test prerequisites were unmet, the relationship between two continuous variables was evaluated with Pearson's and Spearman's correlation coefficients. The relationships between categorical variables were analyzed with Fisher's Exact and Chi-Square tests. Agreement between measurements was analyzed with the intraclass correlation coefficient and reliability with the Kuder-Richardson 20 value.

For repeated tests, the assumption of sphericity was checked with the Mauchly test, and the Sphericity Assumed test was applied in cases where the assumption of sphericity was met, and the results of the Huynh–Feldt test were evaluated for cases where the epsilon value was greater than 0.75 and the Greenhouse Geisser test for cases where it was smaller. In our analysis, mixed-design analysis of variance

Fig. 10 Story Maps of the Groups

Fig. 11 My Story Map Notebook Drawings

Fig. 12 Groups' Story Design

and Bonferroni- Dunn test, one of the multiple comparison tests, and Bonferroni- Dunn test within times were used to make a general evaluation between repeated measurements (Clinical Parameters) and experimental-control groups. $p < 0.05$ level was considered statistically significant.

Results

There was no statistical difference in the baseline measurements for *TechCheck-K* scores between the control and experimental groups (Table 1). The *TechCheck-K* scores of the experimental group were significantly higher than the baseline control group in the post-test and retention (administration one month later) measurements. There was a significant interaction between groups over time. According to these results, *TechCheck-K* scores increased faster in the experimental group than in the control group.

As shown in Table 2, there was no statistical difference in the measurements of the initial coding scores. In the final and retention measurements, the experimental group's coding score was statistically higher than the control group. While the initial and final Coding measurements did not differ in the control group, the final Coding averages in the experimental group were statistically higher than the initial values. According to these results, the coding measurement increased faster in the experimental group than in the control group.

In Table 3, there was no statistically significant difference in the TechCheck-K scores for the whole sample and the control group according to gender, whereas girls in the experimental group had statistically higher mean post-test and retention scores than boys. The experimental group consisted of 35 children (18 girls, 17 boys), and 29 children (17 girls, 12 boys) were in the control group.

In Table 4, no statistically significant difference was found for coding scores in the whole sample and the study group, according to gender.

Discussion

Recent research has underscored the importance of developing curricula that incorporate coding and computational thinking (CT) skills for young children, using developmentally appropriate approaches tailored to their age group. Scholars have demonstrated the effectiveness of such curricula (Bers, 2018; Menon et al., 2019; Wang et al., 2021). This study implemented a design-based story creation program called the DBDS program to support coding and CT skills among children aged 3 to 6. The program was applied explicitly to five-year-old children, and its effectiveness was established in improving coding and CT skills.

Design-based strategies have been widely used in different levels of education to support programming and CT skills (Basu et al., 2017; Dolgopolovas et al., 2019; Garneli & Chorianopoulos, 2018; Repenning et al., 2015; Sengupta et al., 2013). However, it is observed that such approaches are less commonly used in early childhood education. In previous studies, block-based or robotic tools were commonly used to support coding and CT skills through the design process (Angeli & Valanides, 2020; Bers, 2010; Bers et al., 2014; Elkin et al., 2014; Kazakoff et al., 2013; Sullivan et al., 2013). In a study by Kordaki and Kakavas (2017), digital stories were also an effective learning tool for developing CT skills in children, even without a programming language. However, few studies

Table 1 Effects of DBL-DSP intervention on *TechCheck-K* Results

	Group				Test Statistics†		
	Control $n=29$		Experimental $n=35$		F	p	η^2
TechCheck-K Total Scores							
Pre-Test	2.24 ± 3.11	1 (0–13)	1.80 ± 1,37	2 (0–4)	0.572	0.452	0.009
Post-Test	2.10 ± 3.24	1 (0–13)	13.91 ± 1.50	15 (9–15)	**369.283**	**0.000**	**0.856**
Retention	2.21 ± 3.6	1 (0–13)	13.91 ± 1.50	15 (9–15)	**360.832**	**0.000**	**0.853**
Test Statistics¥	$F=1.452$ $p=0.242$ $\eta^2=0.045$		**$F=972.641$ $p<0.001$ $\eta^2=0.970$**				
Group	**Effect: F = 180.109**			**$p<0.001$**		**η2 = 0.744**	
Time	**Effect: F = 856.523**			**$p<0.001$**		**η2 = 0.933**	
Group x Time	**Effect: F = 881.253**			**$p<0.001$**		**η2 = 0.934**	

F: Mixed Order analysis of variance †Intergroup comparison, ¥Intragroup comparison, summary statistics are given as mean ± standard value. Bolded sections are statistically significant ($p<0.05$)

Table 2 Effect of DBL-DSP on CodingTest 2 by Group

	Group				Test Statistics†		
	Control $n=29$		Experimental $n=35$		F	p	η^2
Coding							
Pre-Test	1.10 ± 1,52	0 (0–5)	1.03 ± 1.29	0 (0–3)	0.045	0.832	0.001
Post-Test	0.90 ± 1.37	0 (0–4)	9.66 ± 2.46	11 (0–11)	**291.848**	**0.000**	**0.825**
Permanence	0.93 ± 1.41	0 (0–4)	9.66 ± 2.46	11 (0–11)	**286.046**	**0.000**	**0.822**
Test Statistics¥	$F=1.272$ $p=0.288$ $\eta^2=0.001$		**$F=356.585$ $p<0.001$ $\eta^2=0.921$**				
Group	**Effect:**		$F=201.728$		$p<0.001$		$\eta^2=0.765$
Time	**Effect:**		$F=312.421$		$p<0.001$		$\eta^2=0.834$
Group x Time	**Effect:**		$F=341.1923$		$p<0.001$		$\eta^2=0.846$

F: Mixed Order analysis of variance †Intergroup comparison, ¥Intragroup comparison, summary statistics are given as mean ± standard value. Bolded sections are statistically significant ($p<0.05$)

Table 3 Measurement in All Sample and Study Groups by Gender

Groups	TechCheck	Gender				Test Statistics‡	
		Girl $n=35$		Boy $n=29$		t	p
Control $n=29$	Pre-Test	1.59 ± 1.66	1 (0–5)	3.17 ± 4.37	1.5 (0–13)	-1.365	0.183
	Post-Test	1.41 ± 1.77	1 (0–5)	3.08 ± 4.52	1 (0–13)	-1,389	0.176
	Retention	1.47 ± 1.7	1 (0–5)	3.25 ± 4.56	1 (0–13)	-1,480	0.150
Experimental$n=35$	Pre-Test	1.83 ± 1.5	2 (0–4)	1.76 ± 1.25	2 (0–4)	0,146	0.885
	Post-Test	14.39 ± 0.98	15 (12–15)	13.41 ± 1.8	13 (9–15)	**2.007**	**0.043**
	Retention	14.39 ± 0.98	15 (12–15)	13.41 ± 1.8	13 (9–15)	**2.007**	**0.043**
Total $n=64$	Pre-Test	1.71 ± 1.56	2 (0–5)	2.34 ± 2.98	2 (0–13)	-1.086	0.282
	Post-Test	8.09 ± 6.73	12 (0–15)	9.14 ± 6.06	13 (0–15)	-0.651	0.517
	Retention	8.11 ± 6.69	12 (0–15)	9.21 ± 6	13 (0–15)	-0.681	0.498

‡: Independent Sample t Test (t); Summary statistics are given as mean ± standard and Median (minimum, maximum) values

Table 4 Comparison of Coding Measure in All Sample and Study Groups by Gender

		Gender				Test Statistics‡	
		Girl $n=35$		Boy $n=29$		t	p
Control $n=29$ ($n=17$ girls, $n=12$ boys)	**Coding**						
	Pre-test	1 ± 1.5	0 (0–5)	1.25 ± 1.6	0.5 (0–4)	-0.430	0.671
	Post-Test	0.94 ± 1.25	0 (0–3)	0.83 ± 1.59	0 (0–4)	0.205	0.839
	Permanence	1 ± 1.32	0 (0–3)	0.83 ± 1.59	0 (0–4)	0.308	0.761
Experimental $n=35$ ($n=18$ girls, $n=17$ boys)	**Coding**						
	Pre-test	0.61 ± 1.04	0 (0–3)	1.47 ± 1.42	1 (0–3)	-2.054	0.055
	Post-Test	9.5 ± 2.9	10,5 (0–11)	9.82 ± 1.98	11 (4–11)	-0.384	0.704
	Permanence	9.5 ± 2.9	10.5 (0–11)	9.82 ± 1.98	11 (4–11)	-0.384	0.704
Total $n=64$	**Coding**						
	Pre-Test	0.8 ± 1.28	0 (0–5)	1.38 ± 1.47	1 (0–4)	-1.684	0.097
	Post-Test	5.34 ± 4.87	3 (0–11)	6.1 ± 4.85	9 (0–11)	-0.623	0.536
	Permanence	5.37 ± 4.86	3 (0–11)	6.1 ± 4.85	9 (0–11)	-0.601	0.550

‡: Independent Sample t Test (t); Summary statistics are given as mean ± standard and Median (minimum, maximum) values

have explored using digital stories in early childhood education besides block-based applications.

The DBDS program integrates story-based and design-based learning approaches in this study to support young children's coding and CT skills. It leverages narrative tools as epistemic resources and technological tools as scaffolds. Before creating digital stories, children were introduced to the design process inherent in stories and story design. Subsequently, they crafted their stories, transferring them into a digital format. Children also illustrated their stories and shared them in a collaborative environment. The stories they created underwent iterative development with contributions from group members and other children in the class. The design process is inherently a path from posing a problem to solving a cyclical process. By its nature, stories encompass a design process. As Omand (2014) emphasized, the key to story-based learning lies in posing a problem, creating characters, and constructing a setting that breathes life into the story, marking the evolving process. Throughout the digital story creation program encompassing design, children were exposed to coding and CT skills (algorithms, representation, sequencing, modularity, debugging, software hardware, and program development). The program contributed to enhancing these skills among children.

The effects of the DBDS program on coding and CT skills were analyzed in terms of gender. While studies have shown differing opinions on the impact of gender on coding and CT skills, the results indicate that gender had no significant effect on coding skills, but CT skills showed a significant difference in favor of girls. The pre-test scores of girls were lower, possibly reflecting the impact of gender stereotypes on the cognitive development of young girls. However, the results of this study suggest that girls can perform as well as boys in coding and CT skills when provided with the appropriate technological and technical knowledge environment. The findings may also indicate that girls' interest in storytelling and listening may play a role in their enhanced CT skills.

The impact of the DBDS program on coding and IT skills has been analyzed by gender. While studies on the effect of gender on coding and IT skills present different views, the results indicate that gender does not significantly impact coding skills. However, there is a significant difference in IT skills favoring girls. Girls' pre-test scores were lower, which likely reflected the impact of gender stereotypes on the cognitive development of young girls. Sun et al. (2022) discuss the impact of gender on skills related to computer science and point out that the results are conflicting. However, international studies, particularly in developed countries, show no differences between boys and girls in computer and technology use (DeBell & Chapman, 2006; Montuori et al., 2022; Nourbakhsh et al., 2004; Pila et al., 2019; Portelance & Bers, 2015; Sullivan & Bers, 2013, 2016, 2019; Williams & Ogletree, 1992; Zevenbergen & Logan, 2008). Some studies even report that girls perform better than boys (Martinez et al., 2015; Nourbakhsh et al., 2004). It is noted that gender roles affect attitudes toward technology (Stein, 2004). Some studies in Turkey show that boys use technology, especially computers, more than girls (Akçay & Özcebe, 2012; Konca, 2014). This indicates that gender roles still influence technology use in Turkey.

Overall, the study highlights the effectiveness of a design-based approach using digital stories in promoting coding and CT skills among young children. Furthermore, the findings underscore the importance of creating a supportive environment for children to develop these skills, regardless of gender or socio-economic background.

Discussion on Program

This study examined the efficacy of the DBDS program in promoting children's computational thinking (CT) and coding skills. The pilot application of the program, intended for children aged 3–6, was administered to a sample of 5-year-old children, and the results indicated its effectiveness. Practitioner observations further suggested that the program was developmentally appropriate and fostered active engagement among children.

Computers were utilized in implementing the program. Using computers gave children a clearer view of processes such as software and hardware, aiding them in rectifying errors. However, using tablets could provide children with convenience and different opportunities—moreover, very few children in Turkey, especially children from families with low socio-economic status own tablets. Hence, the prepared program aims to contribute to its utilization in many teachers' classrooms.

Specifically, the program capitalizes on children's natural inclinations towards storytelling and design, which they are familiar with and enjoy from an early age. Merging technology and the design process for creatively inclined children with innate design-oriented skills has served as a scaffold for learning. Additionally, although collaborative group work and design are not widely practiced in early childhood classrooms in Turkey, especially children from families with low socio-economic status, the children in this study demonstrated collaborative behaviors and successfully navigated the design process with minimal guidance.

Although there were concerns regarding the role of a single practitioner in the classroom, it was ultimately found that the practitioner played an important role in guiding children and managing the process. The classroom climate established by the teacher prior to the program's implementation was also identified as a potential influence on the program's success. Future research should explore the program's effectiveness across different age groups and settings.

While the program is designed to be flexible and adaptable to individual classroom needs, it is essential to further test and refine it in various settings, especially using different teachers and student demographics, including implementation with tablet computers. This approach to learning through production with a constructivist perspective can transform preschool classrooms from passive consumers of technology to active creators and innovators.

Limitations and Future Directions

The present study investigated the efficacy of the DBDS program in fostering computational thinking (CT) and coding skills among children aged 3–6 years. The pilot implementation of the program was conducted with a small group of five-year-old children, specifically targeting those from disadvantaged socio-economic backgrounds. The second author, who also served as the classroom teacher, implemented the implementation. Unlike traditional experimental settings, the implementation occurred during 60–90 min periods, integrated into the daily educational routine. While the results indicated that the program effectively enhanced children's CT and coding skills, it is essential to replicate and extend this study with a more extensive and diverse sample and different classroom teachers and contexts. Future research could also explore the program's applicability to other age groups and adapt it to different levels of education.

We observed a much lower score on the pre-test TechCheck-K than what has been observed in previous studies (Relkin et al., 2021; Yang et al., 2023). This finding could be due to several factors, such as different demographic variables (e.g., SES), how the assessment was administered (in a group vs. on one), and the environment (e.g., the COVID-19 pandemic). It is worth noting that the DBDS program has a flexible structure that allows for individualized implementation by classroom teachers. However, further development and refinement of the program may be necessary to ensure its effectiveness across different classroom contexts and populations. As such, the present study represents a valuable pilot implementation of a program designed to support CT and coding skills in early childhood education.

Appendix

Table 5 DBDS Program

Stage	Event Name	Time	Purpose	Coding Skills	CT Skills	Design Process
1. Stage	1. Will BabyBird be able to fly? 2. Story Elements Hunters 3. Aunt Ruth 4. Who Did It? 5. House of the Mouse	60–90 min	Understanding the elements of the story Understanding what symbols are Direction Signs Finding symbols for the structure of the story	Representation Algorithm Arrangement Modularity	Representation Algorithms Modularity Design Arrangement	To ask Imagine Make a plan Create Test and Develop To share
2. Stage	1. Boatman 2. Little Koala 4. Will Yumak be able to cross the river? 4. Everyone Loves Swimming	60–90 min	Storytelling Finding the end of the story Evaluation of the event	Representation Algorithm Arrangement Modularity	Representation Algorithms modularity Design Arrangement	To ask Imagine Make a plan Create Test and Develop To share
3. Stage	1. Ali Baba 2. What is the Name of This Story? 3. Design Your Own Story 4. E-Book creator	90–120 min	Getting started (configuring the story creation process step by step from bottom to top) Identifying the problem (contradiction, conflict) Story-writing-drawing-telling Transferring the Story to the Digital Platform	Representation Algorithm Arrangement Modularity Debugging Program Development	Representation Algorithms Modularity Design Arrangement Program Development	To ask Imagine Make a plan Create Test and Develop To share

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Declarations

Ethical Approval All procedures performed in studies involving human participants are subject to Hasan Kalyoncu University Social, Behavioral, and Educational IRB protocol no. 1810044.

Informed Consent Informed consent was obtained from the educators and parents/guardians of participating students. The students gave their assent for inclusion.

Conflict of Interest The authors declare that they have no conflict of interest.

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