A rapid review on Tangible User Interfaces- augmented storytelling in inclusive education

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Abstract

Tangible User Interfaces (TUIs) application in education showed its benefits and strengths in enhancing learning and effective educational experiences of pupils. One of the potential application fields of TUIs in education is storytelling and narration, where the interaction with tangibles could enhance the involvement of children in listening and creating stories but also the inclusion of children with special needs. However, it is crucial to provide a methodological framework as a guide, not only to design inclusive learning through TUIs-enhanced storytelling, but also to evaluate TUIs application expected to sustain these practices, professionals, and practitioners in early years' education. The present rapid review focuses on TUIs developed with the aim of fostering educational and inclusive storytelling activities with a view to identify relevant studies that evaluated the effectiveness of TUIs in educational settings to enhance inclusive storytelling practices. studies published until 2022 were identified. The results reveal gaps in the current literature and a paucity of relevant studies on TUIs for inclusive storytelling, moreover none of the included in the review implemented a high-quality evaluation design. Further empirical research is necessary to collect evidence that TUIs are effective for enhancing children's storytelling experience and allow inclusion of special needs ones.

Keywords

Education, Tangible User Interfaces, storytelling, inclusion, special needs

1. Introduction

Storytelling is a social and educational practice that has always had multiple functions [1]: from remembering to sharing collective experiences, from learning to pure entertainment. It is an important tool for interpreting reality, to interact with the social world in which we live. According to Bruner [2], narrative thinking is one of the two main ways of thinking in which human beings organize and manage their knowledge of the world, indeed they structure their own immediate experience. Therefore, in addition to favoring the development of linguistic-expressive functions, narration stimulates the cognitive development of the child through the enrichment of knowledge, the exercise of thought and the formation of ideas. The affective-emotional aspect is enhanced as the narrative stimulates emotions and feelings, enriches the imagination, and emotions have a direct impact on learning and cognition [3]; storytelling activates identification processes essential for the internalization of models, norms and values as well as for the acquisition of adequate behavioral rules.

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New means of communication generate new communication scenarios. Among the new forms of storytelling that respond to contemporary educational and methodological needs, the digital storytelling (DS) integrates the art of listening and telling stories with digital media, including text, pictures, recorded audio narration, music, and video [4]. Educational digital storytelling (EDS) facilitates students' abilities to construct their own narrations and meanings through the process of topic research and selection, writing a storyboard, collecting materials to give a real form to their stories, such as images, audio, videos and contents that develop in the digital world and the reader is never passive. Storytelling becomes what (the content) but also "how" to communicate the content; the construction of the narration is just as important as the content of the story itself because it enhances and empowers students' intellect, reasoning, culture and creativity.

It is also known that new technologies always have more impact on children's development but also on their methods of learning. Schools and educational context adapt their early years' education curricula based on the importance of application of technologies in education. Digital natives are used to mobile phones, tablets, computers, to the entire digital world: the research on the impact of the digital technologies on children's cognition and development is ongoing and no unique answer is possible, but what is known is that many of them could not be suitable and adapted for young children. Especially in education, the interaction with the environment is crucial when the pupils must understand concepts that connect with reality and develop their sensory-motor and cognitive system.

It is also widely recognized that teachers have always more need to find easy solutions to integrate digital environments and concrete reality, in a world that is complex and full of information and devices and applications that appear but sometimes are not sustained from a methodological and validated framework [5]: the design of educational technologies should be based on the knowledge of child's developmental stages and abilities that affect learning and interaction with the technology. Following the theoretical framework of Embodied and Situated Cognition theories [6] the idea is that our mind is embodied in our motor-sense system, in the environment, and context in which we interact. In this panorama, in the early stages of life, action (how to explore the world with the senses, walking, etc) and objects manipulation take on a very important role in learning because they become vehicles of knowledge and our mind changes through their use: that is, during cognitive development manipulative and "concrete" actions are gradually simulated in our human mind e become "symbolic" acts.

The features of learning technologies to support a more ecological interaction with contents should be, for example, multisensory and multimodal, allowing an interaction that involves more than one perceptual channel (or communication input): verbal, visual, auditory, spatial and gestural. Tangible User Interfaces (hereafter, TUIs) [7] can be considered as a bridge between the physical and the digital information [Figure 1], for this reason they sustain a natural and ecological interaction of children with technology.

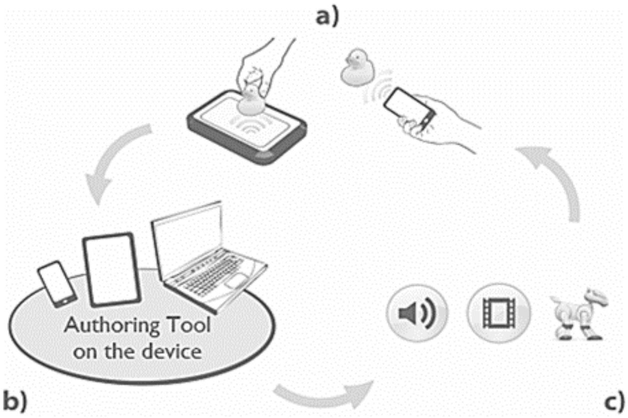

Figure 1: TUIs functioning

TUI technology has been highly exploited in school and education contexts thanks to theoretical and methodological frameworks that sustain its development and use. The theoretical framework refers to classical but also current theories about psychological and cognitive development, such as Piaget theory [8], but also approaches on educational practices, such as Montessori and Froebel ones [9] [10], that highlighted how interacting with specific adapted physical objects and learning through experience represents the most effective learning environment for young children. The methodological framework refers to a set of principles to guide the design of TUIs to enhance learning and pupils' development [11] [12]; they provide a perspective on what aspects of TUI design are important to consider in learning contexts, starting from learning theories and laying out the connections between TUI design choices and learning theories, but they also propose testable mechanisms of action by which TUI design is expected to affect learning.

The hybrid approach perspective is to empower learning through digital technology while leveraging our human ability to grasp and manipulate physical objects and materials. Many psycho-pedagogical practices exploit the direct manipulation of objects and the use of all the senses to learn during the experience. TUIs application in education showed its benefits and strengths in enhancing learning and effective educational experiences of pupils, thanks to the augmentation of learning environments, the innovation of traditional pedagogical approaches through engaging and pleasant learning. A very recent review [13] of the literature on TUIs and interactions in young children's education gives an overview of how diverse the application fields of technology are in the school and educational context and its potential benefits on learning.

TUIs support a natural interaction with learning contents promoting active engagement: the user interacts with augmented tangible objects in parallel with the traditional digital interactions (i.e., touchscreen, mouse, etc.), but this allows a high level of manipulation, attention and reflection. It is then possible for children to learn abstract concepts through concrete representations. TUIs also support social interaction through collaboration, considering collaboration as an essential skill for social development and learning, helping children to develop communication skills. Indeed, TUIs collaborative design processes have been identified as the best approach for active learning in classrooms [13].

One of the potential application fields of TUIs in education, highlighted also from [13] is storytelling and narration, where the interaction with tangibles could enhance the involvement of children in listening and creating stories but also the inclusion of children with special needs [14]. The authors of the review concluded that TUIs seem to be a useful literacy learning and self-expression tools for children thanks to the solicitation of motivation. When presenting a narration, both the digital features, such as sound or animation, and the haptic-initiated feedback represent an active and independent involvement of children in learning from narration contents.

What is missing in the cited review is a focus on inclusive and accessible aspects of TUIs for education. A great potential of TUIs technologies is the possibility to personalize objects and interaction between the user and the system. The high level of platform flexibility allows, for example, a multisensory approach, that is crucial for children that have a limitation of the senses (blindness, deafness). However, it is decisive to provide a methodological framework as a guide, not only to design inclusive learning through TUIs-enhanced storytelling, but also to evaluate TUIs application expected to sustain these practices, professionals, and practitioners in early years' education. The present rapid review focuses on TUIs developed with the aim of fostering educational and inclusive storytelling activities. Particularly, the objective of the study was to identify relevant studies of existing literature that evaluated the effectiveness of TUIs in educational settings to enhance inclusive storytelling practices. It was thought that providing an overview of such evidence to researchers working in the field would be useful to inform the future development of a methodological framework to guide teachers in the implementation of TUI-based inclusive educational activities.

2. Method

2.1. Search strategy

A literature search was conducted according to a rapid review strategy, which has been operationalized as "a form of knowledge synthesis in which components of the systematic review process are simplified or omitted to produce information in a timely manner" [15]. This approach was chosen given that our primary aim was to extract and summarize only the main features of the interventions designed to enhance storytelling through TUI-based applications [15].

The search was performed based on the following databases: Web of Science, ERIC, and PsycInfo. The same keywords were used for each database: 'child', 'student', 'pupil'; 'tangible user interface', ‘TUI’, ‘tangibles’, ‘manipulatives’; ‘storytelling’, ‘narration’; ‘disability’, ‘special educational needs’; ‘SEN’, ‘inclusion’. The aforementioned databases and key words were chosen in a consensus meeting among the authors.

The search resulted in a total of 521 papers. The number of papers was reduced to 457 after duplicates were removed. Figure 1 illustrates the search process and outcome. Initially, titles and abstracts of the 457 papers were screened using the online repository Ryyan. When the titles and abstracts were judged to be in line with the inclusion criteria (see below), the corresponding full-text articles were downloaded. Following this process, 31 full-text articles were downloaded. Those full-text articles were then read by the first and last author and 9 of them were found eligible for the review.

Supplementary search strategies to identify relevant articles were also employed. First, the references of the 9 articles selected as well as the references of recent review articles were inspected. Second, a Google Scholar ‘cited by’ search was conducted using the initially identified 9 articles. These strategies led to the finding of one extra article, with the consequence that 10 articles were finally included in the review. The inclusion of new articles was completed in May 2022.

2.2. Inclusion and exclusion criteria

Studies were included if they satisfied three basic criteria. First, they involved students with any form of disability or special educational needs. Second, they involved a working TUI system. Third, they monitored the effects of the intervention being implemented and relied on qualitative or quantitative research methods or mixed quantitative and qualitative research methods. Studies were excluded if they did not meet one or more of the aforementioned criteria.

2.3. Data extraction and coding

A data charting form was jointly developed by the authors who worked iteratively until agreement was achieved as to the most adequate set of information that should be reported for the single studies [16]. Eventually, the data extracted for each study entailed (a) the year in which the study was published and the country in which it was carried out, (b) the storytelling activity proposed, (c) the main features of the TUI developed, (d) the population and assessment strategy applied, (e) the measurement approach followed, and (f) the benefits (outcomes) for the students and the educators.

2.4. Interrater agreement

Interrater agreement was checked between the first and second author (a) on scoring the eligibility of the 457 papers. The percentage of agreement was 94%. Consensus between authors on the articles with initial disagreement was then achieved after a brief discussion.

3. Results

Key findings of 10 studies identified in this rapid review are presented in table 1. In total, 119 students/children were included in the studies selected. Two studies did not report exact numbers. Types of disabilities involved in the studies included autism spectrum disorders (n = 3 studies), blindness and visual impairments (n = 3), language disabilities (n = 2), deafness (n = 1), and multiple disabilities (n = 1). None of the studies included in the review followed an experimental design to test the effects of the TUI-based solutions developed on the end users. It follows that the results of the reviewed studies are only preliminary, and the devices presented can be considered at an early stage of development.

Table 1
Key findings of 10 studies identified in this rapid review

Publication	Storytelling activity	Form of TUI	Objective of the study	Sample size and age	Setting	Disability included	Evaluation methodology
Alessandrini et al., 2014; Italy [17]	Creating audio sequences to form a story	Voice augmented sheets of paper drawing with tags to play or record audio content	Piloting the effectiveness of the system	Four low-functioning male children with verbal abilities (8–12 y)	Specialized educational center	Autism spectrum disorders	Interviews and focus groups with therapists
Alessandrini et al., 2016; Manchester, UK [18]	Creating voice records starting from pictures of narrative and descriptive activities	Voice augmented sheets of paper drawing with tags to play or record audio content	Evaluate therapists prototype use, its support in therapists' learning objectives, and children's engagement	In Italy, two HF children with verbal abilities (8-12 y) led by two therapists. In Scotland, two participants (17-18 y), MF and HF with verbal abilities	Specialized educational center; school for SEN	Autism spectrum disorders	Prototype trials with children and therapists, semi-structured interviews, and final focus group with therapists
Bonillo et al., 2019; Zaragoza, Spain [19]	Filling the story sentences with prepositions that are missing	A tabletop with traditional toys; a visual recognition software to track the position and orientation of toys placed on the surface; a software for easy creation and execution of activities	Detect problems and suggest improvements	Two children (4-6 y) with neurodevelopmen tal disorders; 8 children with speech disorders (2-6)	Care center	Speech disorders	Trials sessions, informal interview with both with therapist and children

Cullen et al., 2019 [20]	Co-designed story mapping for understanding of the components, remembering, and structuring the events of stories	Multisensory craft materials and other components such as an audio sampler and playback unit and a grid for organizing the narrative structure	Establish design requirements for a story mapping system; to develop and extend co-design methods for working with children in mixed visual abilities	Seven children (4 female), aged 7-10 years with mixed visual abilities, ranging from congenital blindness to full sight	Primary school	Blindness and visual impairments	Co-design sessions starting from preliminary low-tech prototyping to main design sessions, to compose and record stories sessions using the preliminary prototype
El-Ashry et al., 2021 [21]	Distributed making approach to create an interactive tactile storybook collaboratively	Multimedia, tactile book with a 3D pen	Overview of the evolution of the design of the system	None specified	None specified	Blindness and visual impairments	Demonstration
Hengeveld et al., 2008; The Netherlands [22]	Linear stories to stimulate vocabulary and specific language exercises	Modular system consisting of exercise mats where standard set of tagged objects are manipulated to respond to interactive stories and exercises.	Overview of the evolution of the design of the system	Seven children (3-6 y) with developmental ages between 1 year 5 months and 3 years 9 months	Day care center for children with cognitive delays	Multiple disabilities	Field study
Koushik et al., 2019; Colorado, USA [23]	Creating audio stories and sharing creations with others	Tangible blocks with an augmented workspace and a software for interpreting and playing back	Explore the tool concept and the initial design prototype	16 participants (11-65 y) including 5 disabled students (middle and high school), 8 teachers, and 3 staff members—2 Braille	School setting; University Lab	Blindness and visual impairments	Stories creation trials sessions with a combination of students and educational staff using the tool

		users' story programs		transcriptionists and 1 preschool staff member			
Lund & Marti, 2004; Denmark/Italy [24]	Creating stories aimed at stimulating narrative competence, language learning, and emotional expression	Basic building blocks allowing the user to construct an artefact that can perceive input, process, and produce output	Overview of the evolution of the design of the system	Two children with hypoacusia (6 y) and dyslexia (10 y) respectively	Educational service center	Language disabilities	Field study
Parton et al., 2010; USA [25]	Not specified	Language Acquisition Manipulatives Blending Early Childhood Research and Technology (LAMBERT): an RFID scanner connected to a PC to read flash cards	Provide an overview of LAMBERT	1 classroom of pre-school children (3 y)	School for the Deaf	Deafness	Field study
Silva et al., 2019; Portugal [26]	Associating stories with an emotion choosing the correct facial expression matching the emotion	The ZECA humanoid robot, that randomly tells one of the stories and the OPT PlayBrick (Playware Technology), where the child selects the answer	Validate the game scenarios	138 participants – 69 typically developing children (7–11 y - 56.5% female) and 69 adults (20–67 y - 69.6% female)	School (previous work) - Online	Autism Spectrum Disorders	Online anonymized questionnaire to read, observe images, and select the emotions that matches the stories

The storytelling activities augmented by the TUIs concern different objectives, mainly the development of language and narrative skills [17] [19] [22] [24] [25]; but also emotional skills [18] [26], programming skills [23] collaboration skills and story co-design [20] [21]. The objectives become even more specific by identifying the target selected for the activity and above all the type of disability included. It should be emphasized that all the studies except one did not specify or did not foresee the involvement of both typically developing and special needs children, many in fact were carried out with only children with disabilities in rehabilitation settings or special schools. Only the study by Cullen and colleagues [20] realized the inclusion of children with visual impairments in a group of typically developing pupils in a primary school.

Of particular relevance is the association of TUIs with the activities' objectives and target: from the literature reviewed it seems that most of the augmented tangible objects are objects already used in therapeutic / educational activities for children with disabilities. Alessandrini et al. [17], for instance, involved children with autism spectrum disorder in a proof-of-concept study in which children could augment their own drawings on a paper sheet with audio recordings in order to enhance the social stories learning activity; Parton et al. [25] displayed stories on the screen based on the manipulation of cards to stimulate deaf children language development; Hengeveld et al. [22] used objects representative of vocabulary terms with which produce an answer for children with different disabilities and cognitive impairments ; Bonillo et al [19] used tokens with the same function for children with language disabilities ; Lund et al. [24], again, enabled children with language disabilities to build objects with blocks to stimulate the production of content and express themselves despite linguistic difficulties .

Other physical environments include robots and consoles with which to interact to stimulate emotional skills for children with autism [26]; or tactile books augmented by audio [21] for the creation of collaborative adventure stories for children with visual impairments; or multisensory materials that support all the senses connected to a unit of sound reproduction and spatial structuring of the story, always to stimulate collaboration in the creation of stories on themes concerning extracurricular activities including children with visual disabilities [20]; or tangible objects that represent commands and elements of the story read by digital devices when they are placed on the surface, to develop programming skills and narrative sequencing always for children with visual disabilities [23].

These TUIs also allow collaborative and not just individual activities, in fact most of the studies (except [19], [25] and [26], where is not specified) report the opportunity of using the augmented environment and objects to encourage co -construction of the physical scenarios but also the stories, both between children and peers and between children and therapists/educators. Mainly, however, TUIs have been developed in such a way as to allow and motivate an interaction with the stories as well as stimulate the creation of stories by children, compensating for linguistic-expressive skills difficulties, impaired cognitive abilities, and sensory disabilities.

4. Discussions

The analyzed studies described mostly storytelling TUI for enhancement of language and narrative skills, which is clearly consistent with the main functions of storytelling practices and very important especially in pre-school and early primary school years because it influences future linguistic and narrative ability [4].

Moreover, authors reported that this kind of TUIs seems to be effective learning tools for children since they foster their motivation [19], engagement and attentional control [17] [18] [23] and allow them to collaborate and communicate with other people, peers, or teachers/therapists [17] [20] [21] [23]. Indeed, TUIs support for social interaction through collaboration is crucial for students with special educational needs (SEN) students that can benefit from collaborative activities to develop academic and social skills adapted to their conditions, particularly for children with speech disorders, but also sensory impairments.

Due to their mainly explorative nature, the selected studies have gaps and limitations such as lack of methodological framework on the design and evaluation of TUIs specific for inclusive educational storytelling. Most studies lack tools implementation in daily educational environments and do not adopt reliable evaluation procedures to assess potential benefits of TUIs. Specifically, most of the identified studies (a) are preliminary evaluations or even proof-of-concept designs involving first prototypes and (b) are short-duration empirical studies that miss investigation of long-term educational effect of evaluated TUIs. With regard to this latter point, it is important to note that most were carried out in a trial session or as a day study; they involved a small sample of participants that does not allow a significant quantitative analysis; they used non-structured evaluation tools but observation procedures and interviews tools. Moreover, we found no accurate selection and operationalization of expected outcomes in terms of developing skills or interaction.

In the future an effort should be made to adopt both valid method-based TUI design for children and children with special needs, and higher standard assessment approaches with larger participants' sample size as well as research time period, in order to determine if TUIs are truly beneficial for children's learning and skills development, also defining what are the learning outcomes and benefits, with a focus on trials done in school environments.

Limitations of our review need to be pointed out. First, only specific and not all databases were addressed; inclusion criteria had no time limits and some inclusion criteria (for example disability focus-studies in English) could have excluded potentially relevant studies, also studies in other languages from English; then, the search strategy did not encompass all key terms.

5. Conclusions

Storytelling plays an essential role in an enhancement of self-reflective, narrative, emotional, creative and collaborative skills allowing children to interact and express themselves. TUI- based storytelling tools allow interaction with stories and different means of expression and representation, such as pictures, videos, sounds, tangible objects, and feedback, sustaining active children involvement in story content production and understanding, but also personalization and adaptability of materials; so, it could be applied as a facilitator to storytelling also for children with disabilities and special needs.

To conclude, there is a need for a TUI design framework and guidelines for enhancement of inclusive young children's storytelling production and fruition, also to sustain designers, researchers and teachers in managing innovative educational and inclusive practices.

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