A Tangible Constructivist AR Learning Method for Children with Mild to Moderate Intellectual Disability

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Abstract. This paper explores augmented tangible user interfaces (ATUIs) as a new educational paradigm for teaching special need children concepts from abstract domains. Case study being presented focuses on learning concepts of musical notation through constructivist multisensory AR experience utilizing TUI. The study was conducted in collaboration with Speciální Základní Škola Vysoké Mýto (Czech special needs school), where the experiment with such learning method using proposed ATUI called ARcomposer was held. In a user study with 22 participants, it was found that ATUIs are not only useful for children with intellectual disabilities, but that most of the children also yield great educational gains. The results of the study were concluded in a form of quantitative research in cooperation with pedagogues specialized in teaching students with intellectual disabilities.

Keywords: Augmented reality · Tangible user interface
Constructivist learning · Special education · Music education
Manipulative learning · Multisensory

1 Introduction

With rapid pace at which today's media technology is evolving, education is also being affected. Due to recent advances in technology such as virtual reality (VR), augmented reality (AR) and low-cost educational robotics, an ongoing debate between supporters of traditional and progressive learning approaches has been amplified, bringing the topics of hands-on learning and tangible user interfaces (TUIs) back to life. While the first group supports instructivist education - structured, scripted, standardized learning environments and materials, the latter stresses the importance of exploration, construction, and discovery – the constructivist model. A number of researchers [1, 10] suggest interaction models based on embodied knowledge as tools able to support children's learning in abstract domains.

The premise of the constructivist learning utilizing ATUIs is that the students who discover various learning topics by hands-on exploration create deeper and more meaningful knowledge structures [2, 12] especially when it comes to abstract domain concepts [1] utilizing higher cognitive processes such as mathematical operations, some topics from geometry, physics and the topics that require more profound imagination such as writing music. While constructive learning approach is theoretically

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sound, it was proven rather challenging to mediate such experience in real-world classrooms that would suit all the students, hence, it is necessary to develop new tools and approaches and aforementioned technologies seems like a promising direction [7].

Although learning experiences utilizing multisensory TUIs, multi-touch table-tops, and AR/VR applications have been a focus of many recent studies, according to Javier Marco et al. [5], studies that combine augmented tabletop technology and tangible interaction applied to children with intellectual disabilities (IDs) remain scarce and preliminary. Learning disabilities of ID children vary broadly, however, they all share common difficulties such as lack of abstract thinking which prevents them from comprehending higher-order cognitive concepts as spatio-temporal reasoning, logical operations, etc. [9], however, methods utilizing progressive and constructivist learning approaches seem to work better for conveying such concepts than the traditional ones [6].

1.1 Project Goals

The aim of this work is to explore augmented tangible user interfaces (ATUIs) as a new educational paradigm for children with intellectual disabilities (ID). The level of usability and potential educational gains of the aforementioned learning method must be verified. Furthermore, this work researches how learning methods utilizing ATUIs help maintain attention and motivation of such students. In this context, it was decided to design a multisensory, tangible, AR learning experience for music classes in special needs schools (SNS) and explore the benefits this technology offers to ID.

2 Design and Implementation

The TUI of ARComposer consists of five blocks tagged with image-based markers which the users are allowed to compose into a simple melody of up to five tones (See Fig. 1). Those physical blocks are then augmented with a audio-visual information - no different

Fig. 1. One of the participants playing with ARComposer. Both, tangible interface and augmented content is visible in the figure. Different tones are defined by a step of 4 units on Y-axis.

from the relative positions of the notes in the standard musical notation. Finally, the composed arrangement of the blocks can be played as a melody in the looped.

2.1 Application Development

ARComposer application was developed using Unity Game Engine and Vuforia SDK for augmented reality features (See Fig. 2).

2.2 Application Logic

The user controls a maximum of 5 image-based markers during the experience. Serial placement of the markers defines the order of the tones being played. Y-axis position of the markers defines the sound (tone), the color of the augmented etiquette and the name of the tone dynamically displayed on the marker. The first marker being introduced is a "base marker". Positional data of this marker are retrieved from Unity scene and compared with all non-base image-targets. If current Y-distance between two tones changes by 4 units (virtual size of the marker) all the variables are set accordingly. The updates are executed on every frame so all the feedback is live. The user can press the space bar on the keyboard to play the melody of the tones in a looped sequence in intervals of 0.7 s.

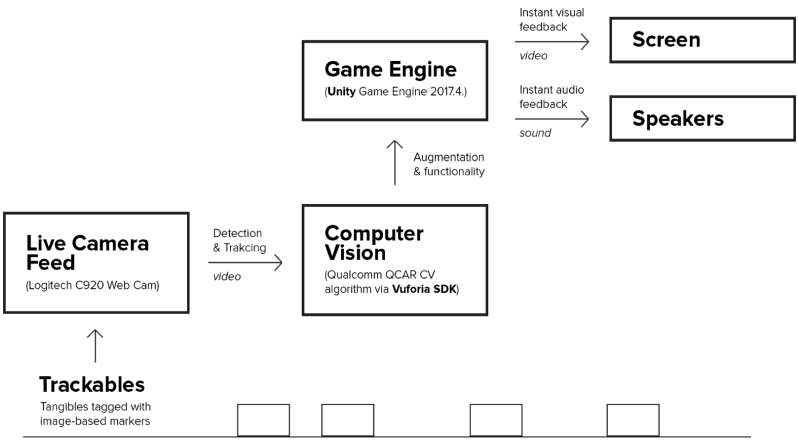

Fig. 2. Diagram showing different components of ARComposer system.

3 Experimental Procedure

During the experiment, students with mild to moderate ID (IQ 36-69) from Special needs school in Vysoké Mýto were introduced to the ARComposer application one by one and the results were recorded after the sessions. The data were collected in May 2018. The first part was a collection of the data about the child. This data was collected from special pedagogue who had the diagnosis cards of every test subject. The data

collected were mainly gender, age, grade, level of ID (IQ range) and other possible disabilities. Following was the data collection of musical history of every child before the experiment, which was collected directly from the children.

The second part was the introduction to the game setup and tangible mechanics following a pre-written script which was carefully consulted with the special pedagogues. The experiment consisted of several tasks that the children tried to accomplish, practicing concepts of lower/higher pitch, serial placement of the notes in the notation etc.

The last part was the data collection in form of a questionnaire. The questioner was asking the questions and recording the answers to the Google Form document for further analysis.

3.1 Experimental Setup

Evaluating with ID children is difficult and specific conditions must be met in order to achieve smooth experiment such as familiarity with the environment and persons being present during the sessions. Children with ID can keep their attention for a limited time, hence, it is necessary to design the experiment in a short time frame. It is also crucial to formulate instructions or questions in the most straightforward manner for them to be fully understood, preferably in a pre-written script.

Furthermore, favorable lighting conditions are necessary for successful AR experience as well as a neutral working surface that would not confuse the CV algorithm. The application was running on 15' Apple MacBook Pro 2014. The camera was installed at a distance of roughly 1 m above the surface.

4 Evaluation and Results

The usability test consisted of observational methods which were complemented by the adapted DEVAN (DEtailed Video ANalysis) method originally proposed by Vermeeren [11]. In order to assess the educational potential of proposed ATUI, the active intervention method with questions formulated in advance was used together with usability testing. Information about the children and learning outcomes were then analysed from the questionnaires. Expert evaluation method was used in cooperation with pedagogues specialized in teaching children with ID. The data from 22 subjects were collected for further analysis. Twelve of these children were females and 10 males in age from 9 to 13 years. Almost ¾ (68%) of the participants were over 12 years. All participants were attending 3rd–9th grade of the SNS in Vysoké Mýto. Distribution of mild/moderate intellectual disability was three-quarters mild ID and ¼ moderate ID with 4 autistic children.

4.1 Usability

Usability tests revealed several shortcomings. Among the biggest issues was marker occlusion problem and subsequent loss of the tracking and augmentation when children accidentally covered the tangibles with their hands. Another poor design decision was

use of analogous color scheme for the augmented etiquette. Using colors that are next to each other on the color wheel unfortunately resulted in insufficient color contrast between various tones and thus degraded orientation for those children who were orienting rather by the colors.

4.2 Educational Impact

When it comes to declarative knowledge gains, participants were tested on the number of the tones they remembered shortly after the experiment. Compared to the number of the tones they knew from before the experiment, the gains were significant since most of the children (20%) before the test did not know any tones, while right after the experiment 21 students (96%) remembered at least one tone from which 19 participants (86%) were able to recall at least 3 tones by their names.

In regards to procedural knowledge gains, the results were even more satisfying. All the children except for one autistic (96%), did understand the concept of arranging the tones on the vertical axis in order to influence the resulting pitch of the tone. Average percentage of the positive answers about procedural and declarative knowledge was 86,5% of successfully answered questions which is considered significant.

5 Conclusion

No decisive performance differences were found between the groups of students with mild/moderate IDs. It was helpful to consult the questions in the questionnaires and pre-written script with special pedagogue before the actual experiment as it unveiled the importance of correct formulations.

While usability tests uncovered several shortcomings, it turned out that constructivist learning methods using ATUI are well-suited for the education of ID children. The hands-on experience where the children have to physically manipulate the tangibles kept the children attentive during the whole session. Furthermore, due to the naturality of the tangible interface, the controlling of the application was usually effortless from the very beginning of the session. The live feedback helped the children to orientate between the tones considerably and they got the grasp of the TUI very quickly. Furthermore, their motivation has increased significantly after initial successes and after hearing the melody they composed in the looped sequence, they were notably very proud. All the children apparently enjoyed the experience very much and the educational gains seemed almost like a bi-product of a children play.

Constructivist learning approach using ATUI turned out to be not only completely usable for ID children, but also yield great educational gains in both procedural and declarative knowledge domains. Successfully conveying such abstract concepts as composing music by arranging high-pitched or low-pitched tones or placing the tones serially to create the sequence was one of the main goals of the proposed system, thus such results can be considered as very rewarding.

6 Further Development

Most of the shortcomings revealed by the usability test can be easily fixed. Occlusion problem can be fixed by placing the marker on the bottom of the graspable object which would be tracked by the camera installed beneath the transparent surface. When it comes to future research, long-term effects of such application need to be studied. Furthermore, there is a need of a comparative study in order to confirm or disprove the hypothesis that the constructivist approach using ATUIs helps ID children grasp abstract concepts faster and with less effort than the standard instructivist approach.

Potential evolution of the ARComposer might bring more features such as different blocks with varying note values such as a half note, quarter note or even rests. Such features would make the application more complex, hence suitable more for regular children in elementary and music schools than ID children.

Another interesting update might be a gamification of the application. Furthermore, this research initiated a conversation with the pedagogues with further suggestions and potential areas of research, such as: Preparatory classes of music schools; Sensory education (up, down, before, behind, below); Listening practice for children with impaired hearing; Gripping objects (especially for children with cerebral palsy); Melodic/rhythmic exercises; Practicing a song and Concentration.

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