Augmented Creativity:
Bridging the real and virtual worlds to enhance creative play

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Abstract

Augmented Reality (AR) holds unique and promising potential to bridge between real-world activities and digital experiences, allowing users to engage their imagination and boost their creativity. We propose the concept of Augmented Creativity as employing AR on modern mobile devices to enhance real-world creative activities, support education, and open new interaction possibilities. We present six prototype applications that explore and develop Augmented Creativity in different ways, cultivating creativity through AR interactivity. Our coloring book app bridges coloring and computer-generated animation by allowing children to create their own character design in an AR setting. Our music apps provide a tangible way for children to explore different music styles and instruments in order to arrange their own version of popular songs. In the gaming domain, we show how to transform passive game interaction into active real-world movement that requires coordination and cooperation between players, and how AR can be applied to city-wide gaming concepts. We employ the concept of Augmented Creativity to authoring interactive narratives with an interactive storytelling framework. Finally, we examine how Augmented Creativity can provide a more compelling way to understand complex concepts, such as computer programming.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Animation; I.3.8 [Computer Graphics]: Applications—;

Keywords: Animation, Augmented Reality, Games, Storytelling, User Interaction

Figure 1: *Creative* AR *apps permit children to engage their imagination as they explore and interact with the world around them.*

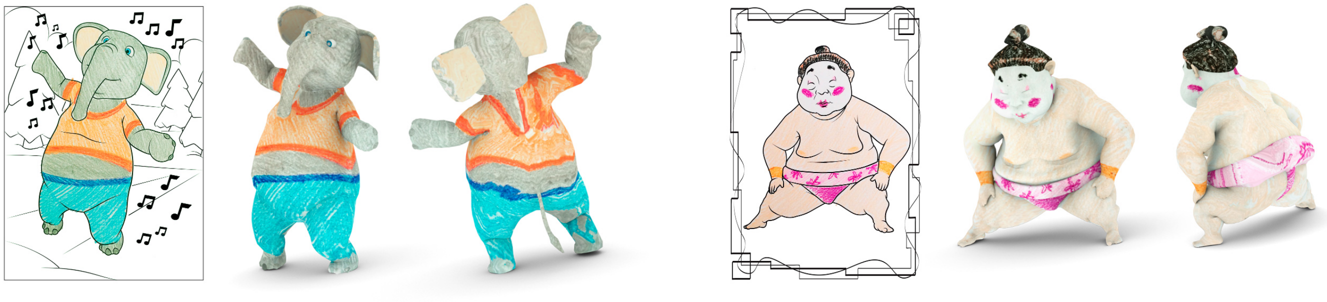
1 Introduction

Creative play allows children to engage their imagination as they explore and interact with the world around them. This process of active discovery contributes to a rich and memorable childhood and provides a foundation for creative problem solving skills that are crucial throughout an individual's life. Physical interaction with one's surroundings is a critical component of the experiential learning that lies at the heart of creative play. However, as prepackaged content and digital devices become more and more popular and ubiquitous, children spend an increasing amount of time passively consuming content or absorbed in the digital world. Television and video games dominate while creative activities of exploration and discover suffer in this increasingly digital world.

AR holds unique potential to impact this situation by providing a bridge between real-world activities and digital enhancements. AR allows us to use the full power and popularity of mobile devices in order to direct renewed emphasis on the traditional activities of creative play. We refer to this concept of enhancing real-world interaction, discovery, exploration, and imagination through AR as Augmented Creativity. In this work, we present the concept of Augmented Creativity in the context of six working prototype applications that each form a unique bridge between the real and digital worlds in order to enhance creativity, support education, and open new interaction possibilities.

Educational games pose the challenge of combining an educational value with the fun of playing a video game. The result is often unbalanced towards the educational content steering the overall gaming experience away from the entertaining part. Augmented Creativity aims to combine educational and entertainment values together by integrating them into an AR experience that explores new ways of interacting with the application.

Our Augmented Creativity coloring book app provides a seamless bridge between the real-world activity of coloring and computer-generated animated characters, allowing children to experience the creative process of animation by customizing their own character design. Our music apps provide a tangible way for children to explore different music styles and compose their own version of popular songs. In the gaming domain, we show how to transform passive game interaction into an active real-world movement that requires coordination and cooperation between players. We employ the concept of Augmented Creativity to narratives with an interactive storytelling application that allows a child to interact in creative ways with augmented characters. We show how these concepts can



- **Creative Goal** Fosters imagination, allows character individualization, helps to express feelings about character.
- **Educational Goal** Improves coloring skills, 3-D perception, and challenges imagination.
- **Potential Impact** User-painted characters and levels, scripting virtual worlds through coloring.

Figure 2: *Coloring Book Application*

be applied to creative problem solving in the context of city exploration. And, finally, we examine how Augmented Creativity can provide a more compelling way to understand complex concepts, such as computer programming.

2 Related Work

Much work has been dedicated to understanding creativity, how it can be inspired and supported [Amabile 1998][Runco 2004]. A variety of research has been presented that aims at cultivating creativity through the help of computers. In particular, many music related projects, projects targeting AR books, as well as storytelling projects exist, as presented in this section.

An early example for fostering creativity in the digital age is the work by Folkestad et al. They present a long-term empirical study that analyzes and evaluates computer supported music composing by teenagers [Folkestad 1995]. The Music Table [Berry et al. 2003], based on the Augmented Groove project [Poupyrev et al. 2000], showed how early AR technology could support music composing. Markers act as composing operations generating MIDI events that are fed into a composing system. Compared to our music application, their markers represent operations to make changes to the composition while our makers directly represent an instrument. An advantage of our system is that it allows to directly play the song in real-time and explore various combinations of instruments without requiring any knowledge of music theory.

A prominent early example of AR technology is the MagicBook [Billinghurst et al. 2001]. Large markers are integrated into the pages, which enable viewing virtual content through Virtual Reality (VR) glasses, based on which page of the book is open. The user can see only the virtual content and not the book as the VR glasses are opaque. Grasset et al. employ a mixed reality approach to further improve the user's experience [Grasset et al. 2008]. In their application, the user can see both, the virtual content as well as the physical book. They add various visual and auditory effects to an existing illustrated book to enhance the reader's immersion. The Haunted Book [Scherrer et al. 2008] is a prime example of well-integrated AR content in a book. The camera is mounted on a lamp on the table and the augmented book is viewed through a computer screen. Their focus lies on interaction between the virtual content and the physical book.

While the MagicBook as well as the Haunted Book present attractive examples of immersive AR applications, they lack user interaction components. Hence, the content is static such that each reading of the book results in the same experience. Similarly, applications are often held back in creativity due to the lack of interactivity, as interactivity is the cornerstone to foster creativity. Augmented Creativity relies on AR, which promotes interactivity and hence creativity. Pushing the boundaries of interactivity, AR façade [Dow et al. 2007] is an AR version of the renowned desktop-based interactive drama, Façade. Similarly, our authoring framework for interactive narratives employs AR to overcome the limitations present in a previous authoring framework [Kapadia et al. 2011], which possibly hinders creativity due to poor interaction.

3 Applications

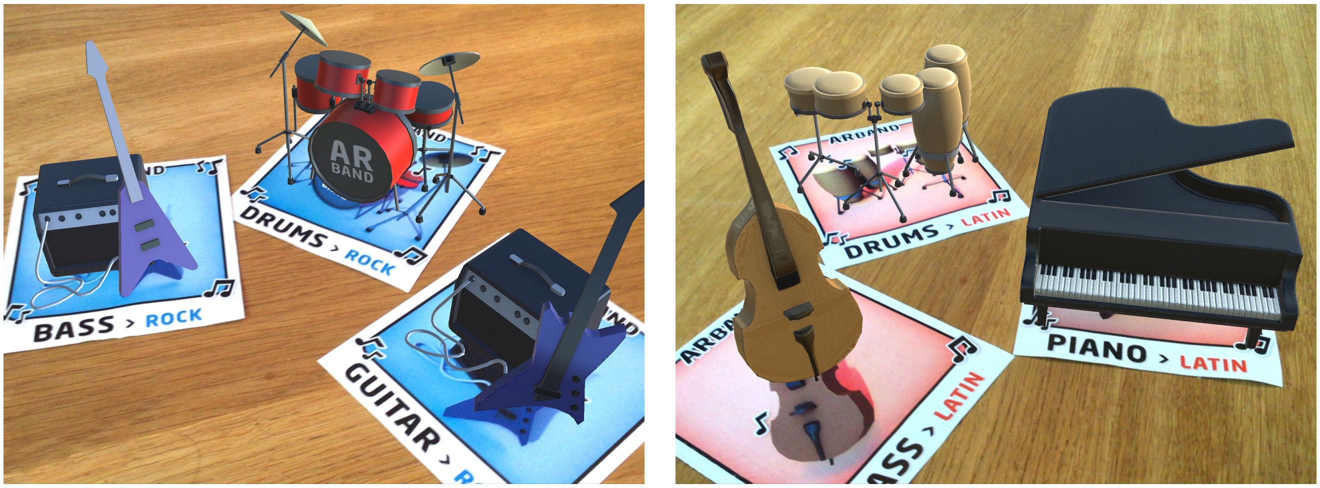
The following sections develop the idea of Augmented Creativity in the context of our six prototype applications in depth, highlighting their creative and educational goal, as well as their potential impact.

3.1 Coloring Book

Figure 3: *After coloring the octopus character, the user inspects the automatically textured 3-D model of the octopus on the iPad.*

Coloring books capture the imagination of children and provide them with one of their earliest opportunities for creative expression. However, this activity suffers from the popularity of television and digital devices. For these reasons, we have developed an AR coloring book app.

With this app, children color characters in a printed coloring book and inspect their work using a consumer-grade mobile device, such as a tablet or smartphone. As depicted on Fig. 3, the drawing is



- **Creative Goal** Experiment with different instruments and styles to rearrange your favorite song.
- **Educational Goal** Teaches concepts of arrangements, styles, and the disposition of the band components.
- **Potential Impact** Collaborative music arrangement experience, learn about the disposition of an orchestra.

Figure 5: *Music Arrangement Application*

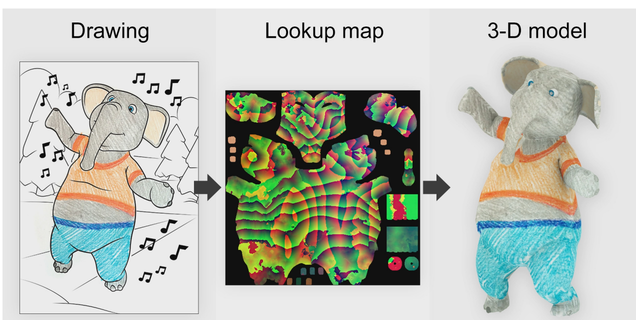


Figure 4: *A lookup map defines which regions from the 2-D drawing correspond to which regions in the 3-D model's texture.*

detected and tracked, and the video stream is augmented with an animated 3-D version of the character, which is textured according to the child's coloring. Accomplishing this goal required addressing several challenges. First, as the 2-D colored drawing provides texture information only about the visible portions of the character, texture for the occluded regions, such as the back side of the character, is generated using a UV lookup map, as shown in Fig. 4. Second, our method targets live update, so that colored changes are immediately visible on the 3-D model as the child colors. Therefore, we have developed a novel texturing process that applies the captured texture in real time while avoiding mirroring artifacts and artifacts due to parametrization seams, under the constraint of a very limited computation budget. Third, the pages in an actual printed coloring book are not flat but exhibit curvature due to the binding of the book. We have developed a deformable surface tracking method that is robust to page deformation and properly tracks the drawing and lifts texture from the appropriate 2-D regions. Finally, the practical consideration of authoring costs lead us to create an efficient content creation pipeline for creating characters for such coloring books. The resulting app runs at 12 FPS on an iPad Air. We conducted two user studies which validated the texture synthesis algorithm and the appreciation of the app by the users, showing that the app strongly improves the sense of connection with the character, and motivates people to draw more. Details of this work are available in [Magnenat et al. 2015].

This work shows that the AR coloring book application, besides fostering the creativity of children through imagination and the sense of connection to the character, motivates them to color and to explore their work in 3D, providing educational value. In addition, it opens new opportunities in the field of augmented reality gaming, such as the creation of user-colored characters and levels, as well as color-dependent behavior, allowing the user to script the virtual world through coloring.

3.2 Music Arrangement

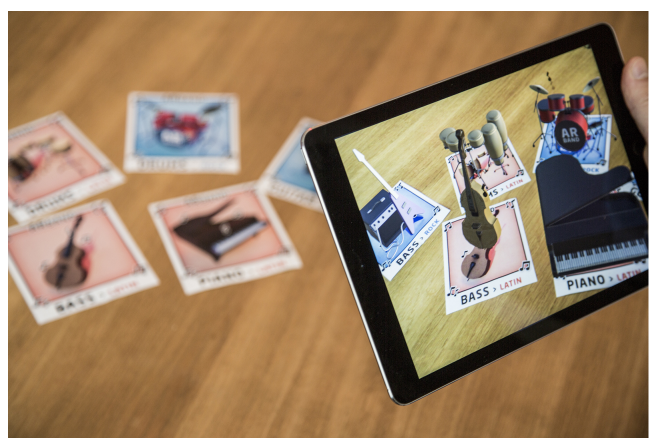
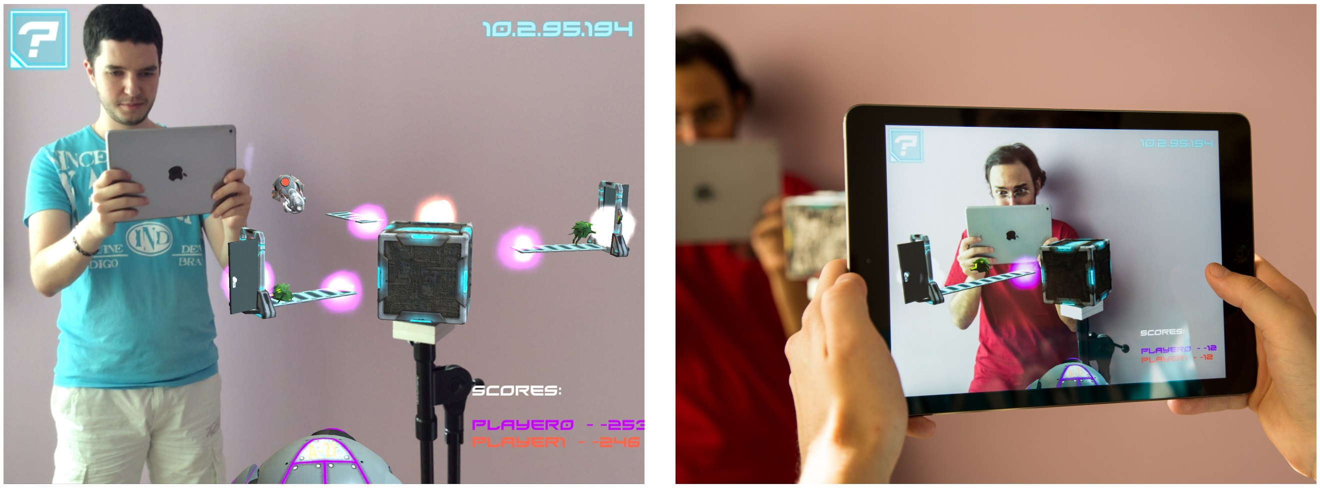


Figure 7: *The user listens to the arrangement he or she just created using the markers on the table while observing the virtual instruments on the iPad.*

Music is an integral part of human life and an important aspect of child development. We have developed an application that combines the endless creative dimensions of music with the intuitive spatial interactions offered by AR.



- **Creative Goal** Devise creative strategies to win the game as a team and score as many points as possible.
- **Educational Goal** Teaches cooperation, team communication, and physical movement.
- **Potential Impact** Positively affects interpersonal relationships and facilitates team-building.

Figure 6: *Physical-Interaction Game*

When composing music, the artist comes up with melodies and rhythms, decides on keys, scales, chords, and tempi, and chooses instruments for each part of the composition. On a higher level, the composer will adhere to a specific music style while writing the song. While there exist hundreds of styles, common categories of styles are Alternative, Blues, Classical, Dance, Hip-Hop, Pop, Jazz, Soul, Rock, and World. Music styles often dictate specific rhythmic elements, instruments, and scales. Nevertheless, every song can be re-arranged with different instruments to express a different style. For example, playing a known Punk-Rock song as Reggae, or a Hip-Hop song as Jazz, keeping the theme and the feeling of the song, might be a wonderful and even educational experience for a musician. With our application, we aim to provide a similar experience to the user.

Our application allows the user to arrange an existing song using different musical elements. We split the available musical elements into two independent dimensions: style and instrument. The user can choose instruments and styles independently and recreate the song as imagined. In our prototype app we provide Rock/Pop, Jazz, and Latin styles and Piano, Guitar, Drums, and Strings as instruments. To arrange the song, the user is given a collection of physical image markers, each representing a specific instrument for a given music style. By placing a marker on a physical board, an augmented version of the instrument is shown and the corresponding audio is played, as depicted in Fig. 7.

All markers play the same song in the same key and in the same tempo. The physical position of the marker on the board affects the composition of the corresponding instrument: moving an image marker closer to the camera will result in a louder sound of that instrument while placing instruments on the sides will affect the stereo composition. Hence, the user can intuitively explore different spatial compositions of the band components to produce a unique arrangement of the song.

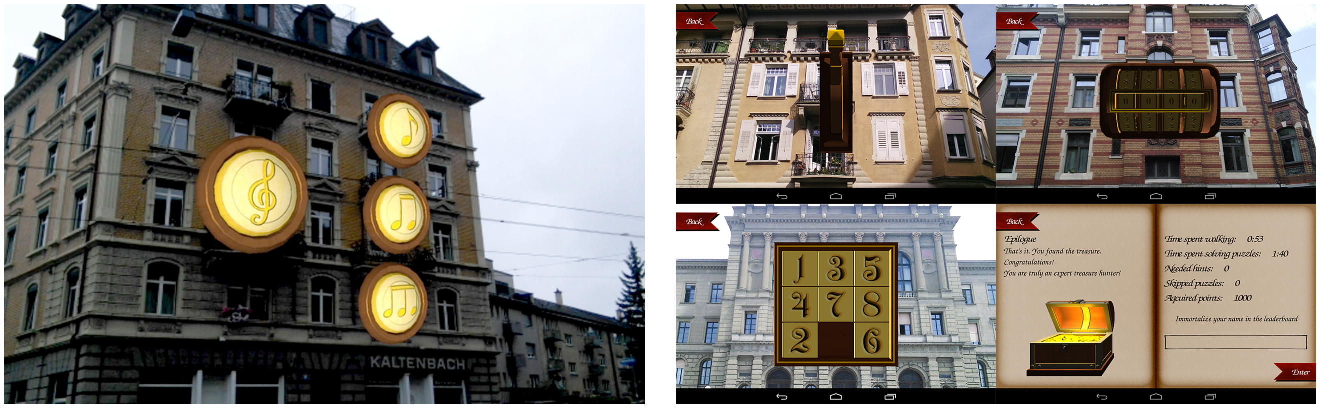
The application has strong creative and educational aspects. The user learns about music styles and the concept of arrangement and how the same song can be played differently in varying styles and with different instruments. Additionally, the application shows the importance of the spatial position of the instruments in a band. AR allows the user to change the position and the volume of the instruments while the song is playing, allowing her or him to direct the virtual band. Finally, this project opens up a wide range of future possibilities. For example, an extended multiplayer version of the application would allow users to collaborate in larger bands with different sections to create unique songs.

3.3 Physical-Interaction Game

The interaction components in computer games are often limited to screens and input devices and, while the games immerse the player in a compelling virtual world, they remove the player from the real world and thus from physically interacting with other players. In this application, we demonstrate how we can overcome this limitation by employing AR technology in a team-oriented game.

We have developed a networked multiplayer AR game [Zünd et al. 2014], which offers an immersive digital collaborative experience. In this game, players work together, communicate, coordinate, and synchronize to apply clever strategies to win the game. As an educational instrument, our game teaches children to quickly evaluate the current situation and decide if they should claim points for themselves or if the chance of winning is increased by leaving the points for other team members. Coordination and cooperation is necessary in order to achieve the highest score.

The players surround a cubical AR marker placed in the center of the room. Each player carries a tablet to virtually interact with the game and the other players. Up to four players can join a match, in which they have to prevent an invading alien force from entering our world. Inside the game, portals are spawned around the cube and the players need to physically align their tablet with each portal to close it before an alien creature passes through it. Players and portals are assigned random colors. Every player can close a portal to score points but a player closing a portal with the matching color receives more points. It is thus in the interest of the team to match the colors of players and portals, the difficulty being that only a player facing a portal can recognize its color. Therefore, the players need to synchronize and optimize their movement, not hindering each other, to successfully close as many portals as possible.



- **Creative Goal** Allows novice developers to build their own city-wide games and allows players to explore the city.
- **Educational Goal** Teaches novice programmers about AR and city-wide games development.
- **Potential Impact** Large range of AR city-wide games.

Figure 8: *City-Wide Gaming Framework*

Our game bridges the gap between virtual and real as players simultaneously maneuver around the cube in both the digital and the real world. It explores the concept of Augmented Creativity from the perspective of finding creative strategies to collaboratively win the game as a team. It bears the potential to positively affect the interpersonal relationship between players and to facilitate team-building.

3.4 City-Wide Gaming

AR holds the potential to provide a novel kind of interaction with cities. By overlaying interactive elements on top of the rich existing structure of buildings, parks, and roads, novel environments and innovative experiences can be created. However, building a city-wide AR app is a significant challenge. To aid developers, we have developed a city-wide gaming framework.

Our AR city-wide gaming framework focuses on scavenger hunt games. The player is sent on a quest that leads through the city to find a hidden treasure. The player visits several locations, which are found with the help of text descriptions and clues. At these locations, the player needs to solve AR puzzles in order to continue. The quests guide the player through historical sites and famous locations of the city. At the same time, the puzzles are inspired by the locations historic events. Our city-wide gaming framework was tested and validated in the context of a hackathon challenge. The participants formed five small teams of one to three people; they were given a location and some pictures of the buildings surrounding it and used these pictures as AR markers. The participants were asked to develop a chapter of the game story and a puzzle. Every team was able to design a quest within the few hours of the challenge. All the chapters were then gathered and merged into a final app that was playable during the event hosting the hackathon.

This work enables creativity and provides education at two levels: the novice developers are given a gentle introduction to the challenging field of AR and city-wide gaming, while the players are provided with a playful tool to discover the cultural background of a city. The successful deployment of this technology opens the way to a multitude of city-wide AR games.

3.5 Authoring Interactive Narratives

Authoring stories bears a promising opportunity to apply a wide spectrum of creative thinking. In interactive narratives, users are immersed in virtual worlds in which they create or influence dramatic story lines. The users become an integral part of a non-linear unfolding story and their actions have far-reaching consequences and significantly alter the outcome of the story.

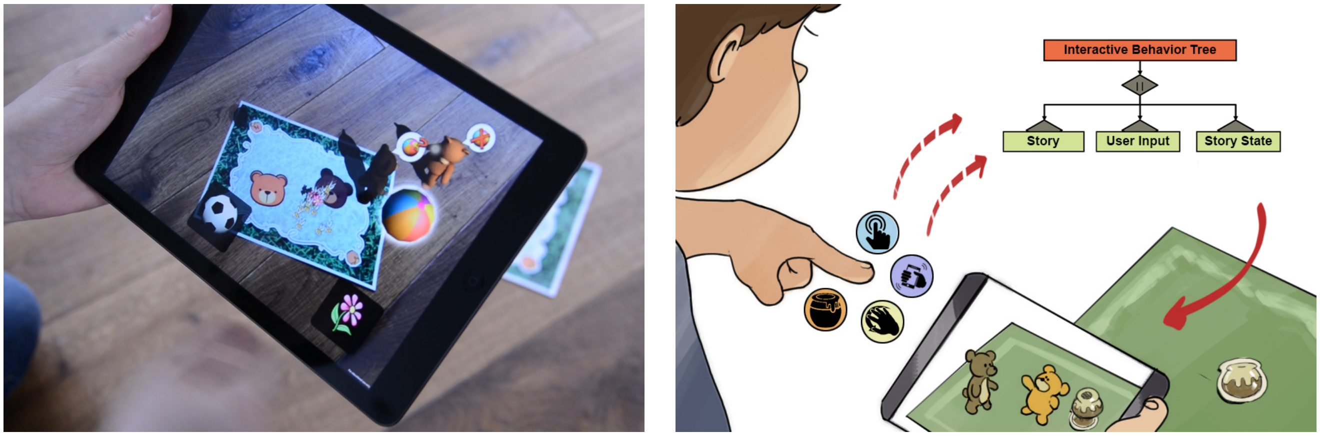
However, authoring interactive narratives is more complex and difficult than linear narratives as they additionally require defining and implementing all possible interactions a user can experience during the narrative. An increasing number of possible story arc paths a user can choose positively influences the quality of the narrative but exponentially increases the authoring complexity. Therefore, traditional narrative applications such as computer games either provide a strong narrative experience with little user agency, such as linear plots interspersed with isolated interactive segments, or contain compelling and complex interactive experiences but with simple narrative structures.

Our interactive narrative authoring framework [Kapadia et al. 2015b], [Kapadia et al. 2015a] facilitates the authoring of complex and compelling interactive narratives and supports the author with automation tools that help to resolve inconsistencies and to completely avoid errors. Our innovative design formalism, Interactive Behavior Trees, increases the modularity, reusability, and maintainability of authored interactive narratives.

Additionally, our AR integration helps the interactive narrative to overcome the cumbersome and unnatural feel of traditional forms of interaction such as monitor, mouse, and keyboard. Augmented Creativity opens up a new host of interaction possibilities for narratives and bridges the gap between virtual content and the real world.

3.6 Robot Programming

The availability of inexpensive electronic components has led to a variety of robotic toys, ranging from pets to cars. Most of these toys only allow simple, or even passive, interactions. Within this range of toys, edutainment robots have a special role, by carrying the promise of improving the skills of children in computational



- **Creative Goal** Reduces difficulty of authoring interactive narratives for authors, experience interactive AR stories as a player.
- **Educational Goal** Teaches concepts and complexity of non-linear interactive story telling.
- **Potential Impact** Create complex non-linear interactive stories that induce high user agency with far-reaching consequences.

Figure 9: *Authoring Interactive Narratives*

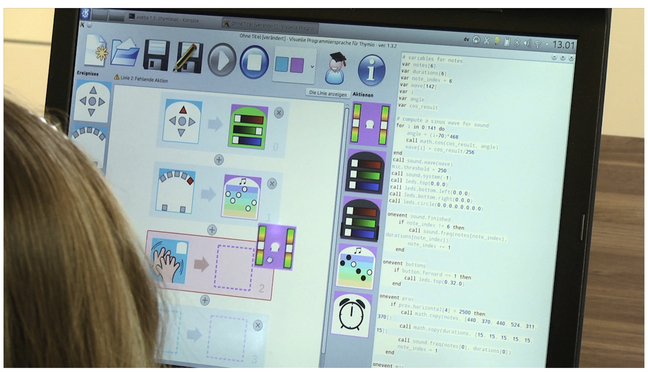


Figure 11: *A child creates a program for the Thymio robot using the graphical interface.*

thinking. However, their actual educational value is not always scientifically assessed; in particular, how these toys allow children to understand the process of program execution is not clear. To improve this understanding, we have developed an application combining an edutainment robot and AR.

In this application, the child programs the behavior of the robot by creating event handlers through the pairing of event and action blocks. For example, such a pair could mean ”when the robot sees an object on its front sensor, it must stop and light in red”. Pairs consist purely of visual elements. Previous studies have shown that this method is effective in allowing novices to program the behavior of the robot, but that without additional aid not all children acquire a deep understanding of the program [Magnenat et al. 2014a], because they do not have a clear picture of which event is executed in which condition. We address this problem by taking advantage of AR, to allow the child to see which event has been executed where in the physical world. With this application, we have shown that the use of AR improves the score on a test for deep understanding and changes the programming behavior of the child, although further studies are required to precisely assess these effects [Magnenat et al. 2014a].

This work shows that visually programming a robot with AR, besides fostering the creativity of children by allowing them to program their own behaviors into the robot, educates them about core computer science concepts. AR plays an important role in this deep comprehension, by making the dynamics of program execution visible. In addition, it opens many new opportunities in the field of gaming, for instance the creation of user-programmed non-playing characters, minions or pets; and a whole new class of competitive and collaborative games based on user-programmed agents.

4 Conclusion

We have outlined the concept of Augmented Creativity and shown how the graphics capabilities of mobile devices can be used to enhance real-world activities. Our work is supported by six prototype applications that explore and develop the concept of Augmented Creativity in different ways, cultivating creativity through AR interactivity.

Our work strives to make innovative use of mobile graphics in order to create compelling experiences that direct attention to classic real-world creative activities while offering engaging and exciting digital enhancements, fostering education, and opening further possibilities in the field of AR gaming.

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- **Creative Goal** Create user-defined behaviors for robots and virtual agents.
- **Educational Goal** Teaches programming and computer science concepts to understand the dynamics of program execution.
- **Potential Impact** User-programmed non-playing characters, minions or pets in games; games based on user-programmed agents.

Figure 10: *Robot Programming*

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