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Main Conference Preface

ILRN 2018 is the fourth annual international conference of the Immersive Learning Research Network, following the 2017 edition in Coimbra (Portugal), and returning for the second time to the United States, after the Santa Barbara edition in 2016.

There have been sixty-seven submissions to the conference in 2018 encompassing long and short papers, posters, demo proposals, special tracks and workshops. Albeit a third less than last year when the total was ninety-four, it is fifty percent more than in the last North American edition. Clearly, while travel logistics from other continents to the United States still pose challenges to participation, the research area is attracting more attention in North America, and more people overseas are overcoming those challenges. Of a total 150 authors of accepted papers and posters, 55% are from North America and 45% from the rest of the world, with Europe accounting for 21%, Africa 12%, South America 7%, and Asia 5%. The iLRN goal of developing a balanced transatlantic (and beyond) event enabling exchange of practices and research is being achieved. Authors of accepted contributions are from Austria, Brazil, Canada, China, France, Germany, Italy, Portugal, Saudi Arabia, Spain, Tunisia, United Kingdom and the United States. Within the United States, there is exciting diversity as authors are from 17 states: Arkansas, California, Florida, Illinois, Indiana, Massachusetts, Nebraska, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, Tennessee, Texas, Vermont, Washington, and Wisconsin (fig. 1).

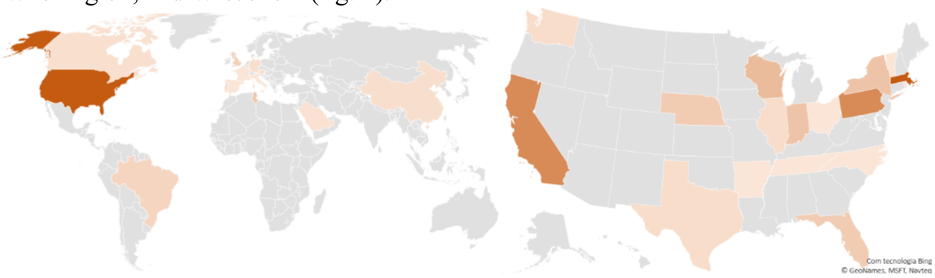

Figure 1: Geographical distribution of accepted paper authors at iLRN 2018

The overall acceptance rate for full papers was twenty-nine percent, with all papers and posters being independently reviewed: full/long papers by 3 – 5 reviewers, short papers by 2 – 4 reviewers and posters by 2 reviewers. All authors were given a good mix of feedback on how to improve their submissions for publication and presentation at the conference. In cases where the reviewers agreed that much more work was needed for a given format, full/long papers were invited to be resubmitted as short papers and short papers as posters. Fourteen of the accepted papers were published in an edition of Springer's series Communications in Computer and Information Sciences, the remaining revised papers and poster abstracts being included in this volume.

The main conference includes four distinguished plenaries demonstrating both breadth and depth in immersive learning. Chris Dede links virtual reality with its ability to empower educational transformation; Bonnie Bracey challenged ideas about purpose

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and use of museums, through the presence of digital artefacts combining the 3D ecosystem and the Internet of Things; Eliza Reilly, showed how teaching and learning and working within native communities on challenges that they care about is an immersive learning context; and Drew Minock explored how augmented reality is raising the bar today by improving productivity and safety, minimizing downtime, and accelerating learning and adaptation.

If you are not already involved in thinking about or researching immersive learning, check out these proceedings, and get excited about joining the iLRN community.

Leonel Morgado & Colin Allison
iLRN 2018 Co-Program Chairs

Keynote and Featured Speakers

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Virtual Reality and Unlearning: Empowering Transformation

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Abstract. Educational transformation requires that people volitionally change from a set of behavioral practices buttressed by organizational supports, policies, and incentives to a markedly different set of practices that requires an altered organizational context accompanied by a shift in assumptions, beliefs, and values at both the individual and institutional levels. Some research in immersive learning, particularly in virtual reality, shows promise of accomplishing the unlearning of deeply held beliefs, values, and attitudes by influencing the mind/brain cognitively and affectively, intrapersonally and interpersonally.

Keywords. Virtual Reality, immersive learning, unlearning

1 The Challenge of Transformational Change

A major challenge in educational improvement is inducing people to volitionally change from a current set of behavioral practices buttressed by organizational supports, policies, and incentives to a markedly different, transformational set of practices that requires an altered organizational context—accompanied by a shift in assumptions, beliefs, and values at both the individual and institutional levels. Illustrative examples of this frequently encountered situation include:

- A teacher/professor transforming instructional practices from presentation/assimilation to active, collaborative learning by students (e.g., using the case method of teaching, or using project-based learning)
- In making the transition from classroom to distance teaching, an instructor transforming from teaching practices effective in the face-to-face classroom to instead using teaching practices effective in online learning.
- An educational organization transforming from credentials certified by seat-time and standardized tests to credentials certified by proficiency on competency-based measures, irrespective of student time taken to accomplish this.
- An educational organization that (perhaps unconsciously) discriminates against certain types of people (e.g., marginalized populations) transforming its individual and institutional behaviors to actively promote diversity and equity.

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Of course, many other illustrations could be given. These examples have in common transformational shifts (i.e., second-order, double-loop, deep) based on a reconceptualization of assumptions, beliefs, and values [1]. Often, this means that individuals and organizations shift to behaviors that are more time-consuming, expensive, and difficult, but more effective based on a new frame of reference. At times, this form of change also involves difficult situations (i.e., wicked, intractable) with multiple stakeholders, competing perspectives, and an absence of resolutions that guarantee the aspirational transformation.

2 The Strategy of "Unlearning"

My interest centers on enabling volitional individual and organizational change (i.e., not based solely on compliance with institutional mandates) that is relatively swift. In a literature review, I found descriptions of individual and organizational unlearning that were primarily cognitive strategies for accomplishing this type of transformation. People who term this "unlearning" typically view that term as a special stage of the learning process, a form of reverse-learning. Some of these approaches are about altering mental models, others involve "management" of the change process, and still others are based on strategies from knowledge diffusion. I am unconvinced by this formulation of unlearning, because in decades of professional experience I've seldom seen strategies that rely on rational processing of information to be effective in creating sustainable change that is truly transformational.

Instead, my experience is that a powerful , negative emotional overlay (on intrapersonal and interpersonal dimensions that are not necessarily conscious) usually undermines rational, cognitive drivers to the point that transformation is, at best, temporarily and partially accomplished before reversion to standard practices and policies. This response to change is documented in a variety of contexts; for example, Kuhn discussed how emotions can undercut scientific rationality in his book, *The Structure of Scientific Revolutions* [2]. I seek to foster "unlearning" that can overcome or undercut this emotional resistance. My hypothesis is that the affective response is based on a perceived threat to personal (and organizational) identity. By this, I don't mean simply what people will intellectually describe when asked, "Who are you?" I include deep, unconscious assumptions, beliefs, and values distributed throughout the mind/brain, including preconscious processing in the limbic system.

Thus, I am devising and studying strategies for unlearning that involve volitionally letting go of a deeply held, emotionally valued identity, in the service of making a transformational change to a different set of behaviors prompted by altered assumptions, beliefs, and values. However, describing this as a shift from one well-defined state to another is too simplistic. I am influenced by the arguments of Brook et al [1] that unlearning may be moving from knowing to not-knowing and from action to non-action, as a transitional step towards developing a transformed form of knowing and acting. In

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such a process, support for an "intermediate" identity that is based on not-knowing and not-acting as a form of exploratory deliberation may be valuable, so that unlearning does not fail through existential crisis when one's new identity is unclear.

3 The Opportunity of Virtual Reality Experiences that Promote Unlearning

I hypothesize that this type of unlearning would be based on a series of very powerful experiences that influence the mind/brain cognitively and affectively, intrapersonally and interpersonally. As a researcher of immersive learning (i.e., virtual, augmented, and mixed realities), I believe these media hold promise of what they might accomplish [3]. Specifically, learning experiences designed to teach complex knowledge and sophisticated skills are often based on "guided social constructivist" theories of learning. In this approach, learning involves mastering authentic tasks in personally relevant, realistic situations. Meaning is imposed by the individual rather than existing in the world independently, so people construct new knowledge and understandings based on what they already know and believe, which is shaped by their developmental level, their prior experiences, and their sociocultural background and context [4]. Instruction can foster learning by providing rich, loosely structured experiences and guidance (such as apprenticeships, coaching, and mentoring) that encourage meaning-making without imposing a fixed set of knowledge and skills. This type of learning is usually social and situated; students build personal interpretations of reality based on experiences and interactions with others in a rich authentic context [5].

Immersive media have affordances that enhance this type of learning. Psychological immersion is the mental state of being completely absorbed or engaged with something. For example, a well-designed game in a MUVE draws viewers into the world portrayed on the screen, and they feel caught up in that virtual environment. The use of narrative and symbolism creates credible, engaging situations [6]; each participant influences what happens through their actions and can interact with others. Head-mounted or room-sized displays can create sensory immersion to deepen the effect of psychological immersion, as well as induce virtual presence (place illusion), the feeling that you are at a location in the virtual world [7].

In particular, the evolution of an individual's or group's identity is an important type of learning for which simulated experiences situated in immersive interfaces are well suited [8]. Reflecting on and refining an individual identity is often a significant issue for students of all ages, and learning to evolve group and organizational identity is a crucial skill in enabling innovation and in adapting to shifting contexts. Identity "play" through trying on various representations of the self and the group in virtual environments provides a means for different sides of a person or team to find common ground and the opportunity for synthesis and evolution [9; 10]. Immersion is important in this process of identity exploration because virtual identity is unfettered by physical attributes such as gender, race, and disabilities [7; 11]. These characteristics of immersive experiences suggest a variety of interventions that could aid unlearning, and research on this topic is very important in achieving the full potential of immersive media for educational transformation.

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Museums, Old and New, Traditional and Digital: Evolving Ideas and Scaffolding

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Abstract. This featured speech explored the evolving nature of museums to include new technologies to increase engagement, interaction, and learning of participants. Several examples are provided including a description of the Science Museum in London, the San Francisco Museum of Modern Art (SFMOMA), the Brooklyn Museum, the American Museum of Natural History, and the Gardens by the Bay. The speech concluded with an example of from the Smithsonian X 3D project and a discussion of future museum projects.

Keywords. Museums, interactive, digitization

We will explore the idea of museums old, and new, from brick and mortar to digital to the museum in your pocket to mass digitalization. Technology and new ideas have changed the conceptual framework of what a museum is. According to the ICOM Statutes, adopted by the 22nd General Assembly in Vienna, Austria on August 24th, 2007: A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment. This definition is a reference in the international community [1]. The definition of a museum has evolved, in line with developments in society. Since its creation in 1946, ICOM updates this definition in accordance with the realities of the global museum community. Fox [2] says boldly: "Everyone should have the opportunity to experience all that the arts has to offer, and technology can help make that possible by putting so much information right at our fingertips."

The audio guide. The museum map. For years, these tools have led visitors on journeys through the world's greatest cultural institutions. They've provided a one-way means of experiencing amazing artifacts and groundbreaking galleries. Now, it's time for some new tools – tools made for the digital, social sharing age. The Cooper Hewitt Smithsonian Design Museum will equip all visitors with an interactive Pen to fully engage with the objects on view and create their own designs. The pen will also store these experiences, enabling visitors to share them online with their social networks (Figure 1).

Figure 1. Cooper Hewitt: Drawing in Visitors with Interactive Pen

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Image source: https://www.cooperhewitt.org/

What better way to experience 200 years of innovation in communication and information technology than through high-tech, digital tools? The Science Museum in London contains a new Information Age gallery that will include apps, games, interactive screens, and more (Figure 2). The San Francisco Museum of Modern Art (SFMOMA) reinvented their entire digital program to coincide with the museum's building reopening in 2016. Their focus is on fostering creative responses to creativity, partnering with artists, game designers, and cultural commentators to create mobile and on-site experiences that are thoughtful, surprising, and irreverent (Figure 3). On any given trip to the Brooklyn Museum, you may miss the tour. Or you may want to know more after reading the sign next to a certain piece. With the Brooklyn Museum's expanded digital efforts, visitors will

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be able to use their mobile devices to ask questions to experts in real-time and get suggestions on additional works of art to explore with help from location-based technology (Figure 4). The American Museum of Natural History has already pioneered location-based technology for a museum app with Explorer. New digital efforts will update this app with features like personalized journeys, exclusive content, and new ways to share experiences at each exhibit (Figure 5). The Gardens by the Bay mobile app will bring the natural beauty of this Singapore horticultural attraction into the digital space. With interactive trails and engaging stories, the app will connect visitors with the plants surrounding them in a new and more meaningful way (Figure 6).

Figure 2. The Science Museum, London: Creating Journey through Information Age

Image source: https://www.sciencemuseum.org.uk/see-and-do/information-age

Figure 3. San Francisco Museum of Modern Art: Reinventing the Digital Experience

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Image source: https://www.sfmoma.org/

Figure 4. Brooklyn Museum: Bringing Experts to You

Image source: http://www.brooklynmuseum.org/exhibitions/luce/

Figure 5. American Museum of Natural History: Utilizing Location-Based Technology

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Image source: http://www.amnh.org/exhibitions/permanent-exhibitions/biodiversity-and-environmental-halls

Figure 6. Singapore's Gardens by the Bay Connecting Nature with Digital Space

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Image source:
https://www.facebook.com/gardensbythebay/photos/pb.361992263834380.-2207520000.1409778802./782180058482263/?type=3&theater

Cultural Involvement

Google has a set of cultural resources that people can share and curate to a specific subject, country or object [3].

Involving the audience

There are several ways in which digital museums can involve audiences. New platforms are allowing museums to break free of the confines of the academic ivory tower and engage with their communities like never before. They engage the audience, they open the dialogue and involve the participant, they break down the walls of inaccessibility, they have and cultivate a global following, there are user generated content campaigns, they utilize crowdsourcing, and there are emerging cultural aggregations. Museums break the cultural bubble. Museums integrate mobile tools into their exhibit or learning space. I will share some of these tools.

Some museums allow you to use a tool to take some contents of the museum home with you. Museums initially used social media just to advertise events and exhibits, but quickly jumped into a world of interactive education and user generated content.

Digitalization, Personalization, National, Cultural and Mass Digitalization, and Global Sharing

The Smithsonian has engaged in a special initiative that is a part of digitalization of museums [4]. Smithsonian X 3D launches a set of use cases which apply various 3D capture methods to iconic collection objects, as well as scientific missions. These projects indicate that this new technology has the potential not only to support the Smithsonian mission, but to transform museum core functions. I will share examples of this project. Researchers working in the field may not come back with specimens, but with 3D data documenting a site or a find. Curators and educators can use 3D data as the scaffolding to tell stories or send students on a quest of discovery. Conservators can benchmark today's condition state of a collection item against a past state – a deviation analysis of 3D data will tell them exactly what changes have occurred. All of these uses cases are accessible through the Beta Smithsonian X 3D Explorer, as well as videos documenting the project. For many of the 3D models, raw data can be downloaded to support further inquiry and 3D printing. The Digitization Program Office is the hub for the Smithsonian's inquiry into 3D. It support all 19 museums, nine research centers and the National Zoo in their quest to increase the quantity and quality of Smithsonian digital assets. The team uses a variety

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of 3D scanning methods and tools to capture the geometric and sometimes color information of Smithsonian objects and scientific research sites: laser, structured light, photogrammetry and Computer Tomography (CT). A 3D scan is essentially nothing more than millions or billions of points of measurement of an object's surface, or in some cases density. Once an object or research site is scanned you are able to use that data in many different ways, including:

- Deliver content online using the 3D Explorer [4]
- Allow schools to freely download and 3D print iconic Smithsonian objects in the classroom
- Provide new measurement tools for research
- Provide conservators a condition report for Smithsonian objects

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The Indigenous Vision Interactive Map

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Abstract. This presentation focused on environmental stewardship program developed by Souta Calling Last and her organization, Indigenous Vision. The virtual reclamation of our landscape narrative will be achieved through the science of Indigenous geography and map making technology that includes virtual reality experiences. The presentation also highlighted the coding and development process of the map and app. Including the concept of geo-fencing Sacred Place Ecosystems.

Keywords. Indigenous, virtual reality, cultural reclamation

1 Bio/Background

Souta Calling Last (Blackfeet/Blood) is the Founder and Executive Director of Indigenous Vision, a national educational nonprofit founded in 2015. Her work on land and water protection started in childhood cleaning beaver ponds. She continued volunteering with streamside cleanups, restorations, community water education, and mining contamination cleanup while obtaining a Bachelor's degree from the University of Montana in Environmental Studies Water Resources. She later gained experience with her tribe as a Water Resource Specialist and Drinking Water Operator and obtained her Master's degree in Innovative Leadership and Change Management from the University of Phoenix. Before founding Indigenous Vision, Souta served as an Environmental Specialist in a National Tribal Drinking Water Program. Her connection to the landscape remained unhindered and she continued to organize lake shore clean-ups at drinking water reservoirs in the Phoenix area. Souta believes the land is a storybook of information filled with ecological and climate knowledge and that honoring ancestral observation will protect the land and water and will promote ideal human health and wellness. She also believes that protecting cultures at risk starts with protecting the environment.

2 Presentation Description

The Indigenous Vision Interactive Map Presentation is centered on empowering the Indigenous identity through virtual reclamation of traditional territories and asserting the Indigenous right and benefit of environmental stewardship. The online resource and workshop curriculum will empower leaders, community members, and activists with a

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tool grounded in Tribal Ecological Knowledge (TEK), reinforced by western science and is delivered with innovative mapping and app technologies that is educational, interactive and entertaining. The virtual reclamation of our landscape narrative will be achieved through the science of Indigenous geography and map making technology that includes virtual reality experiences. TEK explains characteristics of the landscape and eye witness accounts of climate change marking the coming and going of various species and eras. The Interactive Map and App is a revolutionary networking resource and educational tool that provides a platform to learn about landscape history, culture, environmental science and efforts of protection. The project will allow for a large support network of native and non-native alike to educate and assist in the protection of land and water. Mapping layers focus on the risks and challenges to Indigenous stewardship and the close proximity of damaging industries and expansion of modern development. The project will help minimize stories of conquest and genocide and allow the indigenous narrative to stand side-by-side or replace racist narratives. Her presentation will also highlight the coding and development process of the map and app. Including the concept of geo-fencing Sacred Place Ecosystems. Scattered throughout the environment on the reservation and off, are cultural places of significance, each location requires a thriving “sacred place ecosystem” that is not commonly integrated in current environmental management, and not included at all in current environmental education.

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Incorporating Multi-Media Design, Science, with Game Creation to the Community

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Abstract. This presentation covered the work of Native Teaching Aids and Flathead Tech 4 Good by Rebecca Goff, one of the founders of the former organization. She discussed the need to address large problems facing the world, including global warming, pollution, food deserts, and many more challenges. She then addressed the inherent ability of games to help create solutions to these kind of problems, and shared examples of Game Jams that Native Teaching Aids and Flathead Tech 4 Good have sponsored.

Keywords. Game Jam, global warming, food deserts, water

1 Facing today's problems

In today's world we are facing many issues: global warming, pollution, food deserts, and many more challenges. It is our belief at Flathead Tech4Good and Native Teaching Aids, that if we all work together, defining this as the closest community, experts, incorporating youth, and any interested parties, taking on community issues, we have a strong motivation to get things done. Also, by collaborating on this level with the intent to face these problems head-on, there is much we can accomplish.

Native Teaching Aids, established in 2013, has worked these past five years working with tribes, schools, and other communities to create materials that teach indigenous language, culture and history. The company started in digital media design, creating online dictionaries, lesson systems, and mobile apps. Noticing that this had a limited access to the entire community, and interactivity between people is the best way to study and learn a language, Rebecca and Brandon Goff, the co-founders of the company, incorporated games into their inventory.

2 Using Game Jams to Solve Problems

By utilizing card games and board games in the language, or focusing on the culture and history, it not only aided in the learning of the language, but also brought conversation to the table and more opportunities for the community members to learn from their elders, and the learners were learning while engaging in a fun activity. When a student or learner is learning Spanish, French, or English for example, if they wanted to immerse themselves

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in the language, they could go to Spain, France, the United Kingdom, or anywhere else that language was primarily spoken. Because of the genocidal efforts put into place by the early years of the United States Government such as the notorious "Trail of Tears," the "Kill the Indian Save the Man" movement where countless Native American and First Nations children were taken from their homes and striped of their identity to conform to the "colonial" identity. These people's language, and way of life were seen as "wrong, dirty, or stupid."

This movement was effective because elders stopped teaching their ways of life to their children, stopped speaking their language, and many languages were lost because of this. When people ask me why I do what I am doing since I am not Native, I answer, "because I am human." We are now in what many people call the Seventh Generation. This is the generation of change, not to go back to the old way, because there is no going back there, but taking control of the injustice that still continues to this day and changing to create a better world. Part of creating this better world is instead of competing with one another, we at Native Teaching Aids feel that it is important to work together, because we should all be working on problems that are bigger than ourselves if we are to make the impact we want.

By taking on these large problems, we have been able to involve and incorporate the community. A few years after our inception of Native Teaching Aids, myself, Brandon Goff, and Jonathon Richter formed Flathead Tech 4 Good(FT4G). Our organization takes a community issue and "gamify's" the problem in order to teach the community what the problem is, how can we stop it, and is there a long term solution. FT4G holds 3 game jams, but they are not like the traditional competitive game jam. The jam is patterned as Fall: information dump Friday, concepting ideas and prototyping Saturday, present to the experts on Sunday. Winter: Playtest, and activities revolving around the issue. Spring: celebration and present to the community. We hold them seasonally, Fall, Winter, and Spring.

For example, last year we chose the watershed issue. On Friday evening we had scientists from the Flathead Lake Biological Station come in and explain to the high school and junior high kids who were present about the importance of Clean, Drain, Dry, the threat of the Zebra Mussels, and other pollutants that could damage the lake. We also had the Flathead Lakers, which is a community run group that raises awareness and holds different clean-up events. We had someone from the Salish tribe come and speak about the cultural importance of the biological diversity of the valley. This information dump results in a lot of note taking, we wall paper the room with notes and information. On Saturday morning we meet and Native Teaching Aids takes the youth through game design techniques, we bring a stack of conventional games and show them how to design and create their own games. We bring poster board, markers, scissors, glue, tape, stickers, many things to get them creating and designing. This past fall we had two games designed by the end of Saturday night.

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Sunday morning, the speakers from Friday and parents were in attendance as we had the youth present their games. They were play tested and then I met with the students and came up with a “what’s next” to-do list. Then in January, FT4G utilized Native Teaching Aids’ offices and had a mentorship month. We spent the first week talking about how to mix creative and technical writing together and wrote all the content for both games. The following 3 weeks were spent on graphic design, where we taught the students how to design in Adobe Illustrator.

For the Winter Gam Jam, we invited the EAGLES students, who are leaders in their high schools in the valley. We playtested the games, received feedback, and then performed some activities to start the Water is Life Treasure hunt that we are aiming to incorporate at all the public schools in Mission and Lake counties eventually. Making a plan for the scavenger hunt and making final steps plans for the two games that were created in the Fall game jam, we closed on Sunday with some fun VR activities.

Native Teaching Aids’ offices were utilized once again to finish the games and perform a final print. In the Spring Jam in May, we presented the near-final copies of Mussle Hustle and Water Warriors with great interest from the community. Sci-Nation and SpectrUM from the University of Montana was there with their projects they had done with the junior high school students creating Rube Goldberg devices. This Spring Jam, was more of a celebration than creating anything, and by involving the community at large to experience and learn.

“Look deep into nature, and then you will understand everything better.” -Albert Einstein Science is meant to raise curiosities and solve problems. If we do not incorporate and involve our communities, our youth, and experts working together to solve these problems, we will not be able to move forward in a positive light. “Education is the most powerful weapon you can use to change the world.” - Nelson Mandela

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Engaging Indigenous Communities in Citizen Science

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Abstract. Invited panel at iLRN 2018 presented by the National Center for Science and Civic Engagement (NCSCE) and Montana Transcending Barriers: Connecting Indigenous and Western Knowledge Consortium.

Keywords. Civic engagement

1 Description of Presentation

The National Center for Science and Civic Engagement (NCSCE) has launched a new initiative, funded by the Keck Foundation, to advance durable and equitable collaborations between indigenous communities and local educational organizations. The aim of this initiative is twofold: to provide engaging, inquiry-based learning opportunities around environmental and health challenges of immediate relevance and interest to indigenous youth and their communities, and to transcending perceived conflicts between "traditional" and "western" scientific knowledge. During this Invited Guest Panel presentation, members of this "Transcending Barriers to Success: Connecting Indigenous and Western Knowledge" consortium (Hawaii, Alaska, California, Arizona, and Montana) will present an overview of the project and highlights of their respective statewide efforts. The panelists hope to engage the Immersive Learning Research Network conference attendees in conjuring immersive learning possibilities related to these rich, diverse, and compelling community contexts.

A goal of this presentation is to leverage this project and NCSCE's national community of innovative STEM educators as a catalyst for deeper engagement with members of the iLRN community who have expertise in these multimodal digital exhibits that are increasingly integrated with physical presentations (cultural artifacts, land, water). These are a new form of "immersive learning" space now popularly called "X-Reality".

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2 Montana Transcending Barriers: Connecting Indigenous and Western Knowledge

Montana Transcending Barriers: Connecting Indigenous and Western Knowledge is organized around Salish Kootenai College's Tech4Good outreach projects and partners with the Confederated Salish and Kootenai Tribes' Natural Resources Department, the EAGLES Youth program, Native Teaching Aids, Riparian Games, the Watershed Education Network, and The University of Montana's SpectrUM Discovery Center, Broader Impacts Group, and Flathead Lake Biological Station.

3 The National Center for Science and Civic Engagement

The National Center for Science and Civic Engagement (NCSCE) is a dynamic and inclusive network of innovative educators committed to advancing STEM capacity and civic engagement. Its signature program SENCER (Science Education for New Civic Engagements and Responsibilities) helps educators connect civic issues to STEM content by encouraging a multidisciplinary and project-based approach to formal curriculum and out-of-school learning, actively engaging students in authentic real-world problem-solving that fosters transferable skills for citizenship and career success. Since 2001, the educational work of NCSCE has been supported by the National Science Foundation and a range of other public and private foundations. It now serves more than 500 formal and informal educational institutions, reaching over 6,000 educators, administrators, and community-based representatives through symposia, leadership programs, consultations, and online resources, impacting hundreds of thousands of students. NCSCE supports institutional collaborations across sectors, including the academy, government, and NGOs. NCSCE develops regional leadership through nine SENCER Centers for Innovation (SCIs), offering expertise, local support for members of the SENCER community, and meetings and workshops to complement national professional development symposia.

4 Presenters

Dr. Eliza Jane Reilly, executive director of NCSCE and project PI, Research Professor at Stony Brook University

Jonathon Richter, Lead Instructor and Dept Chair, Media Design, Film, & Television, Salish Kootenai College

Denielle Perry, Assistant Professor, School of Earth Sciences and Environmental Sustainability, Northern Arizona University

Main Conference

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Augmented reality impact in the development of formal thinking

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Abstract. Experiential activities in classrooms and their repercussions in the process of building senses (or meanings) are of great value for the cognitive development of students. In this perspective, this paper presents the making of a virtual and augmented laboratory prototype in which the objective is to contribute in the process of helping physics students develop formal thinking, through the demonstration of invisible occurrences and situations that involve natural phenomena, as well as allowing the interaction with multimedia resources and educational objects. Therefore, discussions about the potential of virtual laboratories and augmented multimedia resources as technologies capable of aiding in the cognitive development of physics students will be exposed along this article.

Keywords: education; formal thinking; virtual reality; augmented reality; STEM;

1 Introduction

Teaching and learning physics is a hard task, as is reported in innumerous works. Teachers do not always have the conditions to offer practical activities due to the lack of laboratories in schools and, additionally, several experiments are not capable of completely exposing the natural behaviors that are happening once that certain phenomena are not visible to the human eye (such as electricity, magnetism, heat, etc). Som can even entail environmental or personal hazard (such as radioactivity) and, thus, cannot or should not be done without the proper security measures, which prevents them from being performed in most schools and even some universities.

The hardship in teaching and learning physics, particularly in electricity related subjects, can also be explained by the absence of formal thinking in teenagers, as a consequence of failing to evolve from the concrete thinking of a child to the formal thinking of a teenager, such as is described by Inhelder and Piaget [1]. According to the constructivist theory, knowledge is neither in the objects nor in the people but it derives from the action of people over the objects. Considering that the evolution of thought could be delayed or anticipated in consequence of the conditions in the context in which children and teenagers find themselves, it is desirable to investigate whether creating the opportunity to perform experiments in virtual labs could entice conditions to accelerate the formation of formal thinking, necessary to the physics learning. Inhelder and

adfa, p. 1, 2011.

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Piaget [2] describe three formation stages of formal thinking:

- Stage I (until 7 to 8 years of age) – subjects' attentions are aimed at the triumph or failure without considering its mechanism. The subject acts only to reach the objective and does not ask itself how it is done.
- Stage II (from 7 to 9 until 11 to 12 years of age) – the beginning of concrete operations. Subjects are limited to a "reading" of the facts, which is now exact since it is organized through concrete operations of serializing and correspondence, however, they do not look for a reason for these facts through formal operations of implication and others, which is characteristic of the hypothetical-deductive thinking.
- Stage III - Formal stage – The final phase, preparatory to adult thinking, takes place between twelve and fifteen years and involves the appearance of formal as opposed to concrete operations. Its most important features are the development of the ability to use hypothetical reasoning based on a logic of all possible combinations and to perform controlled experimentation.

Under certain conditions, an acceleration in the cognitive development would be possible minding some general principles that can be found on the basis of each one of the learning process of an individual:

- Subject activity: A genetic theory implies that the cognitive development is made essentially by the interaction between the subject and the world that involves it. A situation of apprenticeship is as more productive as the subject is more active. Thus, practical learning opportunities are valuable for the cognitive development.
- Scheme coordination: A second principle is that during the cognitive evolution demonstrated by the transversal studies, the knowledge progress can be defined by the fact that every new structure integrates the previous schemes, coordinating them. The experiential activities and their observable elements are not sufficient to provoke an authentic thought progress while they are not inserted in an inference system that allows the chained processing of the successive stages of the observations provoked by the different phases of experiencing.
- Evolution stages: offsets of some wingspan were frequently noticed in several studies undertaken in different cultural environments. Lateness or precocity may be explained by the degree of solicitation exercised by the environment of general cognitive elaboration; sometimes it is sufficient to place a problem to unleash mental processes already present in an underlying manner, even though they are not requested in the everyday task. In laboratory environments, it is possible to create the conditions necessary for this to occur.

As a consequence of this, the science, technology engineering and mathematics (STEM) education has supported itself in the practical and experiential use of real laboratories. As was highlighted by Klahr, Triona & Williams [3], hands-on science promotes learning because it is consistent with the concrete-to-abstract nature of cognitive development, because it provides additional sources of brain activation via kinesthetic involvement, and because its intrinsic interest increases motivation and engagement.

With current technologies, new approaches came to support the process of cognitive

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development. On this view, Scalise et al. [4] indicate that many of today's students experience a portion of their scientific study through virtual labs and simulations, experiments and demonstrations of scientific phenomena delivered up via computer software. "Students may flourish in the traditional science-lab setting, intrigued and motivated by the tools, the sights and smells, and the surprising (and sometimes impressively startling) outcomes of experimentation, but they may also be adept at and drawn to emerging technologies, thriving in a virtual setting, with its visual cues, instant feedback, and self-pacing options for repeating a unit or moving quickly ahead" [4].

However, in many cases, the experiments require an abstraction level still not fully reached by all students in formation. Such a level is known as the formal operational stage and it begins at approximately age twelve and lasts into adulthood. As adolescents enter this stage, they gain the ability to think in an abstract manner by manipulating ideas in their head, without any dependence on concrete manipulation [4].

Several types of research have converged to promote learning through practices, aiming at building knowledge through realization, thinking, testing and exploration. In a broader sense, the active learning has been seen as a relevant teaching method for learners to develop critical skills and knowledge. This is especially relevant to STEM education and engineering courses that have to prepare future professionals for solving problems that could not be anticipated, what requires experiments to bring a proper solution. The experiential learning emerges as an important element for the approach discussed in this article, which involves augmented reality (AR) resources to promote learning through the understanding of experience and its transformation into knowledge.

The virtual labs have been receiving attention regarding the development of educational solutions using augmented reality due to its ever-growing use in the educational scope at a global level, according to the New Media Consortium (NMC) report [5], which identifies and describes the trends, challenges and the developments in technology that may impact the technological planning and decision making in world education. According to that report, regarding higher education, the technologies and practices that will most likely be in use in its areas for the next 5 years were highlighted. Among them, the intensification of the development of AR technologies was pointed out, accompanied by the comeback of mobile learning to the educational scene starting at 2017.

As far as the cognitive development of students, Gruber et al. [6] claim that, in a pedagogical point of view, experimental activities provided by AR encourage the construction of mental models based on the practical observations of the concepts and principles involved, creating the connection between theory and reality, especially in topics that involve natural and technological sciences. Besides that, the more these activities incite the resolution of practical problems, the better qualified will be the learning of these students, since they enrich and solidify their theoretical knowledge.

Facing such assertions, this paper aspires to expose the implementation of a Virtual and Augmented Physics Laboratory. Its goal is to supply the development of formal thinking through interactive experiences of physics phenomena, which involve the interactive use of three-dimensional objects, animations, and simulations, as well as other educational media that aim to stimulate the active interaction of students in a similar manner to hands-on experiments done in real labs.

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2 Augmented reality in education

AR is the integration of multimedia resources with physical elements of the real world. In this integration, computer-generated graphical elements are presented in the user's technological device, simultaneously with the real environment elements. This way, it is possible to transform the user's surroundings. According to Milgram and Kishino [7], AR is composed of a real environment "augmented" by the means of virtual objects.

AR features expand users' channels of interaction with educational content and attract greater learning opportunities. Other benefits enabled by AR consist in the reach of more elevated levels of motivation and engagement by the users, the 3D visualization of virtual objects interposed with real ones and the scale visualization of phenomena that are not perceptible in the real world through different perspectives or angles. These characteristics aid the users in assimilating abstract and complex concepts, easing the comprehension of a determined educational content (Chang et al. [8]; Furió et al. [9]). Besides that, AR gives support to the comprehension of complex phenomena, providing unique visual and interactive experiences, which combine real and virtual information, helping to explain abstract concepts to students [11].

Still in relation to the pedagogical potential, AR can present multimedia resources with the possibility of different levels of observation (zooming, rotating and translating), transforming the traditional didactic resources, which in many cases impose an elevated cognitive charge in students, overloading their cognitive structures and eventually compromising their performance and cognitive development [12]. The AR approach allows them to observe objects of study through several angles turning explicit certain visions, that help them to comprehend the behaviors of such objects, especially when part of that behavior is explained by invisible characteristics, such as a magnetic field making a coin and a magnet attract each other. AR also allows placing an object of study under conditions that possibly would not be feasible to reproduce in the real world and observe its behavior, which would ease the perception of more generic behavior rules and, therefore, abstractions in the behavior of the observed phenomenon.

3 Advantages of augmented reality for educational ends

In relation to the advantages offered by the multimedia resources developed in AR, some characteristics considered relevant and that promote a broad acceptance of the use of these virtual environments for educational ends are: a) low cost, since investments are limited to technological development, the costs of buying several pieces of lab equipment and maintaining them are cut, as well as hiring the professionals to manage the practical activities; b) no risk to the safety and health of users, once that, contrary to real laboratories, students only interact with simulations, thus never get into contact with hazardous material, e.g. toxic gas, radiation, and electricity, that may harm them; c) user actions do not create environmental harm, instead of what may occur in real environments, in which a certain experiment may use a great amount of energy or could produce dangerous residue that may damage the environment (Gonzalez-Pardo, Rosa et Camacho [13]; Potkonjak et al. [14]; Herpich et al. [15]).

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It is possible to verify that the benefits offered by the AR multimedia elements go beyond that enable the student visualization of the reality with traditional media, e.g. videos, 3D objects, simulations, etc. It also allows the creation of context, which in the traditional ways would not be possible by several reasons, for example: AR enables the demonstration of invisible occurrences in microscopic situations in which would be impossible to view the structures of a certain element (e.g. atoms and electrons); situations that involve a natural phenomenon, such as the electric or the magnetic field; the presentation of dynamic behaviors that vary in function of one or more parameters, which hardens the plain observation for being either too slow (e.g. the atomic decay and the erosion caused by a river) or too fast (e.g. free falling objects and mechanic collisions); the exposure of internal structures that cannot be revealed without affecting the execution of a determined experience (e.g. the human respiratory system or the functioning of a heart); the simple easiness of configuring parameters in order to modify the experiment, allowing the repetition and reversion of the processes being exhibited.

Besides offering a vast array of multimedia resources, AR also presents the portability between different technological devices. In the educational area, AR has presented relevant advances, demonstrating its capacity of contributing effectively to the teaching and learning processes in many diverse areas of study, e.g. electricity [15], fluid dynamics [16], electromagnetism [17], among other areas. The capacity of using multimedia resources consists in an inherent advantage to the AR technologies, since it allows the student to interact with videos, animations and many other possibilities. This perspective encourages the multimedia learning, which constitutes by itself in a benefit in the pedagogical point of view because, according to Mayer [18], people learn better with words and images than with words alone. The author emphasizes the importance associated with the methods for projecting multimedia instructions, with the intention of improving the student's comprehension of the presented material.

4 Virtual Learning and Remote Academic Work Environment

The Virtual and Augmented Laboratory integrates the development of two modules of the AVATAR (the portuguese acronym for Virtual Learning and Remote Academic Work Environment) project [19], which has the main goal to implement ways of enabling the learning of physics by the means of a virtual lab, built in the Open Simulator platform and of a mobile AR application, developed using the Unity platform and the Vuforia framework. To accomplish this, it congregates the use of many diverse technologies that make feasible the access of its users to interactive and engaging simulations, besides innumerous didactic contents, among other pedagogical resources, with the intent to promote the development of STEM areas.

Regarding the development of formal thinking, as was established by Piaget [20], there are four periods in the evolutionary process of the human species: the sensorimotor stage (ages 0 to 2), the pre-operational stage (ages 2 to 7), the concrete operational stage (ages 7 to 11 or 12) and the formal operational stage (ages 12 and beyond). The starting and ending ages for these stages may present variations according to the characteristics of each individual and the richness (or lack thereof) of the stimuli provided

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by the environment in which the individual is inserted. Under the STEM education perspective, the theory elaborated by Piaget [21], the period involving concrete operations specifically talks about an important aspect that refers to the development of the capacity of an individual to interiorize actions. In other words, the apprentice begins to make mental operations and no longer relies only on physical actions typical of the sensorimotor intelligence. For example, if asked what is the size of a certain object, between many, the apprentice will be able to answer correctly by comparing them using a mental action, i.e., without the need to measure them with a physical action.

In the virtual and augmented labs, the student has at hand experiments capable of enticing the development of operations typical of the formal thinking (identity, negation, reciprocity and correlation) or of the higher order thinking, which allows the exploration of variables in the behavior of the experiments, aiming at the intuition of general rules that summarize the functioning of the observed processes. Students usually present difficulties in selecting the correct variables to study the consequences of their modifications. It is also hard for them to formulate hypothesis capable of being tested and, sometimes, cannot come to the right conclusions about the experiments. There is a need to offer a scaffold, a cognitive tool that can aid them to settle these issues and to propose effective and efficient learning situations.

The environments supported by technology can integrate these cognitive tools with the simulations of a virtual laboratory. This would ease the performance of the experiments with varying contour conditions and process reversibility, which would enable different results to be obtained, observed and compared, besides letting them list which elements effectively influence the results. This cannot always be done in a real context, but it can be built in a virtual scenery. In the following sections, each of the two modules of the project AVATAR will be described and presented in better detail.

4.1 Virtual Physics Laboratory

The AVATAR project is composed of educational resources capable of assisting students in the process of learning content related to the laws of physics and the phenomena and processes that occur in nature that relate to the physics principles. In order to build the virtual lab, the use of virtual worlds like the Open Simulator was adopted, which enabled the development of three-dimensional sceneries, interactive simulations and the insertion of several pedagogical objects that can demonstrate to students the occurrence of phenomena and the physics concepts to which they are entailed.

In the virtual laboratory, students are represented by avatars, an aspect that lets them play the role of a character and feel immersed in the virtual environment during their interaction with the learning objects disposed of there. Regarding the educational resources to which the students may interact during their navigation in the virtual lab, several experiments were developed with the intent of exposing the event of physics phenomena in day-to-day situations, as well as in situations found in real physics labs. As to involve students with the inherent educational aspect of the experiments interactive sceneries was built, allowing the user change the experiments, running variables, offering constant feedbacks and allowing them to observe in a clear manner the gains that the simulations can offer to their instructive formation.

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4.2 Augmented Mobile Physics Laboratory

In order to reach a bigger number of users and become broadly available in different platforms, project AVATAR was developed in two distinct modules, the first focus in the use of personal computers as a way to let students access the virtual lab previously presented. The second module, however, encompasses the use of mobile devices. Concerning this module, Figure 1 presents the architecture diagram for the augmented mobile lab, which demonstrates the most relevant actions that students can perform during the use of the mobile device application with AR resources.

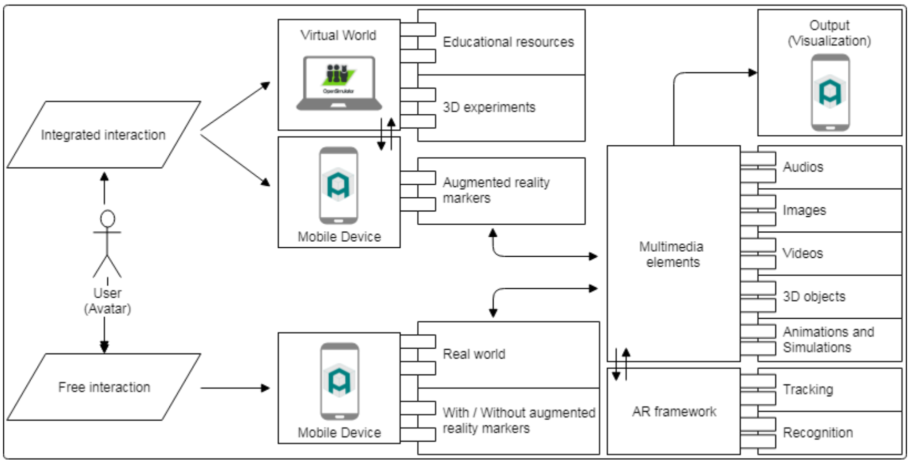

Fig. 1. AR Application Architecture

As to navigate in the AR application, the student has two interactive forms, denominated "Integrated" and "Free" (Figure 1). In the first form, when users access AVATAR's virtual lab, they will find AR markers (simple sprites in the virtual world) associated with the experiments. These markers are there with the intention of combining the virtual elements of AR with the pedagogical resources existent in the virtual lab, by simply pointing their mobile device camera (smartphone or tablet) to the marker and visualizing the educational objects (Figure 2). This process can either be done directly at the computer screen or by a printed version of the markers, which could be handed out by the teacher or found in a textbook. The use of markers is the traditional way of achieving AR, when recognized by a computational vision module, they return the information associated with that marker, which, in this case, corresponds to the physics contents. This way, the user experience is maximized, allowing it to combine the visualization of both simulations, one complementing the other.

The second interactive form amounts to the interaction of the student with the application in an independent manner (Figure 3 and 4). The users can view the educational objects on their mobile devices, anywhere and at any time, without the need to access the virtual lab. This way, the user access, and interaction are eased. This navigation form is built with the markerless AR concept in mind, which consists in the capacity of the application to visualize and perceive the real environment in which the user is in, using the mobile device's camera, gyroscope, accelerometer and other sensors, in order

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to present the virtual elements integrated to this environment, in a seamless manner.

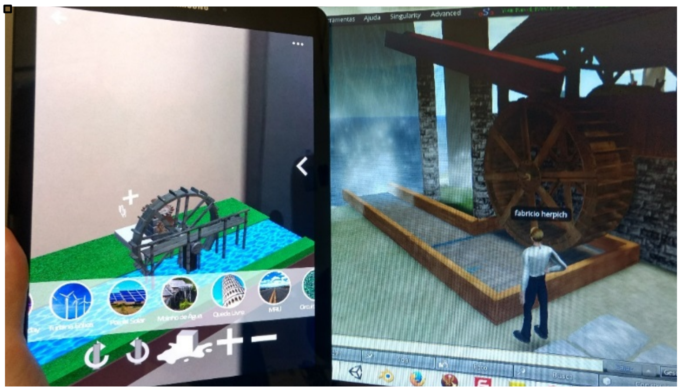

Fig. 2. Integration between the augmented reality app and the virtual laboratory

Relating to the AR application implementation to mobile devices, it was necessary to integrate different frameworks capable of providing tools for this educational solution. Therefore, the 3D Unity tool was used to implement the application and export it for the Android platform, allied with the use of the C# programming language, which allowed the definition of behaviors, via scripts, that the application executes in certain situations. Regarding the aspect that operates the AR functionalities, the framework Vuforia was used, which features a computer vision module that enables the building of interactive experiences and that presents many other resources related to AR [10].

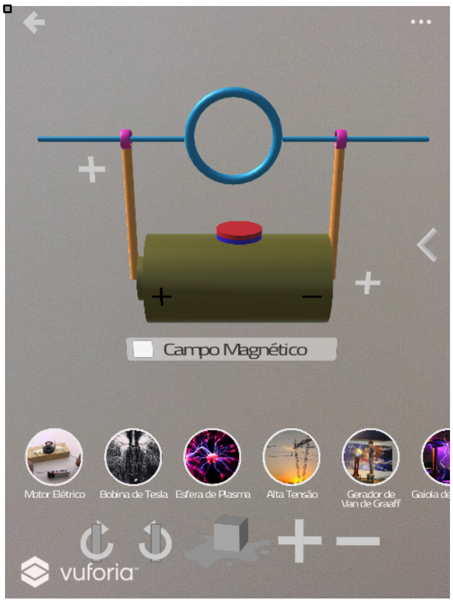

Fig. 3. Animated eletric motor

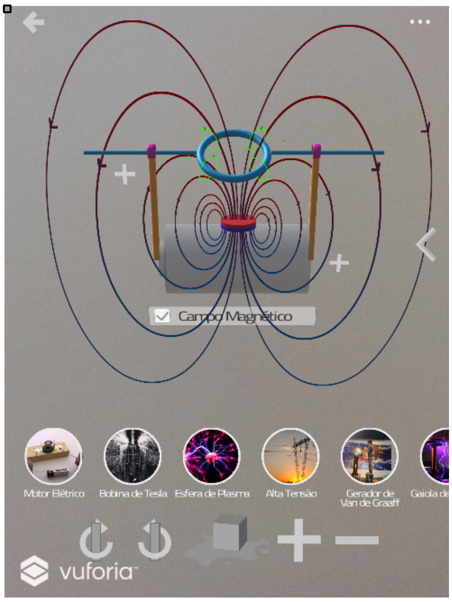

Fig. 4. Magnetic field

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In short, it is possible to list four elementary resources that the application possesses: 1) the chat related option, that the student can eventually use to start a conversation with the chatterbot (conversational agent) ATENA and resolve their questions about the physics experiments; 2) the option in which the student accesses the integrated navigation mode, where the application can be used along with the virtual lab, a textbook or even standalone markers, in order to visualize the educational resources inside a proper context; 3) the free mode, where the student can interact with the experiments without the need for markers or even accessing the virtual lab, visualizing the virtual elements along with the real world around them; and, at last, 4) a user particular inventory, that contains all of the educational resources the student selected as their favorites, with the intention of visualizing them posteriorly, away from the classroom, keeping them in their records.

The application also offers the student a feature to display notes regarding the experiment shown, clarifying the physics principles there present. Another available option consists of the possibility to share on social media screenshots of what the student is currently viewing, to save the object as a favorite, to reposition it to its original location, disposition and size and to watch videos, read and listen to audio clips regarding the experiment at hand. The student can also perform geometric transformations to the pedagogical resources, such as increasing or decreasing its size (scale), moving them around (translation) and spinning them in their axis (rotation), as to perceive them in every possible angle and size. There is, still, the “freezing object” button, which lets the user attach the resource to the device screen, allowing them to reposition it in space and, by “unfreezing” the object again, resetting its position to its new point in space, freeing it from its attachment to the screen. This option gives the user a new form of making spatial transformations, including rotation, scale, and translation.

5 Research results

Along the development of project AVATAR, experiments were done with students of several different ages and educational levels (detailed information can be found in [15], [22], [23], [24] and [25]), aiming to identify if the virtual lab could be perceived as an effective learning resource and contribute to cognitive development. Several verifications could derive from answers received from the participants (with responses between the range of 1 totally disagree and 5 totally agree) of several experiments using the virtual lab built:

An impact in the motivation and in the promotion of change of behavior in obese individuals by combining the use of the virtual world with motion capture devices and interaction with a conversational agent (Santiago, Tarouco and Reategui, [22]).

A positive evaluation of the physics lab and the equivalence of the virtual environment built in a virtual world as an effective learning resource. Through a case study was done with 32 students, the educational resources from the virtual and augmented labs in a general manner were evaluated as useful for learning and capable of expanding its users’ knowledge in electricity (both with a median score of 5.0). It was also observed that the experiments contributed to their learning (with a median score of 4.5) and that the intelligent agents supplied them with useful information (median score of 3.5) [15].

High quality perceived by the participants in the learning scope with the use of AR. Upon the performance of a case study done with 75 participants of middle school, it was possible to identify that the students understand that the virtual and augmented labs contribute to their learning of the tested subject, that it was efficient in pedagogical terms when compared to other activities done with the same subject and that it also contributes to remind them of the theoretical concepts they previously learned in the classroom (all of these factors scored a median of 4.0) [23].

Educational quality determined by educators. A validation of the AVATAR project by pre-service teachers of Science was performed, where it was observed the benefits involving this approach and its resources, demonstrating the wide acceptance and satisfaction in using the virtual laboratory, showing that the users felt motivated to use it in their pedagogical practice and believe that it can assist students in their learning process. In a more emphatic manner, pre-service teachers agreed that the presented simulations in the virtual and augmented labs were proper learning resources for teaching (average score of 4.82) and that they can contribute in the process of learning for the students (average score of 4.9) [24].

The building of a new comprehension level by integrating theoretical and practical aspects through the extended visualization offered in the virtual laboratory. Based on an evaluation composed of three sixth grade classes with 72 students, it was possible to evince that the participants considered that the simulations presented in the virtual and augmented labs assisted them to visualize the experiment in a more practical and real form (average score of 3.83, with a standard deviation of 1.26). Besides that, the students affirmed that the environment format and the visual interaction motivated their performance of the tasks (average score of 3.84 with a standard deviation of 1,18) [25].

When experiencing the expanded events enabled in a unique form in the virtual and augmented labs, the user feels that the inherent aspects of the context field being studied are relevant to explain and predict the behaviors of that phenomenon when observed in the real world. This new comprehension elicits the reason and utility of the theoretical learning. This is the most important and relevant characteristic of the logical thought in its most advanced stage, as proposed by Piaget [2].

6 Conclusion

This work presented the project AVATAR and its educational modules both for personal computers as well as for mobile devices, demonstrating the usefulness of the AR resources combined with the virtual laboratory. Aiming to provide a better learning experience for students regarding contents related to physics and its natural phenomena, the means of experiments, 3D objects, simulations and other educational resources were used.

The authors of this study have been investigating the hypothesis that, combining both technologies, virtual and augmented reality, it is possible to implement resources

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of great potential for education, where the students will obtain a benefit in their learning, once that they will be able to visualize the physics experiments and materialize the involved physics principles. These many times are not sufficiently clarified in books for the better abstraction of students. The application is also highly available, being accessible on mobile devices anytime and anywhere. This way, it is believed that, through the virtual lab and the AR application, it will be possible to contribute for the development of formal thinking in these students, especially in more practical areas, such as STEM.

In general, some contributions of the AVATAR project are: (1) improving the virtual laboratory design in 3D virtual worlds by promoting the use of intuitive and more pleasant environments; (2) increasing the attention to immersive environments and their potential use to education; (3) providing a tool for science learning and teaching; (4) easing the approach of science lessons to young students by virtual environments; (5) building a conversational agent to support students' actions in the virtual laboratories; and, (6) developing experiments simulating the occurrence of physical phenomena to aid in the development of students' formal thinking.

With the intent of improving the application prototype and making it able to be integrated to the day to day of students, regarding physics concepts, as future stages of the project, the development of new educational resources will be considered. These will aim to be combined with the innovative characteristics of the augmented reality, such as better integrating the virtual resources to the user surroundings without the use of markers and geolocated AR targets. Once finished with the development phase, tests with students using these virtual and augmented reality labs will be performed in order to find new evidence proving their capacity for the development of formal thinking in students.

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Interactive Large Structure N-Body Gravity Simulation for Immersive Learning in Virtual Reality

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Abstract. In this paper, we discuss our development and implementation of an Interactive Virtual Reality Application for Immersive Learning that simulates large stellar structure interaction. In contrary to conservative learning material, stellar structure dynamics can be understood effectively with our approach. We identified two major sub-topics, gravitational n-body interaction and the exponential decrease of the gravitational force, which non-interactive learning material cannot cover sufficiently and discuss the advantages of an interactive VR simulation. We tested a group of undergraduate students and investigated their skills regarding large stellar objects interaction prior and subsequently to the VR experience. Our studies have shown, that our immersive and interactive approach significantly adds to one's perception of Newton mechanics on large scale stellar bodies.

Keywords: N - body simulation, galaxy collision, stellar objects, gravity, VR

1 Introduction and goals

Real time n-body simulations[1] of large stellar objects like star clusters, galaxies, or objects that gravitationally interact on stellar magnitude such as black holes or quasars for virtual reality immersive learning[2,3,4,5] have recently become of higher interest due to technological advances and are challenging on several levels.

Large stellar object interaction follows gravitation with a chaotic, friction free trajectory of n-bodies[6]. To identify the mechanics for a deeper understanding, we separated it into two sub-topics: The exponential decrease of the gravitational force and n-body interaction in space. Conservative learning material such as books or movies do not provide an interactive user experiences. Written learning material cannot sufficiently display the developing of large stellar body events, due to the necessarily of having several time frames to see the trajectories and their gravitational interaction. Movies on the other side cannot provide a sense of scaling on dynamic systems due to non-interactivity: Since the gravitational force is decreasing with the square of the distance, but is also depending on the mass of the objects, local clustering is possible and such cluster interact as small closed environment inside a bigger structure. A

adfa, p. 1, 2011.

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movie does not suffice in providing the experience in understanding these local and global effects, because the user cannot investigate interactively on local and global scale, but is rather bounded to the direction of the movie creator. In an interactive environment, a user would be able to implement new objects of mass in a running simulation and can observe its behavior on the local objects as well as in relation to the whole global system (all n-bodies).
An interactive n-body simulation of large stellar objects follows chaotic rules for local objects due to the n-body problem[6]. Conclusions of events such as galaxy collisions are consequently different for each case. We concentrate on the understanding of local phenomena in a global environment as well as the stable states of large stellar structures, which tunes in in time. Consequently statements can only be qualitatively, not quantitatively. Quantitative learning outcomes must concentrate on large stellar objects as abstract singular entities, or on single star-planet interaction, not including an inner dynamic of an n-body system. Such quantitative approaches allow precise calculations of positions and impulse. We rather assess qualitative statements in understanding trajectories of n-bodies and developments of galaxy collisions on a local and global scale. Our tests on human participants take this into account.

Simulating the behavior of stellar objects requires effort in abstraction due to their gravitational interaction with all bodies of the universe, due the range of the gravitational force. Observing events of interest, such as galaxy collisions, a proper time scale[6] must be chosen. Providing an immersive and interactive experience, such as an n-body simulation must be effective in regards to real time capabilities for a virtual reality experience. Since the gravitational force weakens with the square-distance of two body of mass, rational approximations can be made to increase the simulation frame rate.

Observable stellar body activates can be star dynamics inside a galaxy and the resulting rotation speed around the galaxy center in decency of the distance, galaxy collisions and interactions with other stars or massive gravitational objects such as neutron stars or black holes. In order to understand and experience the trajectory of the mass bodies, observations in real time take usually up to several millions of years, so frame-steps must be in respect to a reasonable time scale. The rotation speed of stars around galaxy centers became of high interest since it was found, that this speed is close to constant and appears independent of the distance to the center[7]. This is an indication of more mass being present in the galaxy than can be observed and is labeled under dark matter[8] due to its invisibility for conventional methods. Providing a slider for increasing the dark matter inside the galaxy body of the simulation can be a significant tool for understanding until the rotation curve (along the radius) matches the observed data. Recent simulations of galaxy collisions of two spiral galaxies lead to a qualitative explanations of known galaxy shapes[9], to be a result of such a collision. Given two spiral galaxies with 100 million stars in average, the task for the simulation is to provide results for each frame in real time. Stellar bodies of big mass like supermassive black holes have a strong impact on the dynamics of nearby galaxies[10] and letting a user experience to be able adding massive bodies into the simulation at any

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time and place increases the immersion and the learning outcome in understanding movements of big stellar objects.

2 Setup

2.1 Testing

We tested a group of undergraduate students from STEM fields prior and subsequently to the VR experience. To assess qualitative statements of the skills of the human participants, we provide four n-body scenarios prior and subsequently to the VR experience and note the progress, see fig. 1. We asked for drawing the anticipated trajectory of the mass points as arrows in the right picture of a, b) and c) and a possible stable end state in the left picture.

The purpose of this test series is to evaluate their pre-conditions and common sense regarding gravitational n-body systems. Test a) tells how much the subject believes friction to be of a factor and how the subject interpret the gravitational force. Test b) tells if the subject is familiar with steady orbits or anticipates such. Test c) tells how the participants interpret local and global gravitation due to the indirect proportion of mass versus distance and also if the concept of no friction and steady orbits is present. Test d) is a qualitative analysis how the result of a merging of galaxies is imagined. We quantified the result of the tests with following system: For each test, a maximum of 4 points can be reached. For test a), arrows indicating an implosion (2 point), no cluster end result with steady orbit (2 points). Test b) arrows indicating a steady orbit (2 points), end result positions similar to start condition (1 points), preserving the rotation (1 point). Test c) Ring structure gets warped toward the mass point M (1 point), all ring points follow (1 point) keeping elliptical orbits in the end result (2 points). Test d) end result is merged (1 point), end result is still rotating (1 point) and end result is not clustered into a small center area, but still a large structure (2 points).

After the VR experience, we repeated the questions. Finally, we asked the level of experience in large stellar object dynamics prior to the VR experience, how the participants evaluate the VR experience to have extended their knowledge as well as grade the level of immersion.

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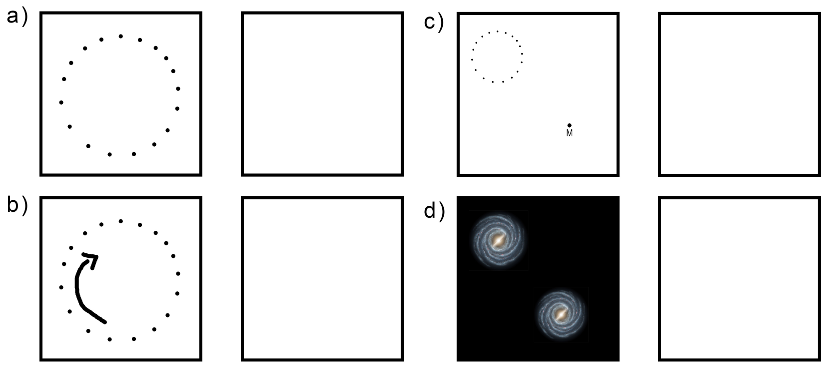

Fig. 1. Assessing the qualitative skills of gravitational n-body systems: a) several mass points of the same mass ordered in a ring structure without initial impulse. (b) The mass points similar to a) are rotating in a circle clockwise. (c) A mass point similar to a) with a mass greater than the whole ring structure is present. (d) Two spiral galaxies collide. We asked for drawing the anticipated trajectory of the mass points in the right picture of a, b) and c) and a stable end state in the left picture.

2.2 Hardware

For our approach, we are using Unity as platform, GPU compute shader for the simulation calculations, and Oculus Rift for the VR experience. Our test run on an Intel i7 with 16GB and an NVidia GTX 1080 Ti graphic card.

3 System

3.1 Methodology

Our task was to simulate interactively single galaxies and its stars movement over time, galaxy collisions and adding/removing stellar objects with a high range selectable mass.

Our galaxy, the Milky Way, has in average number $n = 10^{11}$ to 10^{12} million stars and is a spiral galaxy. Astronomy assumes that to be a typical representation of galaxies in the universe[11,12]. For galaxy collisions of two galaxies of approximately the same body, we have a lower boundary of $n = 2 \times 10^{11}$ stars.

Gravitational simulations must take all bodies of mass under consideration and consequently, without any approximations, all stars have to calculate the gravitational force to all other stars, resulting in an $O(n^2)$ algorithm. Since the gravitational force is decreasing with the square of the distance

$$F = G\,\frac{m_1 m_2}{r^2}$$

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and not linear, we cannot sum up all masses and locations to a virtual average masspoint; *F* being the gravitational force, *G* the gravitational constant, m_1m_2 the masses of the two interacting bodies and r the distance between them. Having $O(n^2)$ on 2×10^{11} stars leaves us with 4×10^{22} operations per frame and is far too much even for our system with 3840 shader units.

As discussed, the gravitational force is non-linear and consequently one cannot make cluster of mass points representing all stars of certain parts of a galaxy to reduce computational time, but the difference of calculating the gravitational force between a star and (a) a mass point or (b) all the stars represented by this masspoint is direct proportional correlated with the area of this cluster and the distance. The more distance between the star and the masspoint, the lesser the resulting error. Taking this under consideration, one would benefit greatly if the designated area of the event gets rasterized in three dimensions with several layers of resolution. Barnes and Hut[13] suggested a hierarchical approach by constructing an octree of a desired maximal resolution. Due to the computational time taken by constructing an octree on the GPU memory every frame as described by Laine and Tero[14], we decided to use buffers representing the 3D area and do the downsampling from higher resolution to lower in our code manually.

3.2 Algorithm

Every star is represented by mass (float), position (3 x float), impulse (3 x float) and an integer for having a linear list later to connect stars in one raster area, having 7 floats and one integer, 32 bytes in sum on a 32 bit system.

We have 7 raster buffers, see figure 1, where the highest resolution is 256^3 and every next buffer contains half the resolution of its predecessor: 128^3, 64^3, 32^3, 16^3, 8^3, 4^3. One buffer element contains the average mass and average position of the masspoint. Having 16 bytes for each masspoint, we need 33.5 MB for the highest resolution buffer, 4.2 MB for the second highest, and in sum 39 MB on the GPU memory for the whole hierarchical raster. To store a list of stars for later faster access of the local stars, the highest resolution buffer has 2 more integers, to hold the index of the actual star of the list as well as to the first star entering the list, needing in additional 17 MB for the first buffer.

Figure 2 shows our approach on an illustration of the Milky Way. The region gets subdivided into smaller areas.

First, we loop over all stars and map their position into the highest resolution raster, adding their mass and position to the average variables of the raster buffer. If the star entering its values to the element of the buffer appears to be the first one, its writing its index to the “first star” and the “actual star” integer. If the “first star” integer already has an entry, its writing its own index to the star “next star” integer of the “actual star” and then overwrites it with its own index.

Then we downsample 8 elements of the buffer to its next lower resolution raster buffer element. Repeating that process for all raster buffer, we obtain masspoints in all different resolutions for the given space.

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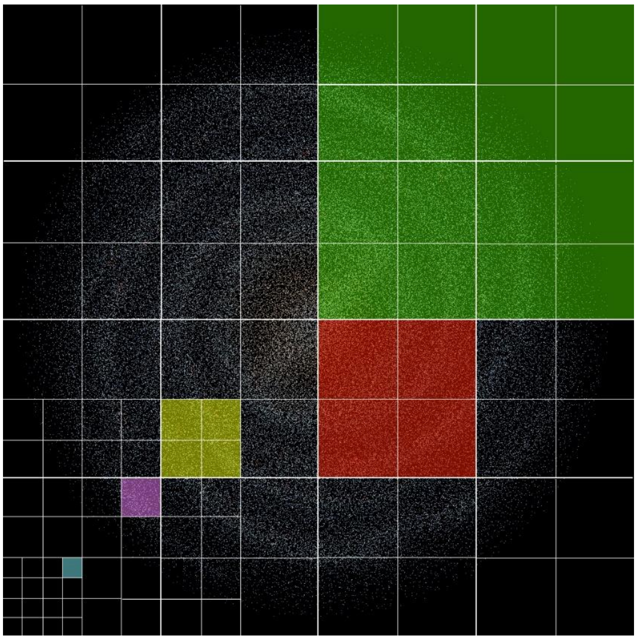

Fig. 2. We use a hierarchical raster buffer to store the average mass and position of the cluster of stars inside the raster elements on seven different levels of resolution, beginning with 256^3 elements, then 128^3 (cyan tile), 64^3 (purple tile), 32^3 (yellow tile), 16^3 (red tile), 8^3 (green tile), and 4^3 elements.

All our calculations take place on the GPU, having 3840 shader units working parallel on the algorithm.

To calculate the force on each star, we loop through all stars k in the local area of the highest resolution buffer, using the linked list we established. Then, we take all first resolution elements around the star (3 x 3 x 3 minus its own element) and repeat that process with the remaining 6 buffers, 3 x 3 x 3 - 1 operations for each, resulting in a sum of (3 x 3 x 3 - 1) x 7 + k which is in comparison with all stars of the given scenery a huge improvement.

If a star is too close to the border of the highest resolution rasterbuffer, it would only interact with the next masspoint, not with a possible close star. Such error can be corrected by increasing the amount of rasterbuffers to cover all border areas, but is subject to future implementation.

Still, 10^{11} stars are a huge computational problem, not only for computational time but also for the GPU memory. Even known dwarf galaxies such as NGC 5457 have a star amount of approximately 100 million stars, hence being problematic in real time as well.

We decided to reduce our galaxies to a maximum of one million stars, letting our stars represent small clusters of stars and believe this approach to still resemble real

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interaction of galaxies. With $n = 10^6$, we need 32 MB for the star buffer and have in average a local group of stars of $k = 3$ for one galaxy filling the entire simulation area.

3.3 Constructing the Galaxy

To construct a galaxy of stars, they need to be distributed according to observation (cluster galaxies, spiral galaxies, etc) and rotating around its center to satisfy

$$v_0 = \sqrt{G\frac{m_1 m_2}{r}}$$

which can be calculated once the positions are set, and v0 being the initial velocity in spiral direction, r the distance, G the gravitational constant and m1m2 the masses of the two stars. To have a realistic distribution, we developed a program to read from an image file and calculate possible star locations. Having a galaxy image see figure 2, we assume brighter areas to have a dense star population. Our algorithm takes the pixel brightness as well as the overall brightness of its surroundings into consideration to determine density, but also the thickness of the galaxy, see results in figure 3.

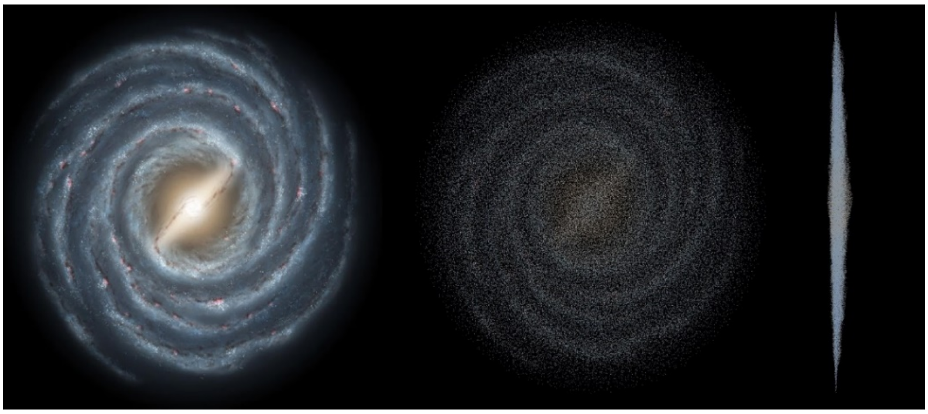

Fig. 3. On the left side an illustration of NGC 6814, scanned and after stars placed into position, the rendered 3D image of top down view is next to the right, followed by a side view of the galaxy.

4 Simulation Results

Our approach executes as timewarp and runs with a framerate of ~60 fps on an Oculus Rift. At program start, the user can choose between several scenarios involving different types of galaxies and collisions. Single galaxies or pairs of such for collision, galaxies which resembles real ones or hypothetical ones to increase the user experience such as pure spirals or rectangular shapes of star clusters.

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Inside the scene, the simulation is paused by default and the user can start/stop the simulation any time or navigating through the scene. Additional stars can be inserted and the mass of this new stars can be selected up to the mass of supermassive black holes, which are represented by a dot to leave them visible for the user.

5 VR Experience

Our test participants were exposed to 4 different scenarios in the VR simulation, each of them in respect to the subject testing prior to the VR experience. The VR experience should challenge the perception the subject had prior and stated on the test.

In the first scenario, the user experiences a spiral galaxy with an initial impulse to preserve the rotation and in consequence the steady state. This initial impulse is slowed down and the galaxy implodes. Because there is no friction involved in space, as well as the dynamic of such an n-body system, the user experiences outer stars to be more accelerated to the center due to their distance to it, resulting in greater elliptical orbits. As a consequence, in time, after approximately 30 seconds, the galaxy spiral shape tunes in again.

We repeat the simulation of the first scenario in the second one. This time, the user is asked to place additional objects of high mass (up to 10 times the mass of all stars of the galaxies) into the simulation, observing the massive disturbance of the galaxy, but also witness the development of a new spiral galaxy with several cluster in their side arms due to local effects.

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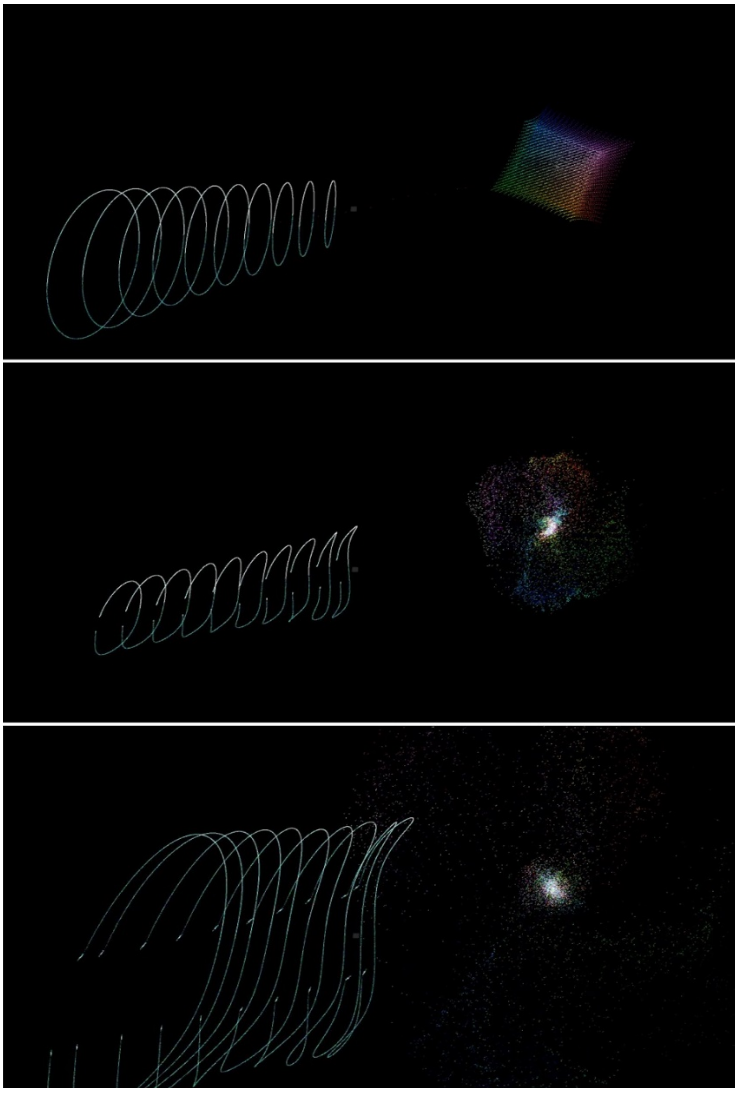

Fig. 4. Evolution of the simulation with 2 conceptual galaxies for better visualization in a two-dimensional image, from top to bottom: In the first image, we see two conceptual galaxies, one being shaped as cube with stars having no impulse, the other one as several rings with different density and masses periodically over each ring. In the next image, we can see the uneven distribution of the rings start to take effect by splitting them up, while the cubed shaped galaxy implodes. Further on, in the third image, the rings bend towards the mass of the cube galaxy while the stars of the cubed one, which started to pass the center at the second image which high speed, are still expanding, though at the center a cluster of stars concentrate.

The third simulation merges two spiral galaxies and in time an elliptical shaped galaxy with two long side arms is formed. In the beginning the two center of the galaxies

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are still preserved, but ultimately merge into one. All of this stages can be observed in the real universe as a consequence of galaxy merging.

The forth simulation bring our subject into a test room, where we present conceptual galaxies, see figure. 4. The cube shaped galaxy consists of stars without impulse and as soon as the simulation starts, the cube implodes. Due to the lack of friction and the preserving of energy, steady orbits tune in in time. Stars from the outer region of the cube get more accelerated, resulting in a big elliptical orbit around the center. Due to n-body dynamics, a rotation is induced naturally and a spiral galaxy is formed.

6 Learning Experience Outcome

After the VR experience, we tested the subject again. The same questions we used prior to the simulation were taken again for testing. In table 1, we compare the prior to the subsequent testing as well as present three additional questions.

It is clear to see, that our testing group of n=41 had a wide spread (10 : max – min) set of initial skills. Comparing that with their own assessment, we found a bandwidth of 14 (max – min) with an average far below their prior testing. We interpret that difference as assessing their knowledge based on institutional learning experience for “question 1” versus common sense and base intelligence for the prior tests.

The effect of the VR experience is overwhelming positive. The subsequent testing resulted in a bandwidth of 4 (max - min), with an average gain of 3.2 nearly closing the gap to a maximum of 16 points. We interpret this result as a success in providing an interactive learning experience to enhance qualitative skills for large stellar object interaction.

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Table 1. Results of our testing prior and subsequent to the VR experience.

n = 41	average	min	max
prior	12 (out of 16)	6	16
subsequent	15.2 (out of 16)	11	16
gain	3.2	0	8
Question 1	4.1 (out of 16)	0	14
Question 2	6.8 (out of 10)	1	10
Question 3	8.8 (out of 10)	6	10

The columns represent the average, minimum and maximum points for the tests. Row 1 represents the data prior to the VR experience and row 2 subsequently. Row 3 represents the gain of points comparing before/after the testing. The question of row 4 to 6 was: 1) My knowledge on galaxy dynamics prior to the VR experience was (0..16). 2) The VR experience extended my knowledge (0..10). 3) Evaluate the level of immersion of the VR experience (0..10). Following point system was taken: 0 … absolute no/bad, 10 absolute yes/good. 41 human subjects were tested.

Overall, the participants evaluated their gain of knowledge uniformly positive (question 2) and noted a highly immersive VR experience (question 3).

7 Conclusion and Future Work

In our work, we have shown that qualitative, immersive and interactive real time gravitational force simulation on large stellar structures in virtual reality have a significant positive learning impact. We have shown, that such simulations are possible under several approximations and abstractions on parallel algorithms for compute shader GPU. We provided a tool for constructing a galaxy from an image file and tested participants on the impact and learning outcome when interacting with our simulation, concluding that such immersive virtual reality experience has significant impact due to the nature of this field of study, being mostly taught in a static and abstract manner, given the time scale and complexity of this stellar events. There is room for further improvement to make the simulation more precise and effort will be made to include

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more stars per galaxy to match real galaxies in future. The next step is to implementing the Lorentz transformation in dependency of the speed of the user while traversing the simulation, in order to warp the perception of space according to relativity.

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The following link was used to learn how to render particles in Unity using the compute shader: https://github.com/antoinefournier/XParticle

The following links were used to learn how compute shaders in Unity work: http://www.emersonshaffer.com/blog/2016/5/11/unity3d-compute-shader-introduction-tutorial, http://kylehalladay.com/blog/tutorial/2014/06/27/Compute-Shaders-Are-Nifty.html

The camera system was modeled in reference to the following link: https://learnopengl.com/Getting-started/Camera

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Identifying Immersive Environments' most relevant Research Topics: An Instrument to query Researchers and Practitioners

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Abstract. This paper provides an instrument for ascertaining researchers' perspectives on the relative relevance of technological challenges facing immersive environments in view of their adoption in learning contexts, along three dimensions: access, content production, and deployment. It described its theoretical grounding and expert-review process, from a set of previously-identified challenges and expert feedback cycles. The paper details the motivation, setup, and methods employed, as well as the issues detected in the cycles and how they were addressed while developing the instrument. As a research instrument, it aims to be employed across diverse communities of research and practice, helping direct research efforts and hence contribute to wider use of immersive environments in learning, and possibly contribute towards the development of news and more adequate systems.

Keywords: immersive environments, research priorities, questionnaire.

1 Introduction

Even after over 30 years of educational research background, the use of immersive environments in education is not an everyday practice (Duncan, Miller, & Jiang, 2012). Although immersive technologies emerged in the 1960s, their educational use mostly started in the early 1980s, propelled by the popularity of text-based virtual words. Hew & Cheung (2010) contribute a valuable overview of knowledge in this regard.

One might hypothesize that perhaps immersive environments are not adequate platforms for learning contexts. However, research efforts addressed this concern and literature surveys have revealed a consensus: immersive technology, if applied within

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an adequate didactic/pedagogic framework is indeed effective for learning (Merchant et al., 2014).

So, if they are effective, what is causing low adoption? Lack of adoption of technological innovations in education is a widespread issue – it doesn't just affect immersive technology. As Dede (2000) already stated, "*Many research-based curriculum development projects foster a few isolated innovation sites, then disappear*." Technology adoption depends on a diversity of issues, schools being no exception. Current models, such as the revised UTAUT (Unified Theory of Acceptance and Use of Technology), deal with a combination of technical, social, and cultural aspects, such as performance and effort expectancy, facilitating conditions, attitudes, and more (Dwivedi et al., 2017). Thus, at the concrete level of immersive environments there could be issues such reliability (impacting performance expectations), the cost of providing and maintaining the educational experience (impacting effort expectancy), and many more. For instance, regarding attitudes a recent survey on one such kind of immersive environments – virtual worlds – concluded that organizations were not using them mostly because of pack mentality: looking over their shoulder they don't see other organizations using them or don't recognize the ones that do use them as being successful (Yoon & George, 2013). Many research efforts have investigated specific aspects of this issue of adopting or valuing immersive environments for learning and a relevant meta-review in this context was provided last year by Reisoğlu et al. (2017).

Our perspective is that studies that focus on such educational issues and practices have a typical shortcoming in that they envisage technology as something static. That is, educational technology as a constellation of products "as is", rather than something that has shortcomings and can change – and indeed changes. For instance, Duncan et al.'s taxonomy (2012) points out that the core research areas are learning theories, educational activity, learning environment, and population, with the supporting technology playing a minor focus – and the name itself, "supporting" technology, demonstrates this perspective of technology as something static, objectified, supporting material for activities, rather than a transformational or enabling factor. The aforementioned Yoon & George survey (2013) even reports that the technology itself does not have a significant impact in the level of organizational adoption – while at the same time failing to reflect whether the technology shortcomings couldn't be the reason for the overall lack of widespread adoption or clear success examples which are indeed identified as the main factors.

We put forward the argument that when studying educational technology from that static perspective, there will be plenty of data about outcomes and impacts of specific features of each product, but little towards potential outcomes of changing the technology itself. This argument stems from current perspectives of technology as mutable rather than static: technology artefacts as ever-changing embodiments of knowledge. Artefacts, by coming into existence, transform the overall context, thus generating new knowledge and new processes, while also changing the assumptions that originated their creation, thus originating new lines of action (Hevner, 2007).

Hence, our motivation is to assist the research community in looking at what needs to change in immersive environments, how they must evolve, to better support learn-

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ing – rather than just study their status. For this purpose, we present an instrument to identify research priorities amongst communities of researchers in immersive environments. This paper is structured as follows. First, we set the scope, by presenting the definition of immersive environments we employed. Then we summarize earlier work on the diversity of challenges for changing and adopting immersive environments in learning contexts. We proceed by explaining how we developed the instrument (a questionnaire) based on that overview; and finally, we present the final version of the research instrument.

2 What are immersive environments?

In the previous section, we associated the concept of "immersive environments" with virtual worlds, by mentioning their early text-based incarnations of the 1980s and more recent graphical environments studies by Yoon & George (2013). Many other technologies could have been mentioned – with simulators possibly springing to mind most readily, given the diversity and richness of this field of inquiry (Rosen, 2013). After all, simulators often resort to contexts where participants are immersed in the simulation. But the match isn't entirely adequate: for instance, physics simulators that provide schematic behavior representations are not immersive in the least; and conversely one simply needs to consider games where physical laws are an inspiration (at most) rather than directives, to find immersive environments which are not simulations. Videogames can also be immersive environments, and the research literature on such games can contribute to better understanding this field, but videogame research doesn't cover non-gaming immersive environments and includes non-immersive games, so again, the match isn't entirely adequate.

Rather, we find the concept of "virtual world" to be a useful proxy for "immersive environments", since "virtual world" as a concept has been subjected to many definition attempts and recently thoroughly analyzed ontologically (Nevelsteen, 2017). This stems from Dawley & Dede's (2014) perspective of virtual worlds as immersive environments "*in which a participant's avatar, a representation of the self in some form, interacts with digital agents, artifacts, and contexts*". That is, our perspective is that immersive environments are simply a superset of virtual worlds, by considering environments where a participant is not using an avatar to interact with the environment but still feels immersed, feels "present" in the environment – i.e., the participant is the avatar. If one considers immersive virtual reality, it is as if one is participating from within the avatar's body; if one considers augmented reality (or mixed reality, a term that is becoming commonplace), it is the participant's own body that is already immersed in the physical world. From the perspective of Presence research, this means we understand as immersive those environments which enable "*a psychological state or subjective perception in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience*" (International Society for Presence Research, 2000).

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Thus, we establish our understanding of immersive environments as the superset of virtual worlds and similar technological platforms, with the common ability to generate a sense of presence. In this we encompass three-dimensional virtual worlds such as Second Life, multiuser videogames such as World of Warcraft, and text-only virtual worlds such as Multi-User Dungeons, but also three-dimensional simulators and non-physical environments such as three-dimensional first-person data visualizations scenarios. In fact, since an avatar is not required, we can consider physically-expanded environments such as augmented reality or mixed reality scenarios, since we all are naturally immersed on our physical environment, which is overlaid with extra virtual content in such scenarios.

3 Technology challenges of immersive environments in learning contexts

In previous papers (Morgado, 2013; Morgado, Manjón, Gütl, 2015) arguments have been raised regarding three categories of challenges that virtual worlds face, preventing their widespread adoption: challenges of making the technology available to educational actors; challenges regarding content production techniques; and challenges related to large-scale deployment. In view of our perspective of immersive worlds as a superset of virtual worlds, as argued in the previous section, we employed those challenges as a baseline for our work. In this section we summarize these challenges.

Challenge Category 1: making the technology available to educational actors. Educational actors must be able to employ the technology that provides the immersive environments. Assuming as trivial the cases were the entire immersive content is provided via physical media, the non-trivial cases are those provided via computer networking, including augmented reality situations where the digital content is being provided over the network. The previous papers point out three sub-challenges:

a. Network architectures and features
b. Software employed by users
c. Isolation vs. interconnection

Challenge 1a) refers to the impact on educational activities (including at the organizational level) of different aspects of computer networking. One example of such an aspect is topology. For instance, client-server networking implies having to manage a central server and provide the bandwidth for each participant to reach it, which can be taxing for some scenarios such as small primary schools and non-formal educational groups; on the other hand, peer-to-peer networking does away with these issues but renders the entire experience dependent on individual participants' machines, which can be harder to manage and organize. Research is needed to identify in detail the actual impact in educational scenarios, both at the individual and organizational levels, of the various technical aspects of computer networking.

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Challenge 1b) refers to the impact of using different kinds of software to provide the immersive environment. For instance, having specialized software that needs to be installed locally raises several concerns which may or not be relevant for different educational scenarios. One such concern is whether installing the software on a participant's computer requires administrative access to it. This is trivial in bring-your-own-device scenarios but complex when an organization manages the computers. Conversely, in bring-your-own device scenarios there is a plethora of hardware configurations and software ecosystems, with associated risks of shortcomings (e.g., performance, screen sizes) and conflicts (mismatching graphic drivers, firewalling or virus detection conflicts, etc.). And from an organizational perspective, the use of specific pieces of software for immersive environments introduces an unknown element of network security and stability: what is the network behavior of that software? how can a network administrator recognize legitimate traffic? does this software opens new pathways for intruders to attack or leverage the organization's network? The previous papers pointed out two alternatives to using specialized software: using Web browsers to access immersive environments and video streaming them while uploading user interaction actions. Immersive web browsing is trending towards the use of WebGL, but its support is far from being widespread, and no research on how immersive environments behave on the Web in actual educational scenarios, regarding the issues mentioned above. As for the video streaming alternative, although a few companies started providing such services in the early 2010s (e.g., OnLive, OTOY, Gaikai, MEO Jogos), the majority has folded. Sony does provide such a service, called PlayStation Now. The scarcity of alternatives has contributed to an almost absolute absence of research results on the educational impact of this approach.
Finally, challenge 1c) deals with the isolation or connection to the world of immersed users (e.g., a class, a training session), and the impact of this isolation/connection on the educational activities. For instance, if each immersive experience is provided by different organizations/entities/software, this may require educational activities to deal with multiple login credentials, multiple sets of user settings, multiple interfaces to learn. These aspects bring with them time and support issues which impact educational activities and need to be researched: for instance, OpenSimulator+Hypergrid is a technology that enables users across different organizations to have a single login and interface for accessing the immersive environment but has been shown to have scaling and security risks (Clark-Casey, 2010), albeit these could be acceptable in some educational scenarios but not in others. In some multiuser environments, such as most massive multiuser games, the environment is "sharded". That is, multiple copies of the same environment are provided on different online servers, and users accessing one such copy (a "shard") cannot interact within the immersive environment with users accessing a different copy (a different "shard"). This is a technical solution for a technical problem (online workload of dealing with many users) but may constrain the planning and feasibility of specific educational activities.

Challenge Category 2: content production techniques. These set of challenges are related to the source of the content found in immersive environments, and whether it can be changed/provided during the educational process or not. The previous papers

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pointed out two distinct sets of challenges, depending on the level of involvement of technical experts:

a. When content is produced by technical experts
b. When content is produced by the participants in the educational process

Here, "technical experts" are not only computer programmers but also graphic designers, modelers, and all other skilled creators which can be involved in the creation of an immersive environment, possibly in concert with learning designers and subject-matter experts such as historians, physicists, or others. If the involvement of experts is high, this leads to better-crafted environments. On the other hand, it diminishes the flexibility and scope of immersive educational activities, since participants are typically focusing on experiencing whatever interactions and content was provided for them beforehand, not on creating or contributing their own.

Regarding challenge 2a), content production by experts implies its own kind of problems. Combining technologists with artists and subject-matter experts implies greater costs in human resources and management complexities, such as different methods of communicating, different goals, different expectations. For instance, Neves et al. (2010) point out that the uncertainty of carrying out communication goals is a recurring condition in videogame development. Overall, there is little research on the impact of decisions that must be made for development, such as which tools to use, what will be the actual workload, what risk may arise during content development and how they can be mitigated, or what methods can enable a project to be more easily changed during development or updated later (Anderson, 2011).

As for challenge 2b), the focus is on different issues, since content production is not done prior to the educational activities but as part of them. There are indeed tools and systems for such "user-created content", and research is needed regarding the experience of users while creating (difficulties, time, frustration or success, simplicity or complexity, etc.). And, on how different participants (teachers, trainers, students, trainees) can learn how to use the tools. Not least, research is needed on how to improve tools beyond their current state, since – as pointed out in the introductions – we must also avoid seeing tools as static technology.

One aspect of content production is considering not only traditional user-created content (3D objects, imagens, videos, single-character animations) but also more complex, interactive content that can be realized in immersive environments, such as multi-character choreographies. Further, user-created content can be interactive, not just passive, but more research is needed on interaction-development tools and processes geared towards non-experts. Instead of simply considering non-experts as unskilled creators in need of limited, simple tools, research needs to consider that expert creators are typically generalists in the application of their creations (e.g., a model can be used for a movie, a game, or an educational activity), whereas for educational actors it may feasible to use specialized tools, that acknowledge the educational context. In this regard, existing research on programming by demonstration (Lieberman, 2001) and computer-supported cooperative work (Cruz et al., 2012) may be tapped, towards new insights and solutions for complex, interactive content production by educational activity participants.

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Challenge Category 3: large-scale deployment. This third set of challenges deals with the integration and interoperability of immersive environments with the ecosystem of educational computing. For widespread use of immersive environments, one must envision them as being enmeshed in the overall computational activities of education – including educational management. For instance, can assignment progress by students be tracked in immersive environments? Can teachers readily realize where in the immersive environments students are requiring support? Can providing that support be streamlined? Can managers of entire schools, districts, or business training companies have a clear perspective of the ongoing activities? Can support staff readily identify issues and solve them? Can the specific content of immersive environments be managed alongside the content of other non-immersive educational computing systems?

These aspects have been the subject of some efforts, such as the SLOODLE project (Kemp & Livingstone, 2006), which enables access to the Moodle learning management system (LMS) from within Second Life or OpenSimulator, or the MULTIS architecture (Morgado et al., 2017), which puts forward a method for LMS interoperability with serious games and virtual worlds. Silva et al. (2014) propose defining multi-character choreographies in a platform-independent way so that can be reused in different environments and Maderer et al. (2013) propose adjusting immersive tasks automatically according to a learner's knowledge or skill level, but these are still early contributions. Considering field reports of requirements from corporate training (Morgado et al., 2016), a significant amount of research is needed to identify and define actual requirements for education contexts, prototype and test new systems, and ultimately provide educational scenarios with immersive environment solutions which are feasible for widespread deployment.

4 Developing a questionnaire for researchers and practitioners

4.1 Motivation

From the above overview of the situation, we believe that an interdisciplinary set of research perspectives is required. The close interaction between the development of technology, its organizational impacts and constraints, the way it empowers changes in educational practice but is also delimited by educational contexts and goals, all point towards a combination of research on Information Systems, Software Engineering, Educational Technology, and Educational Sciences. Other aspects still, such as network security aspects, point towards Computer Science or even Computer Engineering approaches. Improving tools for educators that are not computer-savvy may require adequate contributions from research in didactics of specific fields, from Sports Science to Biology, from Arts to Mechanical Engineering. Others fields still may contribute with significant insights into these areas, such as Communication Sciences, Anthropology and more. In view of this diversity, we aim to establish a research agenda for the community, by analyzing its viewpoint on the challenges,

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which the community may then tackle using each individual researcher's epistemological tools.

4.2 Research focus

Following our stated motivation, we seek to find out what are the perspectives of researchers and practitioners in the field of immersive learning environments regarding the relevance of the various identified challenges towards their dissemination and adoption. Further, we seek to find out whether there are challenges that we neglected to include.

4.3 Setup

When developing a new research instrument, one may resort to empirical data or on theoretical knowledge (Hyrkäs et al., 2003). To pursue the stated focus, given the lack of empirical data, we set forth from the theoretical arguments summarized in the previous section. We arranged those arguments into a tentative form of the instrument, a questionnaire where each topic is queried on relevance. We organized the topics into three sections, matching the three categories of challenges, and in each section included an open question asking for any missing research challenges.
The second phase of developing the research instrument is expert review (*ibid.*). We thus subjected the tentative questionnaire to several rounds of expert feedback. After each round, we updated it following the changes recommended by the experts, resolving reported inconsistencies and ambiguities, and clarifying any items that led to expert misinterpretation, as described ahead in the "Method" section.

4.4 Method

For conducting the expert review, we pursued iterations with researchers working in the field of immersive learning environments. Two researchers were involved (in parallel) in each iteration, whose profiles are summarized below. We have also considered the feedback from a reviewer of the initial submission of this paper to the iLRN 2018 conference as a third phase of expert review, since that reviewer reported having read the entire questionnaire and provided specific feedback on it.

Iteration 1

Expert 1. Reader at a British university, focusing on distributed systems and networking, including the behavior of immersive environments, but also on technology-enhanced learning using these systems. Google Scholar statistics: more than 150 papers, h-index 19, most cited paper with 60 cites. Male.

Expert 2. Associate Professor of Educational Technology at a North-American university, focusing on educational inclusion aspects of immersive environments, on life

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skills training for special needs populations, and art curation. Google Scholar statistics: more than 50 papers, h-index 8, most cited paper with 140 cites. Male.

Iteration 2

Expert 3. Assistant Professor at a Continental Europe university, focusing on motivational and engagement aspects of game design and development, with prior experience in the video game industry. Google Scholar statistics: more than 50 papers, h-index 8, most cited paper with 39 cites. Female.

Expert 4. Professor at a North American university, lecturing on learning design and technology and with a research focus on sociocultural aspects of online learning and entrepreneurship education. Google Scholar statistics: more than 350 papers, h-index 37, most cited paper with 346 cites. Female.

Iteration 3

Expert 5. A reviewer of the original submission of this paper to the iLRN 2018 conference. Profile not disclosed to us due to blind review. Self-reported reviewer confidence as “3 (medium)”.

4.5 Outcomes

Through the expert-validation iterations, were collected several kinds of feedback:

1. Structural - related to the visual organization of the questionnaire.
2. Context clarification - aspects which could be misunderstood by researchers from fields other than computer science;
3. Ambiguity - aspects which could lead to differences of interpretation and subsequent impact on meaningfulness of answers.
4. Missing aspects - new questions which would be relevant to ask

In the following Tables 1, 2, 3, and 4, we provide some examples of these kinds of feedback and questionnaire changes implemented due to it.

Table 1. Changes from feedback of expert feedback – Structural

Initial form and feedback	After feedback
Each question had the relevance options listed below: *This is a sample question text.* - *Not relevant* - *A curiosity* - *Somewhat* - *Very*	We organized the various questions in a table, in each section. E.g.:

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- *Extremely relevant* *This is another question text.* - *Not relevant* - *A curiosity* - *Somewhat* - *Very* - *Extremely relevant* **Feedback:** «*list these in a table format with 1-5 options across the top. This would help users to better read all of the questions in the context of the main statement*» - Expert 2	
Feedback: «The "other aspects" comment area at the bottom of each page and the "Final comments" area on page 7 should be optional, not required» - Expert 2	We made the items "Other aspects" and "Final comments" optional.

Table 2. Changes from feedback of expert feedback - Context clarification

Initial form and feedback	After feedback
Some questions had technical computing terms within. E.g.: *Multiuser interaction in immersive environments and virtual worlds is typically achieved via computer networking, either entirely as a virtual medium or to overlay virtual content on the physical medium in augmented reality.* *Network architecture and features* *The peer-to-peer (P2P) model of networking means that no main computing server (local or online) needs to be available, and that no single server needs to have the horsepower (and network bandwidth) to host the clients. It also means that the operation of the networking depends on the individual operation of peers.* **Feedback:** «*You may want to link to quick descriptions of all technical terms. I knew all of them of course, but I know some educational technology researchers who do immersive learn-*	We have rephrased the text to avoid the dense computational lingo and provided a background information section to clarify the most technical terms. E.g. *Assuming as trivial cases were immersive content is provided via physical media, non-trivial cases are those provided via computer networking, including augmented reality situations where the digital content is being provided over the network.* *Hence, we'd like to find out about the relevance of researching the impact of different aspects of computer networking on educational activities (both at the individual and organizational levels).* *Background information:* *"Client/Server" networking means that an online computer system provides the immersive content. This can be on the Internet or within a private network of a school or business. This computer system needs to*

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ing research but might struggle with some of the more technical terms. For example, client-server, peer-to-peer (...) *educational management methods, network configurations, network impact, network behavior* (...) *attack vectors* (...) *local rendering* (...).» - Expert 2 «*I am not a computer scientist, but am a practitioner and researcher in the design of immersive environments for learning (coming from a content and instructional design perspective) and the questions they are asking seem esoteric.*» – Expert 5	*have the horsepower and network bandwidth to host the devices being used by teachers/students, and enables content management at a single location.* *“Peer-to-peer” networking means that there is no main system, the immersive content is jointly shared by a community of users’ devices; there is no need for network access outside those devices (i.e., it can work for users in a room, without Internet access); it also means that the operation of the network is relying on the individual operation of each peer device (its performance, its connectivity, etc.).*
Some concepts were not immediately understood, even for experts with a computing background. E.g.: *Which educational and training uses of immersive environments and virtual worlds can be enabled by accessing them via video streaming instead of local rendering.* **Feedback:** *«We're mostly familiar with SL style of VR interaction but the streaming video model really requires an example*» - Expert 1 «*Questions are too long, need streamlining*» - Expert 4	We have rephrased and simplified the questions to make them clearer, e.g.: *Identifying learning contexts where using video streaming can render immersive environments feasible.*

Table 3. Changes from feedback of expert feedback – Ambiguity

Initial form and feedback	After feedback
The relevance options were: - *Not relevant* - *A curiosity* - *Somewhat* - *Very* - *Extremely relevant* **Feedback:** «*A curiosity might be less understandable than something like, “A little relevant”* » - Expert 1	We added the term “relevant” to each option: - *Not relevant* - *A little relevant* - *Somewhat relevant* - *Very relevant* - *Extremely relevant*
We were using the expression “Education and Training” with the intent to imply that	We replaced “education and training” with “learning contexts” throughout the question-

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the questions could apply to diverse learning situations, not just formal education, but also professional training. However, this could be misinterpreted. **Feedback:** «*I would be inclined to be careful about referring to training and education as the same thing, and where appropriate phrase the questions in such a way as to distinguish between the two. For example, Medical students spend a lot of time being "trained" whereas Biology students spend time being "educated". »* - Expert 1 «*Clarify the difference between training and education (used together on several pages). Is this an age group difference (adults vs. primary and secondary)?* » - Expert 2	naire.
The main question before each set of items was ambiguous. **Feedback:** «*The main question posed by the questionnaire "how relevant are the following aspects for setting research priorities in this area?" was difficult for me to interpret. Are they asking whether each aspect is a challenge or barrier to being able to conduct research? Or whether each aspect is a relevant area to be studied?"* » – Expert 5	We rephrased the main question, to avoid this ambiguity. It now reads: *Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?*

Table 4. Changes from feedback of expert feedback - Missing aspects

Initial form and feedback	After feedback
We were explaining about how users might use browsers or specialist applications, and asking about the relevance of research topics such as "Context of administrative access to users' machines", "The risk of software conflicts or hardware shortcomings", etc. **Feedback:** «*if the VR is accessed via a standard browser then there is no need to install special client software. Chrome and Firefox have forced Unity to improved the WebGL versions of their outputs by not supporting the Unity (or any other) NPAPI plug-in. So,one useful*	We added the following opening item to this section: *Identifying the value of being able to use standard browsers for accessing the immersive environment rather than installing specific applications.*

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question might be the value of being able to use standard browsers for accessing the VR world rather than installing specialist applications. Once that is out of the way you can certainly ask about admin access to students personal computers at home» - Expert 1	
Lack of relevant context data in the personal information section. **Feedback:** «*"Personal Information" this is very general and doesn't seek to elicit a respondent's self-perceived IT competences, in particular, familiarity with multi-user virtual environments.* » - Expert 1	We've added a topic to the section, asking "*Years of experience with immersive environments*"

5 The final questionnaire

The result of the process is a questionnaire which can be used as an instrument to query communities of researchers and practitioners on immersive environments regarding their views of the relevance of the various research topics presented, as well as collect missing topics, within the provided topics structure.

The final questionnaire is provided in full as an appendix to this paper. It will also be submitted for archival as a research instrument to the open repository of Universidade Aberta, at https://repositorioaberto.uab.pt/ under our authorship.

6 Final thoughts

Immersive environments for education are diversified and rich. The early text-only systems of the 1980s have now been replaced with graphics-intensive environments, and via augmented reality they are blending with everyday environments, hence the novel term "mixed reality". Educational adoption is however lacking, particularly if one looks beyond occasional usage and seeks to find cases of widespread, long-term use. Enthusiasts are leading the way, but widespread use requires technology to become adequate also for non-enthusiasts. Research needs to look at the technological issues from an educational use perspective, from the wide perspective of learning contexts, all the way from the individual to the organization.

With this paper, we are providing an instrument to query the research community involved in immersive learning and ascertain the relevance and priority of an encompassing set of challenges facing immersive learning environments. Hopefully this will lead to a diversity of results across varying communities and contribute to focusing research efforts. Ultimately, our hope is that the research will generate newer and more adequate technologies, rendering the use of immersive environments widespread in education, training, and other learning scenarios.

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Appendix

Questionnaire: Technological Hurdles of Adopting Immersive Environments in Learning Contexts

This survey, for which we thank you for your cooperation, aims to achieve a vision of the needs and perspectives of practitioners and researchers regarding the challenges arising from the use of immersive environments in learning contexts. Your answers will be kept strictly anonymous and will only be used for statistical and category analysis, ensuring the confidentiality of the data.
Please take a moment to complete this survey to let us know your opinion.
The estimated completion time is approximately 20 minutes.

Your contribution is fundamental for this research. Your opinion counts.

For each of the following questions, please answer according your current situation.

1 Accessing Immersive Environments

Assuming as trivial cases where immersive content is provided via physical media, non-trivial cases are those provided via computer networking, including augmented reality situations where the digital content is being provided over the network.

Hence, we'd like to find out about the relevance of researching the impact of different distribution models of computer networking on educational activities (both at the individual and organizational levels).

Background information:

"Client/Server" networking means that an online computer system provides the immersive content. This can be on the Internet or within a private network of a school or business. This computer system needs to have the horsepower and network bandwidth to host the devices being used by teachers/students and enables content management at a single location.
"Peer-to-peer" networking means that there is no main system, the immersive content is jointly shared by a community of users' devices; there is no need for network access outside those devices (i.e., it can work for users in a room, without Internet access); it also means that the operation of the network relies on the individual operation of each peer device (its performance, its connectivity, etc.).

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Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Studying the consequences for the learning context of adopting immersive environments based on client-server vs. peer-to-peer networking.					
Analysing which immersive learning environments would benefit from the decentralized storage and computational workload provided by peer-to-peer, and which would be harmed by it.					
Analysing which educational management methods for teachers, trainers, and educational organizations using immersive environments would these alternative network models imply.					
Researching aspects impacting the daily work of network administrators, such as network behaviour of immersive environments (configurations, performance impact, security, costs).					
Researching the relationship between network behaviour of immersive environments (configurations, performance impact, security, costs) and specific educational activities.					

Other aspects: ____

Still regarding access to immersive environments, we would now like to ask you about issues related to the software that is used.

Regardless of networking, users see immersive environments in software running on their devices. This software may be a commonplace Web browser or a specific application. Both alternatives have implications for home use vs. organizational use.

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Background information:

"Video streaming": some online services carry out the heavy computational task of generating 3D immersive graphics for each user and send the results as a live video, as if watching YouTube, so that even low-end devices can display high-quality graphics. User interactions are sent over the Internet to the servers, which show the outcome on the screen, possibly with a small delay.

Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Identifying the value of being able to use standard browsers for accessing the immersive environment rather than installing specific applications.					
Analysing the feasibility of requiring the use of applications that need be installed in users' or school's machines.					
Studying the risk of software conflicts or hardware shortcomings of immersive environment software.					
Identifying security vulnerabilities and tactics used for malicious exploit of these network-aware applications.					
Identifying methods to streamline installation and updating of immersive environment software.					
Identifying methods to manage, monitor, track, and debug immersive environment software.					
Studying the operational behaviour of immersive environments on Web browsers (e.g., usability, interfaces, vulnerabilities).					
Identifying learning contexts where using video streaming can render immersive environments feasible.					
Identifying learning contexts where using video streaming is not feasible for using immersive environments.					

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Other aspects: ____

Regarding access to immersive environments, we would like to ask about the level of connection between participants and resources.

The most common situation is for participants and resources of immersive environments to be restricted to a specific computer system online, managed by a single organization. However, there are also some cases where people and resources can move across immersive environments managed by different organizations.

Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Analysing learning implications of immersive environments that perform "sharding": users access different copies of the same environment, rather than being all together online, to avoid the computational complexity of managing many users in the same space or on different time zones (this is a typical situation in online multiplayer games).					
Creating/Identifying technological solutions to enable resources to be shared across different immersive environments.					
Creating/Identifying technological solutions to enable users to access different immersive environments without requiring new login procedures.					
Creating/Identifying technological solutions to enable users' virtual personas (i.e. avatars) to access different immersive environments.					
Studying scaling and security issues, at the technological level, of sharing users and resources across different immersive environments.					
Studying the relevance, for					

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learning contexts, of learning content and activities in immersive environments being tied (locked-in) to a specific kind of technology, i.e., of not being able to move them to newer technologies.					

Other aspects: ____

2 Producing Content in/for Immersive Environments

In an immersive environment, the user experiences a virtual shared space, with its own features and content, such as topography, objects, and agents (controlled by other users or by computer systems). This content provides context and features for the educational process. Its production may be done by experts in dealing with the several technologies or by the actors of the educational process themselves.

If the involvement of experts is high, this leads to better-crafted environments. On the other hand, it diminishes the flexibility and scope of immersive educational activities, since users are typically focusing on experiencing whatever interactions and content was provided for them beforehand, not on creating or contributing their own.

Firstly, we would like your viewpoints on the relevance of researching aspects related to content production by technical experts.

Background information:

"Technical experts": people with advanced skills related to content production, such as programmers, animators, artists, sound editors, etc.

Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Identifying the impact on technical workload and project risk of adopting some production tools over others (for content production by experts).					
Identifying the impact on technical development flexibility (e.g., changes, updates) of adopting some production tools over others (for content production by experts).					

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Also on content production, we would like your viewpoint on the relevance of researching aspects related to the participation of educational actors (educators, students, trainers, trainees, etc.).

Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Studying the development processes of immersive environment content by non-technical users.					
Studying the adequacy of current development tools for immersive environment content geared towards non-technical users.					
Designing training methods for development tools of immersive environment content geared towards non-technical users.					
Creating/Identifying development tools that enable non-technical users to create interactive behaviours for objects in immersive environments.					
Creating/Identifying development tools that enable non-technical users to create interactive virtual characters for immersive environments.					
Creating/Identifying development tools that enable non-technical users to define virtual characters' behaviours by demonstrating what is intended and generalizing from that demonstration.					
Creating/Identifying development tools that enable non-technical users to create choreographies of groups of virtual characters for immersive environments.					
Creating/Identifying development tools that enable non-technical users to create interactive stories with multiple virtual characters for immersive environments.					
Creating/Identifying development					

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tools that enable non-technical users to express higher-level semantics, such as “from home to work”, instead of raw data such as x-y-z coordinates.					
Creating/Identifying development tools that enable non-technical users to produce content collaboratively.					

Other aspects: ____

3 Deploying Immersive Environments

Typical education and learning contexts employ software known as learning management systems, which account for organizational structures such as courses, administrative support such as attendance records, and store educational resources and data.

We would like your viewpoints on the relevance of researching the integration of immersive environments with learning management systems.

Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Creating/Identifying solutions for tracking student progress while doing assignments in immersive environments.					
Creating/Identifying solutions for teachers/trainers to be able to identify learning support needs and provide extra resources directly within immersive environments.					
Creating/Identifying solutions for learning management systems collect student assessment data from immersive environments.					
Creating/Identifying solutions for learning management systems to provide feedback and guidance to learners directly within immersive environments.					
Creating/Identifying solutions enabling learning management					

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systems to manipulate the content of the immersive environment.					
Creating/Identifying solutions enabling learning management systems to adjust tasks within an immersive environment according to the learner's knowledge or skill levels.					
Ascertaining the sets of requirements for improving the integration of immersive environments with learning management systems.					
Creating/Identifying solutions for recording what happens within an immersive environment from the users' perspective.					
Creating/Identifying solutions for recording what happens within an immersive environment from a user-independent perspective.					
Identifying technical support staff training needs to support the deployment of immersive environments at organizations.					
Ensuring that all users within an immersive environment witness the same occurrences at the same time.					

Other aspects: ____

4 Personal information

Gender: □ Male □ Female

Age:
□ Up to 24 □ Between 25–35 □ Between 36–45 □ Between 45–54 □ Older than 55

Academic qualifications:
- □ Graduate (BSc/BEd/BA/BEng, etc.)
- □ Master's
- □ PhD
- □ Other

If "Other", which? ____

Field of expertise: ____

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Years of experience with immersive environments and/or virtual worlds:
- □ Up to 5
- □ Between 5 - 10
- □ More than 10

Research area (write none if not involved in research): ______________________

Number of research papers on immersive environments and/or virtual worlds published in the past 3 years:
- □ None
- □ Up to 3
- □ Between 4 - 6
- □ Between 7-9
- □ 10 or more

Final comments (any suggestions, clarifications regarding doubts interpreting questions, etc.): ____

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sCool - A Mobile Flexible Learning Environment

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Abstract. We present sCool, an adaptive mobile-based educational game designed for STEM education. sCool is designed as a two-fold system. The first part is designed for learners. It is a mobile game supporting modes for explorative knowledge collection and also hands-on practical learning. This part is designed to be highly flexible and adaptive to support different play styles, learning habits, as well as course programmes. The second part is designed for instructors and supports a web-based interface to create new courses and assess the learners' performance. In a preliminary study, we found that learners were engaged by this form of learning, but that different form of gameplay should be supported to engage different target groups. In a first study with teachers, the usability was rated as very high and elements such as adaptability of the course material, as well as assessment and analytics of learners' behavior, are important elements of such platforms.

Keywords: Gamification · Educational games · Game-based learning

1 Introduction

Our modern society moves very fast, and new ways of collaboration and working as well as technological inventions requires new and adapted skills and knowledge. STEM (science, technology, engineering and math) fields become increasingly important in this context. Former US present Obama emphasized the importance of STEM as it is " *[...] more than a school subject, or the periodic table, or the properties of waves. It is an approach to the world, a critical way to understand and explore and engage with the world, and then have the capacity to change that world and to share this accumulated knowledge. Its a mindset that says we that can use reason and logic and honest inquiry to reach new conclusions and solve big problems* [1]." There is, however, a lack of interest in STEM topics by students in schools and at universities [2, 3]. This situation calls for further initiatives and support from policy makers, researchers, and educators.

Our modern society has also changed how our children communicate, learn, and play. This new generation, also termed Generation NeXT, grown up or grew

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up with new technology, mobile devices, social media and video games. This environment has changed their ways to communicate, collaborate, and learn. They are seen as prosumer of information but also consume information in smaller portions. They are used to use a variety of sources and media and tend to be multi-taskers using their preferred apps on their mobile devices. Consequent, the Generation NeXT calls for adapted ways how to learn and acquire skills, such as interactive, engaging, and playful micro learning activities accessible by mobile devices [4].

The situation stated so far has motivated us to initiate a research project focusing on a mobile game for razing attention of and teaching STEM topics, in particular computational skills. Educational games and applications, however, tend to support only static content and instructors often have issues adding or changing learning content. Additionally, these games and applications often do not provide any or sufficient assessment options to gain an understanding of the students learning performance, progress, and status. An adaptive and flexible system, which is designed for instructors but connected to the application for students and supporting options such as adding, changing, and removing content, as well as learner assessment would address this issue. In the light of this, the aim of our initiative is to research, prototype, and evaluate a flexible mobile learning tool for STEM education. Thus the main contributions of this paper can be summarized as follows:

- Design and implementation of sCool, an adaptive mobile learning tool supporting different courses and play styles
- Demonstration through a preliminary study that learners experience engagement while learning with this game
- Demonstration through a preliminary study that teachers would use tools to create own courses or course items for an educational mobile game.

2 Related Work

Playing is a natural form of learning and training skills [5], which also has been transferred into the video games domain since many years [6]. Unlike other learning and training scenarios, game-based approaches incorporate aspects such as trial and error, repetition, and improvements as well as fun and reward. Mobile devices are becoming the most important tool for the younger generation [7]. This generation NeXt introduced also the trend of micro learning [8], where smaller units of knowledge are mastered in a mix of different learning activities.

There is a general shortage of STEM (science, technology, engineering, and math) graduates and a lack of interest in related topics worldwide, and in addition, there is still a big gender gap in STEM topics disadvantaging women. To overcome these issues, there are many STEM education initiatives on a national and an international level. (Murray, 2017; UNESCO, 2017). STEM education has also raised increasing attention over the last years in the e-learning domain to support a great variety of subjects, such as game-based and mobile game-based learning [9].

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Based on the situation outlined above, interest for and motivation to learn STEM topics for the generation NeXT can be raised by mobile game-based approaches, which offer small learning experiences in a highly interactive way. In one illustrative example, [10] offered a mobile learning experience to playfully acquire historical knowledge. They could show higher engagement and motivation to learn and significantly higher knowledge acquisition over 458 pupils from 20 classes. An overview of mobile learning trends in this context is given in [11].

Narrowing down to the application domain covered in the research of this paper, there are various research and development initiatives to support computation thinking and to teach coding. MITs Scratch [12] enables children create their own interactive stories, games, and animations using a visual programming language on the desktop. In a very similar way transfers Catrobat [13] the approach to mobile devices. Programmable robots can also engage children and students to learn coding and master challenges [14].

Many game-based approaches also focus on teaching computational thinking and programming. There are desktop programs, such as Robocode[4] which teaches JAVA and .NET by programming a vehicle to fight against enemies, or CodeSpell[5] which uses drag-and-drop block language the create magic spells and apply it in the game environment. Code Combat[6], a Web-based game, requires payers to type in a code in order to control the character and fight the enemies. Code Hunt [15] and CodinGame[7] are also Web-based games teaching JAVA, .NET, or scripting languages, which are optimized for desktop usage. However, most of these tools are designed as web- or desktop-applications. In order to overcome this issue, some programming games are specifically designed for mobile devices. Swift Playgrounds [8] is an iPad game for teaching the programming language Swift to control and move the character in the game. Tynker and Box Island are also games for tablets and teaching introductory computer science concepts [16]. SpriteBox[9] is a mobile game with a mixture of exploration and learning kids to code. It teaches basic principles of programming by exploring knowledge, solving logical puzzles and filling in missing parts of the code.

Video games have shown a great pedagogical potential and this is one of the reasons why there are more and more game-based learning tools. Large-screen devices are already being used by broad masses in educational purposes and these devices have enough space for displaying different types of educational content. So the majority of educational tools for teaching both basic and advanced concepts are being dedicated to desktop and tablet devices. Even though mobile devices are increasingly trending, there is an obvious lack of mobile educational tools for teaching more advanced concepts for high school and first-year university students [17]. Some existing mobile games for learning programming

[4] robocode.sourceforge.net
[5] codespells.org
[6] CodeCombat.com
[7] CodinGame.com
[8] https://www.apple.com/swift/playgrounds/
[9] SpriteBox.com

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are only based on teaching concepts of programming logic. There might be an increasing demand for more educational tools of this kind as the number of mobile users is rapidly increasing. Following, we introduce sCool. sCool simulates a real programming environment, adapts the educational content and the game difficulty to the players needs and offers a web platform for content creation.

3 System Overview: sCool

Even though mobile devices are increasingly trending, there is a lack of mobile game-based educational software for teaching more advanced concepts for high school and first-year university students. A problem which educational games usually encounter is the complexity of level creation. Instead of focusing on educational content creation, educators have to invest a lot of effort in designing every single level. A proposed solution for this problem is based on utilizing procedural content generation (PCG) algorithms for generating terrains, maps, content, and sounds. Adaptive learning and dynamic game balancing (DGB) principles ensure that both the educational content and the game are adapted to a user's ability levels. Therefore, the sCool project was created as a solution for increasing motivation and engagement of students in the age 13-19 in the fields science, technology, engineering, and mathematics (STEM). A programming course is fully implemented and was used as a case study while other courses are in the development process.

The implementation section consists of the implementation of the two main components which are the mobile video game and the web platform. The 3D mobile game was designed as a learning tool for students. It displays the educational content in a form of challenges and quizzes. It was developed with the Unity3D game engine. The web platform provides an interface for educators to easily create courses, add educational content, and track the students' progress. Educators are able to create courses with corresponding categories and subcategories for both practical and theoretical aspects. The final course represents a knowledge tree which is loaded into the game. The knowledge tree for the Python programming course consists of skills such as declaring variables, using functions, branches, and loops. Once students select a course, they are provided with lessons, instructions, and finally tasks which they have to solve. The mobile game utilizes the servers web APIs to obtain the content and afterward sends the results and the statistics back to the server. Also, the web platform provides instructors with tools for leaner analytics.

3.1 Web Platform

When creating a course, educators have to provide educational content for both theoretical and practical modes. In the theoretical mode, educators provide a lesson in the form of text and a quiz with correct and incorrect answers, while the practical mode consists of tasks which are defined by the task description and expected output values. In the first prepared course, a programming course

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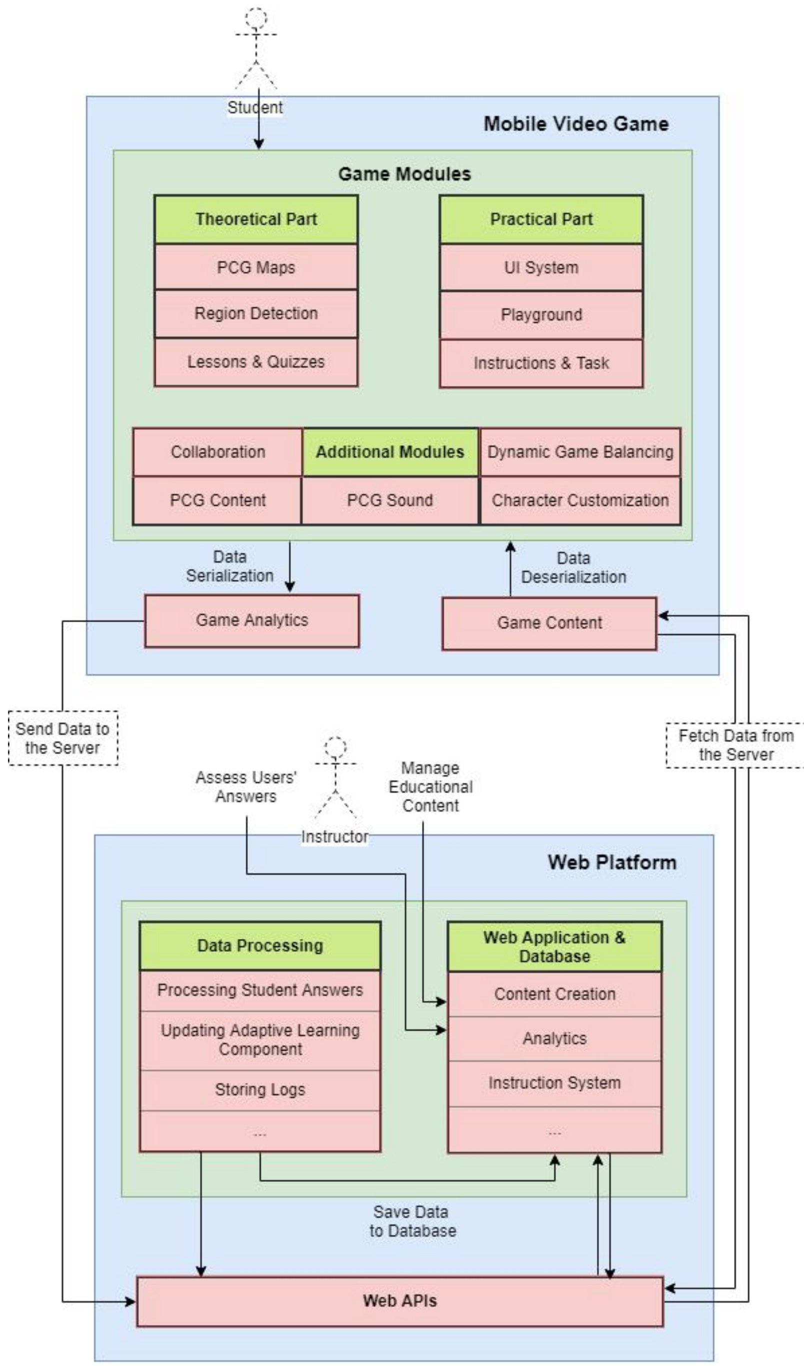

Fig. 1: The sCool game - Architecture.

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featuring Python, students are able to learn more about Python and afterward to type code, solve given task, print results to the output, and compare them with the correct results provided by educators.

The web platform is based on the client-server architecture. The architecture of the sCool project, from the technological perspective, is presented in Figure 1. Every course consists of both theoretical and practical modes, therefore, the process of learning in the game is very similar to a classroom experience. One of the main benefits of the way the content is structured in the game is that the students can see the structure of the entire course, their current progress within the course, as well as, the progress of their classmates.

The web application was built in the ASP.NET MVC web framework. Entity Framework (EF), an object-relational mapper, is utilized for facilitating the data access. By using the EF, the process of code writing was easier as well as the data manipulation. Based on the entity classes, front-end files with Razor syntax are created for generating HTML output. The implemented APIs are based on the ASP.NET Web API framework. This framework offered the Representational State Transfer (REST) interface which served as an access point for a data sent to and received from the mobile game. For serialization and deserialization purposes, Json.NET is utilized, which is a high-performance JSON framework for .NET. After the implementation process was completed, the web application was hosted on the Microsoft Azure cloud platform. A screenshot of the web platform is shown in Figure 2. There is a number of analytics tools which educators can use for tracking individual and group performances as well as to identify weak points and provide support for improving them. The analytics tools are based on MVC components and UI libraries such as Bootstrap[10], Morris.js[11], Flot[12], and others.

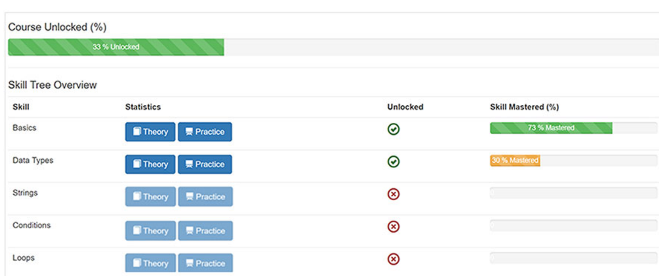

Fig. 2: The sCool web platform.

[10] https://getbootstrap.com/

[11] http://morrisjs.github.io/morris.js/

[12] flotchars.org

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3.2 Mobile Game

This section consists of the implementation of the theoretical and practical modes of the mobile video game. Both of these components require educational content which needs to be retrieved from the server and deserialized before a level starts. The purpose of the game is to help educators focusing on the educational content creation rather than a level, map, or world creation. In order to achieve that it was necessary to use PCG techniques [18].

Theoretical mode - In the theoretical mode, players have to explore maps, defeat enemies by shooting at them, pick up required pieces of information, and provide correct answers to questions which show up at the end of each level. Map structures and terrains are created based on PCG algorithms (Cellular Automata and Perlin noise) which ensure that on every run, players get a different environment [19]. Cellular Automata algorithm was used for generating cave-like shapes and making a distinction between walkable and non-walkable areas. Since generated maps were represented with matrices, it was possible to use those matrices for mesh generation and applying noise to certain parts of the maps. Perlin noise was utilized to ensure that non-walkable parts of maps are transformed into natural-looking terrains. The tree and sound generation was implemented in both modes. The final part of the procedural map generation process was to place game objects such as the player, enemies, obstacles, and pickups on the map. It was necessary to design an algorithm which goes through walkable area and searches for spots where those objects can be placed [20]. A final outcome of the map generation process is shown in Figure 3.

Fig. 3: The sCool game - PCG maps.

Practical mode - In the practical mode of the programming course, the goal is to follow instructions specified by educators, program a robot to avoid obstacles, and collect a disk placed on a map. The obstacles are procedurally created and spread out the map. Two most important components of the practical part are a UI system and an environment (playground). The UI system consists of tabs,

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code blocks, fields, virtual keyboard. Code blocks contain code snippets which generate code when dragged and dropped onto the programming area. Custom Fields were built to replace input fields, which are not convenient for typing the code as they cannot be sorted or nested. The custom virtual keyboard improves the process of typing the code and provides the majority of functionalities which one can find in default mobile keyboard. The most significant component in the playground is Python code execution. That was achieved through IronPython which provides error reporting and allows execution of Python code on the .NET platform. This means that the code which users provide has to be valid otherwise they get an error (see Figure 4)

Fig. 4: The sCool game - programming tools.

Dynamic Game Balancing (DGB) - In both theoretical and practical modes, DGB principles are utilized in order to keep players in the flow channel where the game is neither too challenging nor too easy. Therefore, a DGB approach of Hunckie and Chapman[21] is used. This DGB approach is utilized in a way of adjusting game parameters such as health points, damage value, attack speed, number of enemy units, map size, and other parameters based on the player's progress. If a player is not performing well, then a map becomes smaller, the number of enemies is decreased, and other parameters become respectively adjusted. The procedure is similar to the opposite case as well to avoid boredom and keep players engaged.

4 Evaluation

The system sCool was evaluated in a two-fold study. The first part of the evaluation focuses on testing the mobile game application with students to measure engagement and observe the interaction with the application. In the second part of the evaluation, the web-based tool to create new courses is tested with the target group (teachers).

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4.1 Part 1: - sCool for Learners

The educational mobile game was designed for students. The game was designed to generate a high level of motivation and engagement. Thus, this first study was designed to gain insights into the learners' overall engagement and the usability. The learning efficiency was not evaluated in this study.

Methodology and Participants. 12 (2 female) students between 16 and 20 (AVG=18.5; SD=1.24) were recruited to participate in this study. All of them were students from a high school or in their early years at the university. First, they were asked to fill out a pre-questionnaire with the focus on gaining information about their prior experience with educational mobile games and mobile games in general. After that, they were asked to interact with the game. In a post-questionnaire, the learners' were asked to answer different questions with a focus on getting a deeper understanding of their motivation and engagement. The questionnaire included open-ended questions as well as the standardized questionnaire Game Engagement Questionnaire (GEQ) [22]. The Game Engagement Questionnaire (GEQ) is designed as a scale to measure emotions and psychological states important for engagement such as flow, absorption, presence, and dissociation. 16 questions on a Likert scale between 1 to 7 (7 highest) are used to assess these states.

Results. Most participants mentioned that the liked the gameplay. 58% said that they strongly agree that the gameplay was easy to understand. *I am amazed by animations and the overall design. Its easily understandable and appropriate for the audience. By completing a level youre falling deeper and deeper into the world of programming.* Most users mentioned that sCool is a good supplement to regular learning (M=6.0; SD=1.3) and also mentioned that they've learned something new when using sCool (M=5.5; SD=1.38). sCool was also noted as a tool to make learning more engaging (M=5.58; SD=1.24). We used to GEQ to measure engagement based on flow, presence, immersion, and absorption. Absorption was rated with a mean of 1.87 (SD=0.84), flow with 2.38 (SD=1.03), presence with 3.25 (SD=1.22), and immersion very high with a mean of 3.25 (SD=1.22). As this game is designed as a casual-game supporting shooting activities with a gun, we were interested in the perception of the violence in his game. 9 out of 12 mentioned that it is not too violent, 2 agreed, and one was undecided. This part of the game design is definitely a strong factor for future improvements and further discussions.

4.2 Part 2: - sCool for Teachers

The web-application was designed for the target group "instructors and teachers" to support them in creating new courses and adding and editing course content without prior programming skills. Thus, the tool was evaluated with a focus on usability.

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Methodology and Participants. The web platform is mainly designed for high school and university instructors. They are able to create new courses and course content with this tool. For this evaluation, 10 (2 female) instructors from different universities were asked to evaluate the tool. All of them were already familiar with e-learning tools and the majority of them (60%) had no experience, the rest a little experience with an educational mobile game. In the first step, participants were asked to interact with the web application. After that, they were asked to fill out a questionnaire. The questionnaire was designed with a focus on identifying usability issues and learning how participants learn the new software. The questionnaire included open-ended questions, as well as the two standardized scales (1) System Usability Scale [23] and (2) Computer Emotion Scale [24]. The total duration of the evaluation was 20-30 minutes. The Computer Emotion Scale (CES) [24] is a standardized questionnaire to gain information about the emotion of the users while interacting or learning how to interact with the new software. Thus, the feelings anger, anxiety, happiness, and sadness are measured. These feeling are rated on a scale between 0 and 3. The System Usability Scale [23] is a standardized questionnaire to gain information about the usability of the system. The 10-item questionnaire is based on a 5 point Likert scale and results in a final score in the range of 0-100.

Results. The main emotion described by users was "Happiness". On a scale between 0 and 3 (3 as the highest) the average rating for happiness was 2.08 (SD=0.8), for sadness 0.05 (SD=0.16), anxiety 0.1 (SD=0.24) and anger 0.1 (SD=0.22). The usability was rating very satisfying with a total average score of 84.24 (SD=8.34). The participants were overall excited about the tool and saw the potential for using it as a tool to create own mobile courses for students. This was also expressed by the participants: *"It's an easy and straight-forward way for educators who are not technically trained to use serious games"*. The majority of the participants would also use it in their own courses. However, they would also prefer to have even more options to analyze the students' interactions with the game (more advanced analytics). While the overall rating of usability of the system was very high, we also want to express the strong limitations of this study due to the small number of study participants (10). Also, participants were not required to create courses and course items, which are required for their own courses. To summarize, this study was designed as a preliminary study to gain an overview of the current state of the platform and does not replace a large-scale study. However, it already shows the potential and also the demand for such tools for creating educational game-based courses.

5 Discussion and Conclusion

The goal of the design and development of sCool was to provide a first prototype of a game-based mobile learning application, which can be used by teachers to create and adapt course material based in the own course content and use and transmit it to a playful and entertaining environment (an educational game)

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without any development or game design skills. In this paper, we have introduced the design and development of such as system and also presented a first study to evaluate both parts: first, a playful application, which is designed with game design strategies to engage learners to explore theoretical concepts and train these concepts in a practical part. Second, a web-based tool to enable teachers to add and edit learning content which feeds into the game application. The game application was designed with a focus on engaging and immersing learners into the playful learning experience. The web-based application was designed with focus on user-friendly design to engage teachers to use this tool.

We evaluated both parts in first user studies with the two different target groups (learners and teachers). In the first study with the mobile game application, we were able to show the potential of such playful applications to learn and especially engage and immerse learners. Almost all study participants think that such an application is a good supplement to regular learning and they also mentioned that they learned something new when using this application. Immersion and engagement were both rated as high. However, is was also mentioned that this game only supports a shooting-based gameplay and some thought it might be too violent. For future developments, we plan to include different sorts of gameplay, which are less violent and also attract different target groups. In the second study, we evaluated sCool for teachers with a focus on measuring usability and gain information about how users interact and learn this new software. The usability was rated with a total SUS score of 84.24 as very high and educators, which were also less trained in the use of such applications were able to use it. They especially appreciated the possibility to analyze and assess the students' interaction with the questions and the system. However, it was also mentioned that they would require more assessment and analytics features for a proper student assessment. Even though both studies were limited due to the small number of study participants, these first results demonstrate the potential of this application for both learners and teachers and also show the necessity of creating playful mobile educational tools, which are designed for both target groups in a classroom.

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The accuracy of the vague and the lightness of the weight in VG as a sample of Minor Poetry

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Abstract. Maybe we do not assume or assume with some doubt the idea that gaming will save the world, as Asi and Parker suggest referring to social games. But we cannot surely accept the assumption that Video Games cannot be a form of Art (while wondering whether Art can even be defined and also whether its definition is even needed). The famous Italo Calvino's *Six Memos for the Next Millennium* can offer some strong paradigms to endeavor to outline a first analysis of their poetics. Also Leopardi's *Theory of Poetry* offers an interesting element we consider: in his opinion nothing in itself is so poetical as the V*ague*, not to be confused with vagueness of expression. So, the main idea that permeates these short pages is that Video Games certainly have social, cognitive and many other affordances, but that what justifies the increase in their use could be their ability to generate images from images, and to live even with immersive mode all the elements that make up the material/stuff of poetry from the dawn of time: Lightness, Quickness, Exactitude, Visibility, Multiplicity and Vagueness. The one of them that first sets up images seems to be accurate lightness of software supported by the accurate weight of hardware: it allows her to be not mere surface but deep space affording also the new territories of the digital sublime arousing from two of the four axes on which to place games according to Caillois historical groundwork: *ilinx* (vertigo) and *alea* (chance).

Keywords: Accuracy, Caillois, Calvino, Lightness, Minor Literature, Poetry, Propp, Sublime, Video Games, Visibility.

1 Introduction

According to a recent (2016) report of ISTAT (the Italian National Institute of Statistics), less than half the population in Italy reads books. And moreover, reading books in leisure time is falling sharply. 3 million and 300 thousand readers have been lost from 2010 to today. It is a relevant phenomenon that cannot be overlooked. On the other hand we are witnessing a general increase in the sale and use of Video Games.

Seventeen percent of Americans from the USA in 1992, had read a work of poetry at least once in the past year. That number 20 years later had fallen to 6.7 percent, by more than half. Those numbers come from the national Survey of Public Participation in the Arts (SPPA 2015), a massive survey that's run every few years as part of the Census Bureau's Current Population Survey. "Since 2002, the share of poetry-readers has contracted by 45 percent, resulting in the steepest decline in participation in any

adfa, p. 1, 2011.

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literary genre" the study concludes. Over the past 20 years, the downward trend doesn't show signs of abating. So, if the internet has made poetry more accessible than ever, some numbers reveal that since 2004, the share of all Google searches involving "poetry" has fallen precipitously (fig. 1). Today, poetry searches account for only about one fifth of the total search volume they accounted for ten years ago. It may be interesting to try to understand if people simply do not love poetry books, but love poetry and they look for it elsewhere, for example in Video Games.

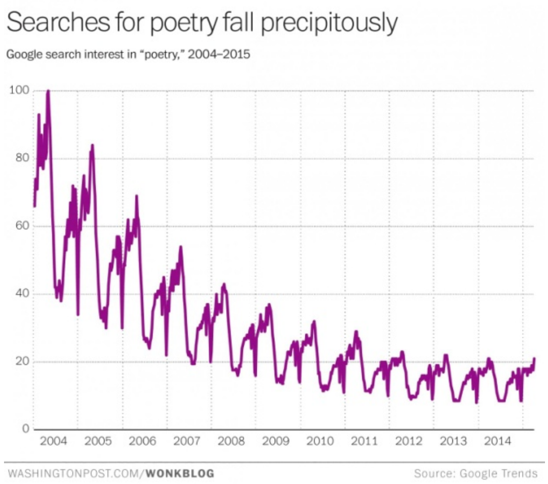

Fig. 1. Google search interest in “poetry” from 2004-2015.

2 Video Games as a form of art

The positions of scholars, academics, writers and mere observers on role, function and dignity of Video Games are still very different and so to speak magmatic. For instance, Asi and Parker’ *Power Play: How Video Games Can Save the World* (2017) highlights case studies of Video Games released over the past 20 years whose purpose was to promote social change in a variety of areas. Co-written by the former head of Games for Change, the stories presented in this book make a strong case for the growing belief that Video Games can be a force for good in the world.

In 2006, at the Conference on World Affairs entitled "*An Epic Debate: Are Video Games an Art Form*?" Ebert stated that Video Games don't explore the meaning of being human as other art forms do. A year later with a kind of half-palinodia he wrote: “A year or so ago, I rashly wrote that Video Games could not be art. (…). Of course, I was asking for it. Anything can be art”. Probably this dispute has no solution, since others, for example Thomas Bets (2014) in his doctoral thesis at the University of Huddersfield, *An Investigation of the Digital Sublime in Video Game Production,* even speak of Computational Sublime: “Therefore the concept of the computational sublime is introduced – the instilling of simultaneous feelings of pleasure and fear in the viewer

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of a process realized in a computing machine. A duality in that even though we cannot comprehend the process directly, we can experience it through the machine – hence we are forced to relinquish control. It is possible to realize processes of this kind in the computer due to the speed and scale of its internal mechanism, and because its operations occur at a rate and in a space vastly different to the realm of our direct perceptual experience". Bets's interests lie in the margins of flow and control; he also observes that it is interesting to see how Huizinga and Caillois examined states of order and disorder in game play. He writes: "Huizinga and Caillois are important to my research because they established the idea that games could be transformative events. Games can take the player out of the mundane world and into seductive virtual space (the magic circle) where the battle between order and disorder might give way to a sublime experience". McCormack and Dorin envisage the computer as the ideal tool for exploring the new territories of the digital sublime arousing from two of the four axes on which to place games according to Caillois historical groundwork: *ilinx* (vertigo) and *alea* (chance).

Furthermore, it seems still not well defined if Video Games can be placed in the wide field of narratives even though stories are important mainly in the ones of them with a pronounced narrative intention. In addition, the elements of play and multiplicity of their narrative makes it difficult to analyze them with traditional critical paradigms, because of the particularity of the elements that make them up, because of the copious presence of paratextual affordances and because the textual artifact of the game is substantially contained in the player's experience. Maybe they are a Minor Narrative (also a Minor Poetry?) according to Deleuze and Colebrook (2001) since they do not appeal to a standard but create and transform any notion of the standard. On the other hand, Deleuze and Guattari would observe that any great literature is a minor literature, deeply refusing (also in its "rhizome") any already given standard of recognition or success. It has in its DNA the bent to transform into something else and in addition contains the seeds of a collective (political?) enunciation.

Minor Poetry, we said. So, focusing on poetry, how is it? What is its current condition? Also, to these questions it isn't easy or immediate to answer, but some indication can be returned. It could be said that it has been at the same time marginalized and is in turmoil. From the revolution of the free verse onwards, everything conspires to the multiplication of styles, techniques, procedures. The truth, perhaps, is that the inherited structure of the poetic forms was in crisis, we cannot go back. But we should remember that poetry is the only art that has changed its medium of transmission, passing from orality to writing: this is a huge thing and it is changing again. At this moment in fact we are witness of the return of orality, in the sense of secondary orality encouraged by electronic media (Ong, 1982).

So, the main idea that feeds these short pages is that Video Games certainly have social, cognitive and many other affordances, but that what justifies the increase in their use is its ability to generate flowing between order and disorder, wandering between accuracy and vague, eliciting images from images, and to live even with immersive mode all the elements that make up the heavy and light material of poetry.

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Maybe the well-known Italo Calvino's *Six Memos for the Next Millennium* can offer us a good compass or, better, some strong paradigms to confirm not just their artistic but, more, their poetic status.

3 Calvino's six memos

When Italo Calvino was offered the 1985–1986 term of the prestigious Charles Eliot Norton Professorship of Poetry he wrote that his confidence in the future of literature consisted in the knowledge that there are things that only literature can give us, by means specific to it. So, he outlined six of them, beginning with Lightness, perhaps, in his mind, the most poetic and gentle of all. The others were Quickness, Exactitude, Visibility and Multiplicity. He died before completing his memo on Consistency. Looking back on his own forty years career Calvino observes: "My working method has more often than not involved the subtraction of weight, sometimes from people, sometimes from heavenly bodies, sometimes from cities; above all I have tried to remove weight from the structure of stories and from language. I have come to consider lightness a value rather than a defect". This is the reason why we start from Lightness.

3.1 Lightness

Calvino's analogy, which better illustrate the gist of lightness, is Perseus avoiding direct eye contact with the head of Medusa while still wielding its power to turn his foes into stone. Let's note that in his intentions the starting point is not the analysis of the myth to classify the old heroic narratives in mythology like in Joseph Campbell's seminal work, *The power of Myth* (1988): we mean the well-known monomyth theory whose flexible structure is useful to both players and designers. This theory surely offers a solid framework to analyze narrative Video Games as has been shown by Carli Wrisinger in his *"Link"ing Monomyth and Video Games: how The Legend Of Zelda connects myth to modern media* (20014). As we will understand beyond Calvino access the myth with other aims. He who flies with winged sandals, Perseus, is the only hero able to cut off Medusa's head: he does not turn his gaze upon the face of the Gorgon but only upon her image reflected in his bronze shield. To cut off Medusa's head without being turned to stone, Perseus is supported from the very lightest of things, the winds and the clouds, and fixes his gaze upon what can be revealed only by indirect vision, an image caught in a mirror. Medusa's blood gives birth to a winged horse, Pegasus, and the heaviness of stone is transformed into its opposite: lightness. With one hit of a hoof on Mount Helicon, Pegasus gives rise to a source where the Muses drink. When his enemies are about to overwhelm him, he just has to show it, holding her by his sinuous strands, and this bloody booty becomes an invincible weapon in his hand. It is a weapon that only uses in cases of dire necessity, and only against those who deserve the punishment of being transformed into statues. "Here, - Calvino remarks - certainly, the myth is telling us something, something implicit in the images that can't be explained in any other way. Perseus succeeds in mastering that horrendous face by keeping it hidden, just as in the first place he vanquished it by viewing it in a mirror.

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Perseus's strength always lies in a refusal to look directly, but not in a refusal of the reality in which he is fated to live; he carries the reality with him and accepts it as his particular burden".

Lightness: the "prophet" of software.

Gambardella (2015) in *Profeti della software culture* observes that Joyce, Rilke and Calvino seem to have anticipated our "numerical humanism", in which digital media dominates and writing tends to coincide with orality. But it is precisely in this solid linguistic hybridization that all the skills of literature are preserved. Calvino himself introduces to the idea of hardware and software: "In the boundless universe of literature there are always new avenues to be explored that can change our image of the world. But if literature is not enough to assure me that I am not just chasing dreams, I look to science to nourish my visions in which all heaviness disappears. Today every branch of science seems intent on demonstrating that the world is supported by the most minute entities, such as the messages of DNA. Then we have computer science. It is true that software cannot exercise its powers of lightness except through the weight of hardware. But it is software that gives the orders, acting on the outside world and on machines that exist only as functions of software and evolve so that they can work out ever more complex programs. The second industrial revolution does not present us with such crushing images as rolling mills and molten steel, but with "bits" in a flow of information traveling along circuits in the form of electronic impulses. The iron machines still exist, but they obey the orders of weightless bits".

So, it seems that we can deduce that Perseus's task is the task charged to artists: it is to acknowledge the weight of their content and to create the desired effect but without an obvious confrontation with the material. This could refer also to the hardware that game designers are called to challenge: they have to accept the burden of programming language, treat it gently and make it affordable, like the fine grace of the coral touches the savage horror of the Gorgon. And why not thinking to the weight of natural body and anxiety that players can leave, diverting their sight to lighter images while playing? Once again let's listen to Calvino's words: "Whenever humanity seems condemned to heaviness, I think I should fly like Perseus into a different space. I do not mean escaping into dreams or into the irrational. I mean that I have to change my approach, look at the world from a different perspective, with a different logic and with fresh methods of cognition and verification". Of course, Calvino's thought should not be forced: in fact, he doesn't mean that when people have problem they have to escape in virtual reality: but actually, they do it. Like other people, when they are in troubles, find solace in reading poetry, just because it may give lightness to weight. Nevertheless, the *anguiferum caput* (the snake-haired head) sometimes transforms into stone, holding back in its coils and turning in aholic the ones that look at it; but more often it happens that it turns itself into the elegant beauty of coral: and its horrible weight fades like nightmares in dreams.

Lightness in motion.

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Calvino explains that a work must be light “in the highest degree,” it must be “in motion” and it must be “a vector of information”. Motion refers to the progression of the plot and to the outlook the reader takes on throughout the text, and lightness of motion relies on abstraction and allusion to the subtext containing these changes. A vector implies that motion in a single image radiates all the story. To give an example of this concept Calvino uses the character Guido Cavalcanti, from Boccaccio’s *Decameron*, vaulting over a tombstone: this implies that the heaviness of the fear of death does not limit the protagonist’s enjoyment even if he is deeply aware of his own mortality. With all evidence Video Games in their ontology satisfy this criterion of being in motion regardless of the function of the game. Their space is not a merely geometric space, but a space "that lives on the movement of the user's body" (Diodato, 2005) with or without a purpose. In an interesting post in Gamasutra (2014) Oscar Barda game designer, head of *Video Games at La Gaits lyrique*, director of the Them Games studio, and theoretician of Video Games speaks of movements in Video Games; *“*Justwalkingism” he says “is an art movement dedicated to start game design anew: to strip games of the clutter of mechanics that hinder the player’s relation to the world. To seek a deeper and more meaningful journey by pacing games and allowing the player to sip inside the space through forgetting goals and assertions of dominance”. It is a sort of autotelic wandering that evades the heaviness of life and its constraints. Not to mention the flight, a reaction to the weight of living in folk tales: the search for lightness as a flight to another world is a common occurrence. Propp in his *Morphology of the Folktale* (1968) lists a great number of examples of the hero flying through the air: on horseback or on the back of a bird, in a flying boat, on a flying carpet, on the shoulders of a giant or a spirit, in the devil’s wagon.

3.2 Accuracy and the Vague

Lightness for Calvino goes with accuracy, not with vagueness and the haphazard. In fact, Paul Valéry said: “Il faut être léger comme l’oiseau, et non comme la plume” (One should be light like a bird, and not like a feather). Calvino adds: “One might say that, in Newton’s theories, what most strikes the literary imagination is not the conditioning of everything and everyone by the inevitability of its own weight, but rather the balance of forces that enables heavenly bodies to float in space”. On the other hand, according to Leopardi in *Zibaldone* poetry aims to producing the effect of the vague. What is clear, precise and definite is not so appealing as its opposite. It is the very nature of illusion, mainly poetic illusion that should produce in us the sense of vague. Are the two instances conjugable? And how? Through the accuracy of coding and the vague? The vague instilled by both vertigo which consists of an attempt to momentarily destroy the stability of perception and chance as a sort of passivity and randomness? Could we consider this conjugation a sort of digital sublime according to Bets? He notes that’s the digital sublime exhibits the same core features of its non-digital counterpart and represents a point where human comprehension cannot keep pace with the subject's apprehension of concepts or experience. In other words, the sublime occurs when the subject is faced with ideas or phenomena that are beyond their power to process or determine, i.e. they are light and vague even if supported by the exact accurate calculus

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of software and the strong weight of hardware. So, when the elements of a digital experience such as autonomy, abstraction, permutation or complexity become undeterminable by the subject the gap between apprehension and comprehension gives rise to the sensation of the digital sublime. In his thesis, in fact, both chance (in terms of permutation) and vertigo (in terms of overwhelming audiovisual stimuli) are potential triggers for the digital sublime. Although Caillois refers to physical or sensory activity as the stimulus for *ilinx* (the dance of the dervish, the rollercoaster), he extends the idea of chaotic play into the space of the digital sublime.

3.3 Visibility

Calvino defines himself as son of the "civilization of the image": this is the reason why he proposes the strategy of visibility as the starting point to access the linguistic and literary forms, because they are the translation of imagination into the universe of sensible forms. He distinguishes "two types of imaginative process: the one that starts with the word and arrives at the visual image, and the one that starts with the visual image and arrives at its verbal expression".

So Calvino thinks to imagination as a tool for knowledge, with the rational and analytical intention that is implicit in science. But for him imagination is also closer to the sphere of art products where styles and traditions are mixed and blurred in a common and shared "participation in the true of the world". Calvino identifies another aspect, "a repertory of what is potential, what is hypothetical, of what does not exist and has never existed, and perhaps will never exist but might have existed". From this we can understand how he has foreseen what has been raised by the advent of virtual and augmented reality, the current stage of imagination carried by technological tools, which has found tremendous expressive forms in contemporary visual culture dominated by the digital image. This is completely clear when he writes that imagination is "a kind of electronic machine that takes account of all possible combinations and chooses the ones that are appropriate to a particular purpose": it seems he is describing the processes of a software when generating digital images, a "gulf of potential multiplicity" for their true nature, because they can carry out the link between imagination and visualization.

4 Conclusion

Surveys show the current decrease in the ability of people to understand what is read and also the decrease of reading practices; this reduction increases if referred to poetry. It does not seem out of place to suppose that people have abdicated to it, but we prefer rather think that they recover poetry through other means and in new spaces: the listening to the roving rhapsods and the attendance of the written page are perhaps even replaced by the Video Games, whose use is significantly increased. They, despite their different functions and graphics, provide users with elements that humanity has always needed: experiences and images (visions) that lighten the weight of life and the matter without denying it; the vague, in the movement understood as repetition, digression and wandering; the sublime as tension and challenge to reach an exactness guessed and

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never completely grasped (embraced). So, lightness, accuracy, vague, wandering, visibility can be conjugate from people choosing to play Video Games; maybe they also combine reading, maybe not. What seems sure is that they anyway experience art in the form of poetry in its most intimate power to generate images by wandering lightly between them with exact vagueness.

So when the gamer feels that the world is turning into stone, a slow petrification (more or less advanced depending on people and places but one that spared no aspect of life), he tries to escape the stare of Medusa and enters unawares the space of poetry: he embodies the space of the Video Games that generates and sustains its lightness assuming the weight of the material that composes it, physical weight, energy of bits but also memory and cognitive conceptual mental weight of ideation and composition. There hardware is the heavy face of the lightness of the flight.

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Building Human-Scale Intelligent Immersive Spaces for Foreign Language Learning

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Abstract. Immersive technologies (e.g., human-scale immersion) especially augmented with Artificial Intelligence (AI) have been sparingly used to teach foreign languages. This work discusses an AI equipped immersive room to teach Mandarin Chinese and, by doing so it brings two perspectives together - the pedagogy of foreign language teaching and the technology that has been built to support its goals. We therefore have translated specific teaching outcomes and requirements of foreign language learning into technology problems and brought forth a Cognitive Immersive Room (CIR) - a human-scale immersive room equipped with an AI Agent to teach foreign language. We have discussed a pilot study with 16 college student participants to show its usability and explore ways of how the room could be used as a part of the foreign language curriculum.

Keywords: Immersive Learning · Chinese as a foreign language · AI assisted learning.

1 Introduction

The use of immersion in teaching foreign languages is highly praised. We define virtual immersion for our context as visual, cultural and linguistic. It is enabled with multi-modal interaction in its input and output (e.g. Speech and gesture for input. Audio-visuals for output). One can imagine the use of a context-rich environment, giving users the feeling of almost being in a foreign country, as they practice their foreign language in a natural way and complete meaningful tasks.

In this work, we elaborate on a 360 degree human-scale panoramic display that is equipped with a virtual AI agent who can "see", "hear" and "talk" to its occupants (students in this case). We have aimed to build an experience that is as close as possible to traveling to a foreign country and allowing students to practice their spoken conversational skills. However, building the experience of living in a foreign country is not enough for this use-case until the AI Agent can actually aid language learning. We thus describe the functions in this room, and how they specifically target requirements and outcomes defined by task-based

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language learning pedagogy, yet keep the experience natural. This work therefore presents a multi-disciplinary approach between Artificial Intelligence, Immersion and Foreign Language Pedagogy where pedagogy has driven technology design and development.

In the next sections, we review the existing literature in the domain, briefly describe the technology we have built to give readers a broad context, outline the learning expectations from the pedagogical aspects and describe the specific features of the system that were driven by pedagogical expectations. We show in a pilot-study that the immersive environment was likable and usable, and shed light on the future directions to make this a successful learning experience.

2 Literature Review

Virtual Immersive learning has been hailed by several experts in the community. Most of the discussion in this domain revolves around VR/AR applications. In this section, we only briefly touch upon the trends in this space by meta-reviewing review papers. This is not an exhaustive list of applications out there. Such a list can be found in papers specifically meant to review the space of immersion and technology, examples of which are [1] and [2].

We see two trends in the discussions; using multi-media (e.g videos) as immersion and using AR/VR applications to achieve immersion - both possibly aimed at presenting knowledge and practice to the students in a multi-modal way (e.g sound, graphics, etc.). We realize the importance of context-richness as [3] have shown that such a multi-modal presentation is effective in second language acquisition.

Some examples of these systems are - [4] have explored teaching formulaic expressions using a scenario based interactive environment where the users are presented with videos and are able to enter their answers to questions in the videos. Whereas, [5] have explored CAVE environments to teach language through immmersion. Authors like [6] have explored other immersion techniques such as Second Life and developed a task-based learning paradigm using it. While [7] have reviewed four immersive technologies, some of which combine the use of AI and immersion and understand speech-based input in order to deliver a richer and naturalistic conversation experience

We see that most of the applications built are philosophically following the "instructors use what they have" paradigm like [8] explores the use of available internet tools and how it aids language teaching. However, it is hard to find a perspective that first drove the requirements from a language teacher on what would help their class - this is one of the novel points of this work.

In addition to virtual immersive worlds being important, it is also duly noted that the embodied agent domain has significantly contributed to the language learning experiences of students. [9] have reviewed such agents and its effects on speech correction for students and we take inspiration from them for enhancing our embodied virtual agent (described later) in the future.

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From the literature review, we see that although multi-modal learning is explored in how information is presented to the students. It hasn't being explored too much as a means of input to the system. That is, systems do not exist out there in the language teaching domain that can interpret multiple simultaneous modes of input (such as gesture and speech) as also noted by [10] who points out that gestures are important in communication and language learning. [10] herself has built a system that takes in gesture input from the learners in order to move the characters in the virtual world such as picking up an object, etc. However, there is another component of multi-modal input that has yet to be explored. We know that natural deictic expressions wherein speech and gestures are used together to communicate are common. This is especially seen while communicating in a new language that is being acquired because, the speakers sometimes fall short of vocabulary necessary to communicate. We haven't been able to find a system that can take into account such a multi-modal dialogue as input to teach foreign language and is another novel point of this work.

We also see that most of the applications that are in the space of simulating reality do not explore human-scale immersion or non-intrusive device based user-experiences augmented with AI which we believe provides a more naturalistic experience.

Therefore, we justify that a system is needed that does the following

- Allow a conversational (speech based) experience
- Understands naturalistic conversation that involves deictic speech
- Requires no hardware to be worn by the user
- Is rich in visual context and culture by using human-scale immersion

The above points guide us to simulate a real-life experience of traveling to a foreign country - a type of immersion highly hailed in the community. However, it needs to additionally be designed to meet some pedagogical goals outlined in section 4. In the next section, we briefly describe the system itself and how it aims to satisfy the above points.

3 Achieving Natural Realism

This section sets up our readers with the context for the next two sections by giving a brief idea of the user experience.

We have used the Cognitive Immersive Room (CIR) which is set-up as a 360 degree panoramic screen that surrounds a group of users as seen in fig. 1 and its computer generated representation in fig. 2. The display has a diameter of 12m and height of 3.8m.

For the context of this work, the interaction can be imagined as - the users can come in into a simulated Chinese restaurant and talk to the AI Agent (embodied as a Panda on the screen) in the context of a typical restaurant experience using lapel-microphones and gestures (in case of deictic remarks). The panda is able to understand what the users are saying and is able to respond (through actions, facial reactions, images and speech) appropriately. We urge more enthusiastic

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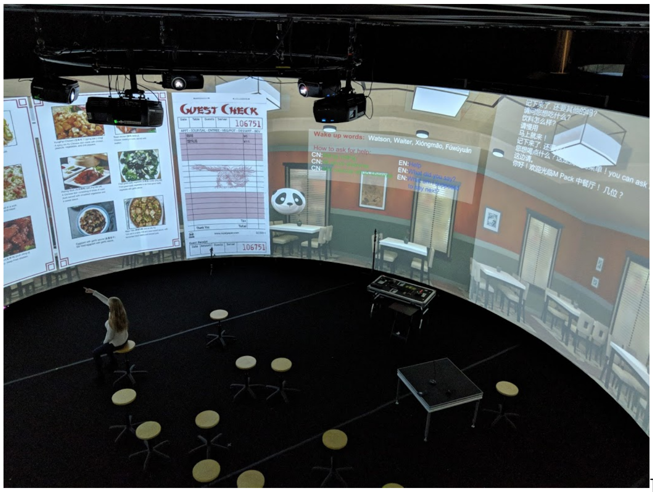

Fig. 1. Interaction in the immersive restaurant (top-view)

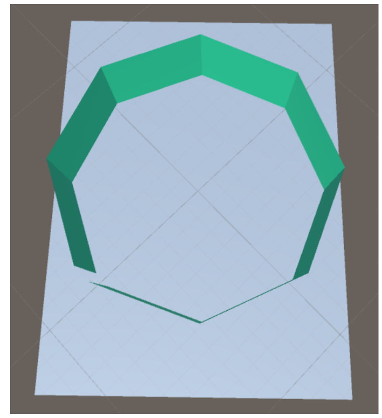

Fig. 2. Computer render of the CIR display

readers to see [11] who have explained in detail the exact interaction that is possible. Additionally, a short demo of the system can be seen here[3]. Such a system can be used in foreign language learning classes in addition to classroom instruction so that students get a chance to role-play in a realistic scenario with context (e.g. visual, audio, etc.)

4 Pedagogical Requirements

From the literature review, we can see that the use of VR/AR, intelligent learning tools and environments mainly focuses on the "tool" or "tutoring" features of the emerging technologies in foreign language teaching and learning. It lacks of interactivity or communication in context, that is, the sense of immersion in real-life situation. In addition, all designs are technology-driven. Seeing the shortcomings of existing design and/or research, the current work started with the collaboration of designers, programmers and language teaching experts since day one of the research project. The technical designers (e.g., designers and programmers) asked a fundamental question to the instructor of the Mandarin Chinese course: What pedagogical goals or requirements you would like to see in the immersive classroom? From the instructor (i.e. language acquisition expert), an ideal cognitive immersive classroom would provide a near real-life experience to the students so that they could interact with an AI agent for task-based learning. Specifically for the pilot scene, we chose ordering food as a task to be completed in Mandarin Chinese in an immersive restaurant. In this restaurant, the students are expected to interact with the AI Waiter, from greeting to ordering

[3] https://www.youtube.com/watch?v=lZWtDqhFlAc

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food, to consulting and clarifying food items and requesting a check. Please note that the system is designed for students who have learned the vocabulary and sentence structures required to complete these tasks through their classroom instruction. The pedagogical requirements for the task-based, communicative language learning are:

1. Collaborative Learning: Students work as a pair or groups to help with each other in the learning process
2. Task-Based Language Teaching (TBLT): Students need to complete the food-ordering task which differs from most other existing research into VR/AR immersive Mandarin language learning
3. Communicative: Students have opportunities to communicate with the AI agent like how they would communicate in a real-world
4. "Interpersonal" communication: Students interact with the AI waiter as if they were customers at a Chinese restaurant
5. Noticing and Awareness Raising: Students need to be alerted for errors and correct their errors for the success of a communicative task.
6. Scope of Language: The technology considers the limited knowledge of the students and help raise it through the dialogue
7. Culture: The system should consider that culture presentation helps aid language acquisition.
8. Help: Students need to have tools (e.g., visual, audio, and/or textual) to help or assist them when they are stuck in the process of task completion.

5 Technology that Supports Pedagogical Goals

Given the goals from the language teaching expert, we set-out to build a system with the following technology specifications and show how they map to each goal. We use *#number* notation to refer to a point from the previous section.

1. Enable Visually-Rich environment: We employed the 360 degree panoramic screen seen in fig. 1 to immerse the students in a restaurant scene with a rich 3-D model of a Chinese restaurant. This aids part of requirement #3 and #4 by simulating the "real world" and provides the visual context for where this communication needs to happen.
2. Minimal use of wear-able devices - In order to encourage collaborative learning (#1), we want the students to be able to look at each other and communicate with each other freely in the "restaurant". This becomes difficult with technologies that employ headsets or other intrusive devices. Thus, we ask the students only to wear a lapel microphone in order to communicate with the system. This has motivated the development efforts of human-scale immersion and computer vision to recognize gestures. It adds to the realism of the environment by allowing a free, natural and interpersonal interaction (#3, #4), and allows for collaborative learning.
3. Voice-Based Dialogue: We use speech-to-text(STT) and text-to-speech (TTS) to have our agent *listen* and *talk* to the students in a natural fashion(#4).

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We additionally use the Watson Conversation Assistant to have the agent *understand* what is being said and pick appropriate responses. The STT expects near-perfect pronunciations otherwise it would misunderstand what was said and lead to the agent being in a confused state. This enables TBLT using speech as the agent responds to each task successfully completed using speech(#2) (e.g. greeting, ordering food, etc.) and also allows for interpersonal communication (#3).

4. Transcription: In order to give feedback on the pronunciation of the students, they were at all times shown the transcription of what they said in real time. This was displayed on the screen and idea was that the students will be able to identify exactly which word was misunderstood and repeat their sentence with focus on that word raising their awareness (#5) of their pronunciation on specific pinch-points.
5. Dialogue Creation - In order to keep the communication natural, we do not give the students a script to follow. Instead, we use the agent-initiated dialogue paradigm where the agent always initiates the next turn and asks specific questions that can be answered by the students. This way, we get to achieve three objectives: stick to tasks that can be accomplished using the language level of the students (#2) (e.g. students cannot accomplish tasks like getting a take-out at the current language level and the agent could avoid that dialogue branch); elicit certain responses from the students chosen by the language teacher as a general tough spot and; use some out-of-scope vocabulary to raise the level controllably (#6). Such a dialogue is designed to be interpersonal e.g. students could ask "what kind of tea do you have?" and talk directly to the waiter (#3,#4). Each dialogue turn could be considered as a task that the student needs to complete (e.g. ordering food) and is communicative through speech. Each dialogue turn can be spoken in Mandarin or English (L1) to help the students if they are stuck (#8).
6. Multiple output responses - The agent has a list of sentences for each meaning it wants to convey to the student and it randomly chooses from the list to respond to the student (#2). For example, the agent could randomly choose between asking "What would you like to drink?" or "Do you want a drink?" - both, achieving the same outcome. All alternative sentences are designed keeping in mind the students' expected understanding of the language. This is done to make the system less repetitive and give the students more exposure to language in context to the task (#6).
7. Gesture (pointing) recognition: One of the observations of natural dialogue and completing tasks is using deictic speech, especially while learning foreign languages. Using our sensor fusion research, we were able to combine multi-modal input in order to understand deictic sentences like "I would like to order *this*" (#2) where *this* is resolved by where the student was pointing on the screen (#3,#4). This multi-modal communication allows for affordances when a student does not know how to pronounce something on the menu (#6,#8). As the goal of the interaction is to have minimal wearable devices, we have used computer vision technologies to recognize gestures.

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We encourage readers to see [12] and [13] to read more about how this is enabled.

8. Listening and learning: The AI agent speaks at a standard pace (we did not slow it down as it is expected of the students to learn to understand the standard pace #2). The panda might also use some out-of-vocabulary words (which were carefully placed in certain dialogue turns #6). We expect the students to learn from this experience and, to do so, they could ask the agent questions like "What did you say?" or "Can you repeat that?" (#8) The agent uses pre-coded responses to explain what it said.
9. Story-telling - Chinese cuisine has a rich history and culture behind it (#7). On being asked, the agent can provide an interactive computer-generated narration for the items on the menu. This interactive narration (#3,#4) is presented in L1 given the limited knowledge of students' L2. To achieve this, we have integrated technology from [14].
10. Assessment Module Post-role play, the panda can give feedback to the students in the following ways (#5,#8)

    – Show a list of tasks students did not complete in Mandarin (i.e. tasks skipped by using L1 or deictic speech) - both an indicator of lack of language execution. This list provides the teacher and the students with opportunities to improve the students' language (#2). The students can practice sentences related to the tasks skipped with the AI Agent.

    – Pitch-contour: Since Mandarin is a tonal language, at the end of the module, students can practice the tone of individual words with the Agent. They can do this by comparing the graph of their own pitch-contour against the graph of the ideal pronunciation in real time and, hearing the correct pronunciation from the Agent.

Table 1 summarizes the mapping of the technology design to the pedagogical goals. Pedagogical goal 8 i.e. providing with the right amount of help to the students so that the role-play can go on in this new interaction paradigm is a greater challenge and has been further discussed in detail in [11].

Table 1. Summary of pedagogical goals mapped to technology design

Pedagogical Goal	Technology Design
Collaborative Learning	2
TBLT	3,5,6,7,8,10
Communicative	1,2,3,5,7,9
Interpersonal Communication	1,2,3,5,7,9
Noticing and Awareness Raising	4,10
Scope of Language	5,6,7,8
Culture	9
Help	5,7,8,10

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6 Technology Implementation

This section gives a brief overview of the implementation of the technology design discussed in the previous section.

Visuals: We use Unity Game Engine[4] to drive the rich visual output on the massive panoramic screen. Special software can warp the displays and achieve the effect of panoramic vision.

Gestures: Commonly used wearable devices that recognize gestures are replaced with computer vision systems that can "see" the user and recognize gestures. We mainly use the skeletal tracking from Kinects and software on top of it to identify gestures from the skeletons. This has been throughly described by [12].

Speech: We use IBM Watson Speech-to-text[5] and Conversation service [6] to classify the verbal input into one of the pre-defined intents designed by us. The intent recognized in this stage is used to drive the interaction. E.g. if intent recognized was *greeting*, the interaction would be that the panda moves to the host-stand and says "hello" to the students. We use Baidu services for text-to-speech generation[7].

Many of the above discussed technologies are a research area of its own. Additionally, a massive engineering effort has gone into integrating them especially with sensor-fusion. It is hard to describe all the details in this short work which focuses on outlining the technology design principles that were followed to justify pedagogical requirements.

However, [13] have outlined the integration engineering efforts giving a detailed overview of the implementation of all technologies involved, while [12] have specifically outlined the workings of the computer vision systems. A combination of these two works will give enthusiastic readers a good insight into the implementation of the technology.

7 Pilot User Study

The aim of this work is to build technology to support the pedagogy. While doing so, the first step in building a new interaction paradigm is to measure its usability and likability. In order to do that, we conducted a pilot study discussed here briefly to show that the interaction was usable and likable. Through a series of testing and feedback over several months, we were able to improve the interaction by identifying interaction challenges and designing solutions to them that are described in detail by [11].

In the eventual formal user study, we invited 16 students from the class of the collaborating professor who teaches Chinese-1 at the same university. We asked them to interact with the system in Mandarin in the food-ordering context. We

[4] https://unity3d.com/
[5] https://www.ibm.com/watson/services/speech-to-text/
[6] https://www.ibm.com/watson/services/conversation/
[7] yuyin.baidu.com/tts

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observed that the students were able to complete most of the tasks showing that the system is usable. We asked them several questions post-interaction to evaluate how natural the system was as this hints towards how well we were able to immerse the students. All of the students indicated that the liked that they were able to gesture and point to menu items (i.e. deictic speech). On the subject of "Did the immersive restaurant feel realistic? Why or why not?", the overall sentiment was positive with at least 10 people strongly indicating that they liked the system. The general complaints were with respect to the floating head of the panda and the lack of leniency in speech-recognition. This encourages us to further enhance the system. Our biggest encouragements were feedback on the lines of the students being able to learn a new word simply through the interaction and the context that was provided to them. The exact pedagogical benefit of this study is still work-in-progress but the positive comments hint towards success. Additional analysis of the user-study can be found in [11].

8 Conclusion and Future Work

We have presented a prototype version of a system that was built to support specific goals of TBLT in Mandarin Chinese language learning for college students. This system is a multi-disciplinary collaboration between educators, language learners, computer scientists, electrical engineering etc. Our pilot studies show a promising future for this project and we plan to scale this to multiple scenes having multiple agents to support different roles and types of dialogues.

9 Acknowledgment

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Digital Exploration of Ethnic Facial Variation

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Abstract. The characteristic patterns of ethnic variation of the human face are seldom explicitly described. This paper addresses the question of how these characteristics may be explicitly described. A lexicon of 77 discrete 3D facial attributes has been developed for purposes of describing ethnic differences. While conventional descriptors are usually discrete-valued (categorical), these attributes are continuous-valued, each interpolated within a bounded range represented by a pair of basis shapes. They are also quasi-orthogonal, allowing for arbitrary combinations to reconstruct the shape of a mesh face to represent any of a large space of ethnicities. Unlike holistic representational schemes used for facial recognition, these attributes are local and 'semantic' (human-understandable), providing an intuitive basis for describing and visualizing the space of ethnic variation.

Keywords: ethnicity description • 3D modeling • face space.

1 Introduction

The human face varies with ethnicity around the world. Despite their individual differences, the individuals within each geographic locale share facial characteristics indicative of their ethnicity. The ethnic variation of the human face is seldom explicitly addressed in education. It would be of great value to foster the appreciation of the face as telling the story of the commonality of all of humankind and the diversity in our global distribution. Faces tell about origins and cultures. The language with which a face tells this story should be taught. What would constitute a descriptive language to express and communicate these differences? This paper summarizes a study by Wisetchat [1] as it applies to teaching an appreciation for how ethnicity is reflected in the human face. By what means are these characteristic ethnic differences to be described? It is a language not of words but of shapes, specifically three-dimensional shapes. Modern technology enables immersive visualization of three-dimensional shape in compelling ways that facilitate our learning a language with which to describe faces. An interactive animation framework is introduced that allows exploration of the space of ethnic variation via a set of intuitive, human understandable, facial shape properties.

This paper emphasizes a matter of some pedagogical importance: how to convey in concrete and understandable terms shape qualities that, while visually apparent and rec-

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ognizable, are seldom described explicitly. The shape of the nose, for example, is usually described by reference to exemplars, typically extremes such as a 'bulbous' or a 'beak-like' nose. Similarly, terms such as 'high cheekbones' or a 'square jaw' may be helpful in describing the particularly distinctive features of an individual but of little help in developing an appreciation for how ethnicities differ visually, and in what regards individuals of a given ethnicity share some facial characteristics. Instead, there is heavy reliance on providing examples to supplement any text. Images and graphical depictions, while evocative, are not descriptions. A few more formal descriptive terms (e.g., *dolichofacial*, *mesognathous*) have been adopted to categorize facial dimensions and proportions based on anthropometric measurements between facial landmarks, however few such measurements reliably distinguish between even very different ethnicities [2-4]. Moreover, few facial features are diagnostic of one or another ethnicity by their presence or absence. The epicanthal fold, for example, is present in Asian eyes and generally absent in Europeans and Africans, however most other facial features differ only by degree across ethnicities, and often vary to a similar degree within an ethnicity. Virtually every aspect of a face is subject to variation, both among individuals within a population and across geographically distant populations: the dimensionality of the space of possible faces (however it is parameterized) is very great [5, 6].

In attempting to appreciate the differences in such high-dimensional data, one encounters many of the challenges common to data visualization in general. This is regarded as unavoidable since facial variation is both complex and subtle, and certainly ethnicity cannot be trivially reduced to a small number of factors. Fortunately, as discussed below, technology adopted from digital facial animation permits composing a specific face based on a *description* (a set of attribute-value pairs in a specialized lexicon) then *visualizing* that face in three dimensions. The appearance of a specific combination of facial attributes serves to capture characteristics of an ethnotype, and by 'morphing' from one to another, the differences between two ethnotypes can be very vividly conveyed.

1.1 An 'Ethnicity Face Space'

Since faces generally vary simultaneously along many dimensions, a representation that spans the range of ethnicities would constitute a high-dimensional 'face space', where the specific choice of dimensions for this face space depends on the specific application. We distinguish two types of face space: an identity face space (IFS) for representing individual variations within a homogeneous population of faces, and an ethnicity face space (EFS) for representing variations of faces across ethnotypes. An IFS is intended for detecting the identity of an individual while an EFS is intended to represent facial characteristics. Both are similarity spaces [7, 8], but otherwise there is little reason to expect they share dimensions or indeed dimensionality. In our application of an EFS, we are not concerned with ethnicity *recognition* (the analog of IFS-based face recognition), but rather, ethnicity *description*. To visually explore facial variation across ethnicities, any proposed scheme needs to span the range of ethnic variation and to facilitate visualization of similarities and distinctions between ethnicities.

The concept of an *average* face is central to an IFS: it constitutes the origin of a space in which to map individual faces as *variations* on a mean [5], [7]. A core presumption of an IFS is that the sample set of faces is homogeneous and that individuals

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are normally distributed about the sample mean along each IFS dimension, placing the average face at the origin of the IFS [7]. Since our EFS is not intended for ethnicity detection (the analog of face detection with an IFS), there is no need for a central-tendency presumption. Moreover, we avoid problems of measuring a global mean on which to map ethnicities as variations. A global mean across all facial ethnotypes would exhibit very large variance, since within-ethnicity variance in facial dimensions has been shown to obscure most across-ethnicity differences, even between very different selected ethnotypes [2]. Finally, in not attempting to measure a global mean, one avoids issues of sample bias, since some very populous ethnicities would greatly overshadow other important but smaller ethnicities. Fortunately, for our purposes, ethnotypes need not be described as variations on a global sample mean of ethnicities.

An EFS for face description has two core characteristics: 1) it represents faces with absolute rather than relative dimensions or axes, and 2) the dimensions are semantically meaningful, allowing the space to be 'navigable' by humans. In both regards the EFS is starkly different from an IFS, for which the dimensions correspond to relative differences, and being the eigenvectors determined by principal components analysis (PCA) on some training set, those dimensions are 'holistic' measurements derived across the entire face (e.g., 'eigenfaces') and not semantically meaningful [8], [10, 11].

Anthropometric face measurements (e.g., the width of the nose) are local, individually interpretable, and intuitive. They are also ad hoc, as they reflect what are regarded as useful as well as being efficiently and reliably measured [11], rather than any arguably complete, principled set of measurements. Likewise, fiducial points for image registration and delineation are based on an ad hoc set of convenient and conventional image landmarks [1]. In the same regard, a set of shape descriptors would be expected to be ad hoc, and while useful, not mathematically comprehensive. But unlike conventional anthropometry, the goal will be to capture subtleties of facial shape that are often salient indicators of ethnicity. The goal of creating such a set of descriptors is utility, not completeness. Advancements in scanning technology permit anthropometric data collection within increasingly fine resolution and spatial precision, but that data comprises measurements (e.g., two- or three-dimensional position information plus color and texture). While the shape of the face remains implicit in these dense sets of measurements, they are of great value in modeling (Section 4).

1.2 Summary of Development of the Descriptive Vocabulary

As surveyed below, a set of facial attributes with which to describe ethnic variation was identified (Section 2), then represented as three-dimensional basis shapes (Section 3), which were used as deformers of a polygonal mesh as controlled through an interactive user interface called the Ethnicity Modeler (Section 4). The development followed the spiral model methodology [12] since the process of converging on a representation scheme involved successive refinement and experimentation in order to defining a set of attributes that were additive, i.e., able to be assigned values in arbitrary combination and able to represent a broad range for each attribute, as discussed in Section 3. Once implemented, evaluation included a repeated-trial experiment to measure attribute precision, an accuracy study for some calibrated attributes, and user interface usability and applications (Section 5).

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2 Identifying Facial Attributes

The human face can be regarded as having separable regions (eyes, nose, mouth, etc.) which can be measured and analyzed individually [13]. Likewise, the geometric complexity of the face is primarily contained within those regions with few facial characteristics defined along the borders between regions or spanning across regions. Therefore, an EFS can be regarded as composed of independent subspaces for the nose, eyes, and so forth. This simplified the search for attributes to one region at a time.

While individual faces vary considerably within an ethnicity, image averaging of multiple individuals of a given ethnotype reveals common characteristics associated with each ethnicity [14, 15]. To identify salient facial attributes, two-dimensional image averaging [14] was first performed on sets of photographs of individuals of differing ethnicities (primarily East Asian, African, and European). Movies were then created showing continuous blending transformation between the two images (e.g., an averaged East Asian 'morphing' into an averaged European), which were then analyzed region-by-region.

Consider for example the region of the eye in isolation. The image-averaged eyes of three ethnicities in Fig. 1 illustrate subtle, yet salient, ethnic *shape* differences. These attributes correspond to anatomical soft tissue shape features such as the epicanthal fold (ECF), the supratarsal fold (STF) and the superior palpebral sulcus (SPS), in addition to the conventional anthropometric properties of the palpebral fissure (width, length, inclination, canthal inclination, interpupillary distance, etc.). The eye region alone exhibits at least 20 such attributes that differ across ethnicities (as well as individuals), ten of which are identified in Fig. 1.)

In order that facial attributes may serve as EFS dimensions, they should be orthogonal (independent). Unlike dimensions based on individual fiducial (2D or 3D) sample points, facial attributes commonly share landmarks, and thus are not strictly independent. But as descriptive attributes, however, they are 'quasi-orthogonal', i.e., each can vary substantially independently of other attributes. For example, a supratarsal fold (STF) in the upper eyelid can co-occur with either a deep SPS or prominent SPC, despite their spatially overlapping (Fig. 1).

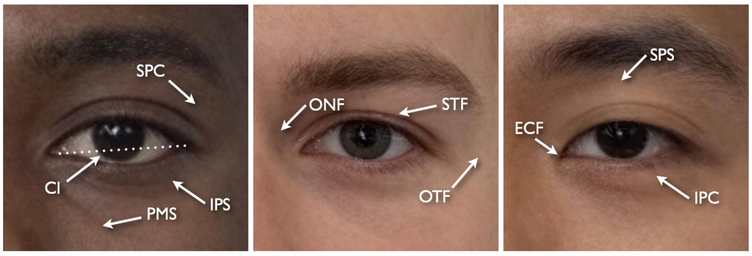

Fig. 1. Averaged images of three ethnicities (African, European, and East Asian), with ten salient shape attributes indicated: CI = canthal inclination, ECF = epicanthal fold, IPC = inferior palpebral convexity, IPS = inferior palpebral sulcus, ONF = orbitonasal fossa, OTF = orbitotemporal fossa, PMS = palpebromalar sulcus, SPC = superior palpebral convexity, SPS = superior palpebral sulcus, and STF = supratarsal fold.

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Having identified a salient facial attribute for some facial region, we are concerned with capturing its absolute range of variation across a span of ethnicities, without an expectation that the distribution of this attribute exhibits a central tendency or mean. The origin of the EFS (corresponding to the default shape of the face) is simply a starting point for describing facial variations. Emphasis here is on creating a descriptive space for the nose, eyes, etc. that spans human ethnic (if not individual) variation.

3 Representing Facial Attributes by Basis Shapes

Linear-weighted summation underlies the synthesis of faces in 2D [16] or in 3D [17, 18] from a set of orthogonal basis functions derived from PCA. Linear-weighted summation also underlies the well-established technique of blendshape deformation in facial animation, wherein a 'base' 3D mesh (the default facial expression) is deformed by weighted combination of a number of basis shapes or 'targets' that share the same topology but with shape variations representing different facial expressions [19, 20]. Unlike the 3D 'eigenmeshes' derived from PCA, blendshape targets for digital animation are seldom orthogonal. Multiple basis shapes may influence the same vertices in the base and their combined effect on the base mesh frequently results in adverse interactions that require corrective measures [21]. The summation of multiple shapes, or shape-additivity, is a highly-intuitive means to create a shape as by graded combination of shape extremes. In facial animation, the set of targets constitute the dimensions of a multidimensional 'expression space', each dimension of which corresponds to local changes to the mesh topography, and are separately interpretable i.e., semantic.

In the application of basis shapes to represent the dimensions of ethnic variations in facial shape, the process of developing a set of meshes, each representing a facial attribute, shares many of the frustrations of creating blend shapes for digital animation, however the technique permits creating precise representations of shape features in various combination, matching samples of varying ethnicity, as will be discussed. The benefits of achieving continuous, graded 'shape additivity' outweigh the difficulties of overcoming the consequences of the basis shapes being not strictly independent in their combined effect.

To illustrate the representation of local shape attributes as basis shapes, eight of the ten attributes labeled in Fig. 1 are shown in the top and middle rows of Fig. 2. The extreme for each attribute is represented as a 3D mesh (such as the most pronounced ECF or STF). The bottom row shows four distinct linear combinations of the eight eye

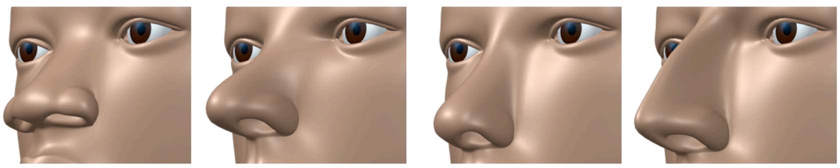

Fig. 3. Various combinations of nose attributes. About 20 nose attributes were identified, some corresponding to conventional scalar landmarks and others to local shape variations usually not measured anthropometrically. In combination, these attributes create a very large space of nose shapes and dimensions.

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attributes. Note that these are unsigned attributes varying from 0.0 (absent) to 1.0 (maximum). Other attributes are signed, and vary between -1.0 (minimum) to 1.0 (maximum).

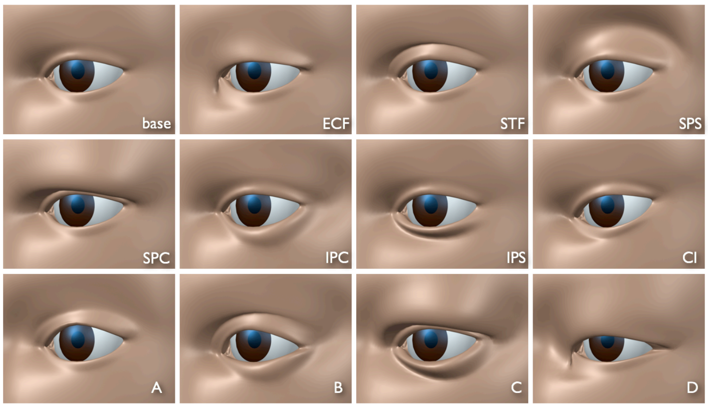

Fig. 2. The top and middle rows show representations of eight ethnically-significant eye attributes as basis shapes, each depicting an extreme value for that attribute (such as the pronounced depth of the superior palpebral sulcus, or SPS, above the upper eyelid). The bottom row shows the result of additivity of these shape attributes: A = STF + SPS; B = STF + OTF + IPC; C = SPC + IPC + IPS + ONF + OTF; D = ECF + SPC + ONF.

Ethnic variations in other facial regions are also amenable to modeling by linear summation of the quasi-orthogonal basis shapes. For example, Fig. 3 shows four distinct noses composed by combinations of different weights for twelve basis shapes. These models capture anthropometric dimensions between conventional landmarks, plus shape features such as alar contour depth, columellar show, alar prominence, etc. Quantitative calibration of the resultant shape permits matching the model to traditional anthropometric landmarks, whether derived from the literature (e.g., [1]), from averaged 2D images of ethnicity samples [14, 15], or by matching 3D data of ethnicity samples (Section 4).

Since facial regions are spatially separable to a significant degree, few basis shapes interfere across regions. Interference does arise within a facial region due to sharing surface patches, e.g., the complexity of folding in the tarsus of the upper eyelid (Fig. 2), but those issues were identified and eliminated, or at least minimized, through extensive testing of combinations of weights across the set of basis shapes. In total, about one hundred basis shapes were created across six facial regions that together influence the shape of a polygonal a model for the entire face to visualize a large range of ethnicities. Additional attributes can be introduced as required in order to create finer shape distinctions.

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4 Ethnicity Models

The *ethnicity modeler* EM provides an interface of about one hundred parametric controls, each directly corresponding to an EFS dimension, and implemented in Autodesk Maya using blendshapes (Fig. 4 shows the controls for the eye attributes, for example). The EM was then used to reconstruct the surface geometry of averaged face meshes representing different ethnicities. Each sample mesh consisted of the average of twenty individuals of common ethnicity and gender generated using the Di3D stereo-photogrammetry surface imaging system [22, 23] with delineation using MorphAnalyser 2.4.0 [24]. The scan data was imported into the EM and aligned such that the eyes in the scan were superimposed on those of the parametric model, then the shape parameters of the EM were iteratively adjusted manually, attribute-by-attribute, until the model's mesh approximated that of the sample mesh (Fig. 5). The required precision is practically determined by individual differences within a homogeneous sample population, which have standard deviations of typically 3-6 mm [2]. Here the model parameters were adjusted until the surface and the scan data deviated generally by less than ±1-2 mm.

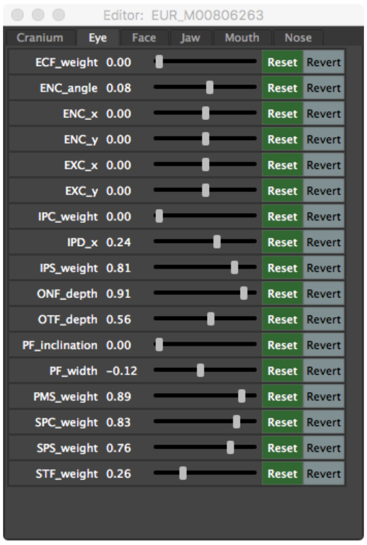

Fig. 4. The Ethnicity Modeler provides interactive controls for all 77 attributes, organized into tab panes. Here the eye attributes have been selected. These controls were then adjusted to create a close match with empirical data, such as provided by stereo-photogrammetry (Fig. 5).

Fig. 6 shows models of two African and two East Asian individuals. The modeling of individuals of various ethnicities was quite useful, as individuals often will reveal unexpected attribute extremes, that then required revising the underlying basis shapes in order to accommodate such extremes (and consequently revision of any models that had used the earlier version for those extremes, a consequence of the exploratory, spiral development process).

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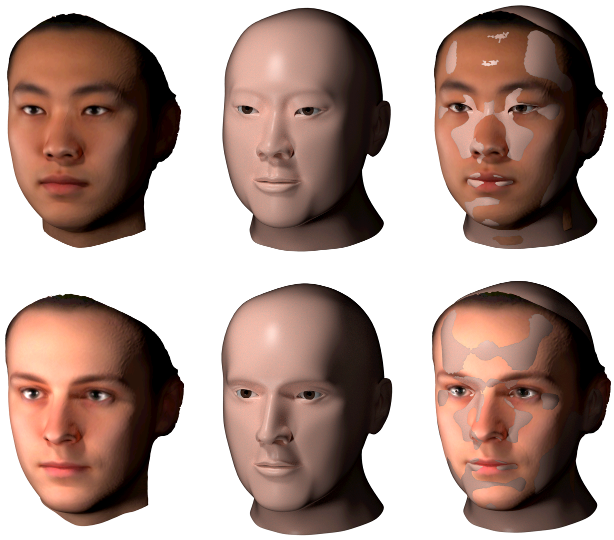

Fig. 5. In the upper row, the parametric model (center) has been adjusted to closely approximate the stereo-photogrammetric average of 20 male East Asian faces (left). The lower row shows the model matched against the averaged face of 20 European males. In each case, after a manual process of adjustment, the model mesh eventually matched the scan data to within ±1-2 mm generally, i.e., to within the uncertainty due to individual variation. The mottled patterns (right) shows this close correspondence (and reveals residual asymmetries in the scan data) when the two meshes are superimposed.

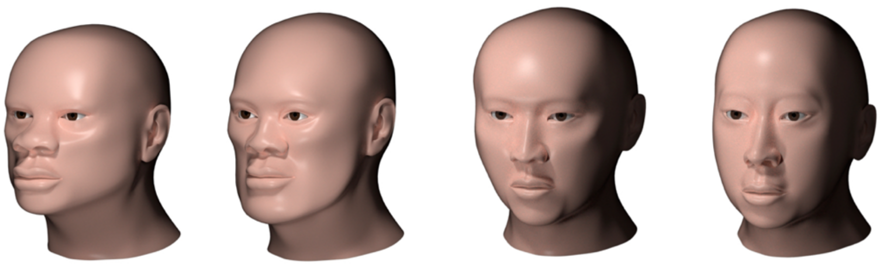

Fig. 6. Two African male individuals (left) and two East Asians individuals (right) were modeled, demonstrating the ability to parametrically capture a broad range of both ethnic and individual variation.

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5 Evaluation

This modeling of a broad range of ethnic variation, as well as individual variation, would appear supported by a schema based on roughly 100-200 attributes (this study having implemented 77 attributes, but each facial region could have benefited from having additional, more subtle attributes). The schema was developed to support both representation and visualization. As a representational scheme, it was important to evaluate the precision and accuracy with which the model could match empirical data (such as stereo-photogrammetric scans). A study was pursued by the first author, wherein stereo-photogrammetric data for males of two ethnicities (East Asian and European) were matched repeatedly for 10 trials each, and the mean and standard deviation was then computed for each of the 77 attributes for each ethnicity. The standard deviations revealed that measurement uncertainty was generally less than 10% of the range of the corresponding attribute. Those signed attributes that correspond to anthropometric dimensions (such as mouth width or nose length) were repeatable to 5% or less, while some unsigned shape attributes (such as the depth of the shallow sulcus below the eyes or the roundness of the tip of the nose) showed larger trial-to-trial variances, found to be more difficult to judge, with a few such attributes having just noticeable differences of somewhat greater than 15% [1]. Regarding accuracy, five of the dimensional attributes were calibrated in millimeters. The mean attribute values were compared with the corresponding anthropometric measurements values (from [2]) for the two ethnotypes (East Asian and European), and the Ethnicity Modeler results generally matched to within one standard deviation, i.e., the variance due to individual variation [1].

The Ethnicity Modeler interface was developed only with the limited goals of supporting the development of the facial descriptive and visualization scheme. As shown in Fig. 4, each facial attribute was controlled directly through a slider widget. Adjusting the EM mesh in order fit empirical data thus involved a substantial task of adjusting 15-20 attributes per facial region. An evaluation study involving five users (all familiar with user interfaces but only one was an expert in 3D sculpting software) tasked with adjusting the EM mesh to match 3D data, using the Thinking Aloud methodology [25]. The consensus was that the facial attributes were, as hoped, intuitive and understandable, and that they could be manipulated with some ease through the interface by slider widget [1]. The attributes were reported to be natural in for capturing, and communicating, facial shape. Negatively, however, it was immediately apparent that facial modeling by laborious manual adjustment of 77 attributes was an overwhelming task, especially for non-experts. The EM, however, was intended only as a proof of concept of the representation scheme, not as a turnkey modeling tool per se. This experience, nonetheless, raises the question of how to effectively explore such a high-dimensional EFS, a matter for future studies.

6 Discussion

Human observers naturally describe and appreciate faces in terms of local shape descriptors: visual attention is drawn to distinctive shape features of a face (either that of an individual or of an averaged representative of a given ethnotype), many of which are

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associated with landmarks. There is also a universal tendency to base a description on exemplars, especially extreme examples of any given characteristic.

We have found that local shape descriptors can be represented by basis shapes with sufficient specificity to reconstruct (match) facial geometry across a range of ethnotypes, to within the uncertainty that is imposed by individual variations. The shape attributes are local, comprehensible, and consistent with the traditional anatomical nomenclature and literature. While it is challenging to model local facial attributes by basis shapes, and to achieve quasi-orthogonality among them, we can then match sample faces purely by parametric manipulation of mesh geometry in terms of those attributes. More generally, by regarding these shapes as defining an EFS, the resultant space permits exploration of ethnic differences directly in terms of shape differences, and that is its primary intention. Provide that the attributes are scaled to allow covariance to be meaningfully computed, a set of sample models across different ethnotypes would be amenable to PCA.

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Navigation Hints in Serious Games

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Abstract. Serious games provide an engaging environment for students to learn complex concepts. A novel approach for players to achieve learning objectives in a serious game while avoiding potential distractions due to game elements is described. The proposed approach observes player performance in the game exercises and automatically suggests other unexplored exercises to the player. The exercises suggested are selected using a numeric value which is computed based on the uniqueness and the freshness of the concepts underlying the exercises. The approach was implemented in a quantum computing game, *QuaSim*. Our experiments involving 81 players show that the proposed approach aids players to learn quantum computing concepts in an engaged manner.

Keywords: Serious Games · Learning.

1 Introduction

Serious games are a promising approach to meet the learning objectives while providing an engaging learning experience to the players of these games. Serious games have achieved impressive successes in learning in diverse fields including the physical and mathematical sciences, linguistics, game theory and problem solving [1–4]. However, designing serious games that meaningfully combine learning along with engagement continues to be a challenging problem. Games emphasizing education often tend to be media-rich concept practice sessions where game scenarios are repeated until a certain player performance level is attained[5, 6]. Alternatively, certain games tend to over-emphasize the gaming elements to the point where they tend to distract players from achieving the desired educational objectives [7–9].

In this paper, we describe a novel approach that combines the achievement of learning objectives and player engagement while avoiding distractions. In the proposed approach, players must become proficient in a set of knowledge concepts to achieve the learning objectives. Each exercise in the game is tagged with a set of knowledge concepts that the player will become proficient in upon solving that exercise. Player performance in the game exercises is continually observed by the game and used to automatically navigate players to other unexplored exercises. A numeric value is assigned to each exercise based on two

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aspects – degree of uniqueness of an exercise in covering a knowledge concept among all exercises covering that concept and the degree of freshness of exercise in exposing a relatively unexplored concept to a player. In each game scenario, upon completion of an exercise, the values of the remaining exercises are automatically determined and players are navigated to exercises with a high value.

The proposed approach has been implemented in a serious multi-player game, *QuaSim*, that provides a hands-on immersive experience to students and professionals to explore quantum computing, algorithms and cybersecurity protocols. The *QuaSim* scenarios comprise of several exercises such as programming quantum machinery to activate certain energy receptors at different locations in a city in order to learn quantum computing basics. The *QuaSim* scenarios also include multi-player exercises with players communicating secrets over quantum channels while others try to eavesdrop or teams of players launching cyber-attacks on some city infrastructure using quantum devices while others defend. *QuaSim* incorporates the proposed approach as an automatic navigation hint generation procedure, *nhint*, which in each scenario suggests the next game exercise to a player. The *nhint* procedure is available in *QuaSim* in two modes – automatic mode (*a-hint*) where a player is automatically teleported to the next exercise and semi-automatic mode (*sa-hint*) where a player may ignore the suggested exercise.

Our experiments studied the effectiveness of the *nhint* procedure with 81 players. The *QuaSim* game with three modes of *nhint* procedure *nohint* (disabled *nhint*), *a-hint*, and *sa-hint* were played by roughly equal sized groups of players and the effectiveness of *nhint* modes were measured as a ratio of the proficiency achieved to player engagement. The latter was measured in terms of player persistence based on the number of exercises solved. We also studied how many exercises the players using the *a-hint* mode were able to solve correctly in the first attempt in comparison to those using the *nohint* mode. We also conducted a qualitative survey about the player experience with the *QuaSim* in the three modes. Our results show that player proficiency to persistence ratio were highest for the *a-hint*, followed by *sa-hint*, with *nohint* being the least. The *QuaSim* game with *a-hint* also exhibits a superior correct in the first attempt performance. However, in the post-game qualitative surveys, the *QuaSim* with the *sa-hint* was ranked the highest for engaging experience by the players.

1.1 Related Work

Recently, the incorporation and generation hints in serious games has gained considerable interest [1, 6, 10, 11]. Hints in these games trace their origins to the study of hints in intelligent tutoring systems (ITS) where hints guide students to produce the correct solution to a given problem. Previous student data about correct solutions are often used to generate hints that aid a student to complete their partial solution attempts [6]. Inspired by hint generation in ITS's, Conati et al [1] incorporated hints into the game Prime Climb and showed that hints improve mathematical learning in the game. They also studied how drawing a player attention to hints affects learning as well as player perception of

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the utility of hints. In [11], O'Rourke et al incorporated abstract and concrete hints into the math game Refraction. Their work was solely focused on studying the effect of these hints on player performance in math learning. In [6], Wauck and Fu proposed hints targeted at improving engagement in a simple board game. They associate player engagement to the new squares visited by players in a period time and generate hints that highlight unexplored squares. The proposed approach significantly differs from these works in designing hints to simultaneously improve player learning and engagement. In order to achieve this, a numeric value is assigned to each exercise that combines both the learning and engagement dimensions. The knowledge components associated with the exercise are used to assess the *learning potential* of an exercise. Exercises that cover unique knowledge components contribute highly learning component of the value metric. The *engagement potential* value of an exercise is determined based on the player history. Exercises with knowledge components that a player has not encountered earlier or exercises that present previously seen knowledge components in a different context are rated highly on the engagement potential. On the other hand, exercises involving knowledge components that players have encountered earlier exercises and successfully solved are rated low for the engament potential.

2 A Quantum Serious Game

The *QuaSim* is a 3-D interactive game built using the Unreal Engine 3D platform extended to embed instructional videos, web browsers, audio dialogues, auto-graded quizzes, and tests. The *QuaSim* game scenarios are played at different locations of a city including high-rise buildings as well as open spaces. The *QuaSim* includes four single-player scenarios about quantum computing basics and two multi-player scenarios about quantum communication protocols and security attack and defense exercises. In this paper, we focus on the single-player scenario introducing the concept of mapping qubits (quantum bits) onto polarized photons, which we refer to as *qubit game scenario*. Details regarding other *QuaSim* game scenarios will be discussed in an expanded version of this paper.

In the qubit game scenario, several qubit receptors located at different levels of a building must be activated by programming qubits with proper orientation using a given representation of photon. A receptor specifies an angle and accepts qubits programmed at an angle that is either the same, orthogonal to, or in the opposite quadrant to the specified angle. These different types of programming of the qubits make up different exercises. In addition, the programming of the qubits in each exercise must be performed using either the matrix, ket or linear combination of vector representations of the photons. For example, the Figure 1(a) depicts a receptor that is activated by programming a qubit at an angle that is in the opposite quadrant using the matrix notation. The specified angle of 255 degrees is embedded in the green photons in the Figure 1(a) and the player workspace on the left depicts the matrix values used to produce this orientation.

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(a)

PLAYER_ID	SESSION_ID	EVENT_ID	STATE	STATE_DESCRIPTION	EVENT_TIME	EVENT_DATA	SCORE	HEALTH
9838_2	1	1_2	S101	New Angle Displayed	2017-05-03 23:35:32:57	Angle: 345.000000, PuzzleType: Same Quadrant	300	0.65
9838_2	1	21_2	S45	Resumed Game	2017-05-03 23:12:57:532	NONE	400	0.65
9838_2	1	22_2	S46	Paused Game	2017-05-03 23:37:04:642		400	0.65
9838_2	1	5_2	S20	Angle Fired	2017-05-03 23:38:14:800	ket1_alpha: 1,	400	0.65
9838_2	1	5_2	S20	Angle Fired	2017-05-03 23:38:16:730	0	400	0.65
9838_2	1	40_2	S140	Help event H1	2017-05-03 23:40:45:282	H1 Help event	400	0.6
9838_2	1	5_2	S20	Angle Fired	2017-05-03 23:40:45:282	ket1_alpha: 0,	400	0.6
9838_2	1	5_2	S20	Angle Fired	2017-05-03 23:40:47:178	90	400	0.6
9838_2	1	5_2	S20	Angle Fired	2017-05-03 23:41:14:285	ket1_alpha: .997,	400	0.55
9838_2	1	5_2	S20	Angle Fired	2017-05-03 23:41:16:289	4	400	0.55
9838_2	1	21_2	S45	Resumed Game	2017-05-03 23:12:57:532	NONE	400	0.5
9838_2	1	22_2	S46	Paused Game	2017-05-03 23:43:10:837		400	0.5
9838_2	1	40_2	S140	Help event H1	2017-05-03 23:44:01:416	H1 Help event	400	0.5
9838_2	1	5_2	S20	Angle Fired	2017-05-03 23:44:01:416	ket1_alpha: -.966,	400	0.5
9838_2	1	5_2	S20	Angle Fired	2017-05-03 23:44:03:368	165	400	0.5
9838_2	1	21_2	S45	Resumed Game	2017-05-03 23:12:57:532	NONE	500	0.5

(b)

Fig. 1: a) Opposite quadrant, matrix exercise, (b) Sample player action data log.

The player performance is depicted on the upper right by the score and the number of available qubits.

The qubit game scenario has a total of 12 exercises involving a combination of two knowledge concepts – the qubit orientation (3 possible values) and its representation (3 possible notations). Out of these, 9 exercises are basic and 3 are derived by composing the concepts. Each basic exercise is designed to achieve proficiency across the pair of values of orientation and notation concepts whereas the derived exercises require programming the qubit at a particular orientation using multiple representations. These derived exercises serve like a comprehensive test over the concepts learned through the basic exercises. The same format is used across all the *QuaSim* scenarios.

3 Navigation Hints

In general, any *QuaSim* scenario, $G = \{e_1, \ldots, e_n\}$ is a set of n-exercises over a set of concepts $C = \{c_1, \ldots, c_k\}$. The tuple of concepts relevant to an exercise e_i in G is $R(e_i)$. Two distinct exercises e_i and e_j in G are said to be *related* if they share one or more relevant concepts. The set of exercises covering a concept c_j, $E(c_j)$, consists of all the exercises where c_j is relevant. The *concept proficiency* is measured based on exercises covering a concept. The concept proficiency for a concept c_j has the value 1 if the player has solved some exercise in $E(c_j)$ and has the value 0 otherwise. We will assume that there is no dependency among concepts in terms of their proficiency, i.e., achieving proficiency in one or more concepts is not a pre-requisite to achieve proficiency in any of the other concepts. The *scenario proficiency*, $P(G)$ for scenario G, is a k-tuple of Boolean values whose j^{th} component has value 1 if the player is proficient in concept c_j and has value 0 otherwise. Initially, all the components $P(G)$ have the value 0. Scenario proficiency $P(G)$ is *complete* if all of its components have the value 1.

In a *QuaSim* scenario, a player can choose the exercises they want to play. But this some times may lead to situations where a player may take too long to achieve scenario proficiency and may lose interest in the game. We describe a automatic hint generation procedure, *nhint* towards addressing problem. The

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nhint procedure records the player performance (correct or incorrect) at each exercise in a given scenario and determines a set of exercises that the player can attempt next. These are determined by the *nhint* procedure by associating a value with each of the exercises that can be attempted next by a player. The value of an exercise e_i, $v_i = \langle \frac{1}{|E_r(c_j)|},\ c_j \in R(e_i) \rangle$. So, each value v_i is k-tuple whose j^{th} component denotes the number of exercises where the concept c_j is relevant. The j^{th} component of v_i is 0 then the concept c_j is not relevant to exercise e_i. If j^{th} component of v_i is 1 then the concept c_j is relevant only to exercise e_i, meaning that e_i is essential to achieve proficiency in concept c_j.

The *nhint* is an iterative procedure, where in each iteration an exercise with the maximum value among the available exercises is a candidate for the player to attempt next. Ties if any, among the candidate exercises are broken arbitrarily. If the player solves a candidate exercise e_i, the components of $P(G)$ corresponding to the concepts in $R(e_i)$ are set to value 1. The coverage of all concepts belonging to $R(e_i)$ is set to 0 in every remaining related exercise since the player has achieved proficiency in these concepts by solving e_i. Then, the exercise e_i is removed, the value of the remaining exercises are recomputed using the updated coverage values, and the exercise with the highest value is chosen for the next iteration. On the other hand, if the player fails to solve exercise e_i, $P(G)$ is unchanged. The coverage of concepts are unchanged as well since failure does not modify the proficiency in any of the concepts. The exercise e_i is removed, the values of the remaining exercises is recomputed, and the exercise with the highest value is chosen for the next iteration. The procedure terminates with *success* if all components of $P(G)$ are set to 1 and it terminates with *failure* if there are insufficient exercises to achieve proficiency in the rest of the concepts.
Example: Consider the qubit game scenario $G = \{e_1, e_2, e_3, e_4, e_5, e_6, e_7, e_8, e_9\}$ with 9 basic exercises over the set of concepts $C = \{$*M(matrix)*, *K(Ket)*, *L(Linear-combination)*, *S(Same-angle)*, *R(Orthogonal)*, *P(Opposite-angle)*$\}$. The set of relevant concepts to the individual exercises are: $R(e_1)=\langle M, S\rangle$, $R(e_2)=\langle M, R\rangle$, $R(e_3)=\langle M, P\rangle$, $R(e_4)=\langle K, S\rangle$, $R(e_5)= \langle K, R\rangle$, $R(e_6)=\langle K, P\rangle$, $R(e_7)=\langle L, S\rangle$, $R(e_8)=\langle L, R\rangle$, $R(e_9)=\langle L, P\rangle$. The scenario proficiency vector for G, $P(G) = \langle M,S,K,R,L,P\rangle$. A play session guided by the *nhint* procedure where all exercises suggested by *nhint* procedure are solved correctly by a player is indicated in Table 1. The *nhint* procedure ends with success in this session. The *nhint* terminates with success since the player achieves proficiency in all of the concepts in the scenario[1]. The rows 1-4 in the 1 depict the different exercises attempted by the player as suggested by *nhint* and the effects of the player attempts on the scenario proficiency and the next exercise suggested by *nhint*. Each of the nine exercises $e_1 \ldots e_9$ have two relevant concepts each and each of these concepts is shared among exactly three exercises, the values $v_1 = \ldots = v_9 = \langle \frac{1}{3}, \frac{1}{3} \rangle^2$ of all the available exercises are the same. Initially, the exercise e_1 is randomly selected by *nhint* and is solved successfully by the player. As a result, first, the

[1] The components in steps are indicated only if they change. Further, the proficiency values of the remaining exercises are only shown.

[2] For brevity, we indicate only the non-zero components in the value 6-tuple.

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Table 1: Quantum Basics Session Guided *nhint* with no failed attempts.

1. $(e_1,\ v_1 = \ldots = v_9 = \langle \frac{1}{3}\ \frac{1}{3} \rangle,$	$P(G) = \langle 000000 \rangle)$
2. $(e_5,\ v_2 = v_3 = \langle 0, \frac{1}{3} \rangle,\ v_4 = v_7 = \langle \frac{1}{3}, 0 \rangle,$	$P(G) = \langle 110000 \rangle)$
3. $(e_9,\ v_2 = v_4 = \langle 0,0 \rangle, v_6 = \langle 0, \frac{1}{3} \rangle, v_8 = \langle \frac{1}{3}, 0 \rangle,$	$P(G) = \langle 111100 \rangle)$
4. $(S,\ v_1 =, \ldots, = v_9 = \langle 0,0 \rangle$	$P(G) = \langle 111111 \rangle)$

exercise e_1 is removed from the set of available exercises. Then, the values of the related exercises v_2 and v_3 are updated by setting their first component to 0 to mark proficiency in the matrix notation concept(M). Similarly, the values of the related exercises v_4 and v_7 are updated to indicate proficiency in the same angle qubit orientation concept (S). The values of the remaining exercises are (unchanged values are not indicated in the table above) higher than the exercises v_2, v_3, v_4, and v_7 and hence any of them can be suggested by *nhint* to the player to attempt next. Exercise e_5 is chosen randomly and solved correctly. As a result, the exercise e_5 is removed and the values of the related exercises are updated as shown above. Finally, the exercises e_9 is chosen for the player to attempt since it has the maximum value. The player achieves proficiency in two concepts by solving each of the exercises and the corresponding elements in $P(G)$ are set to value 1 after each correct attempt. The player achieves proficiency in all the concepts in the scenario upon solving the three exercises and hence *nhint* terminates with success (shown by S in row 4 above).

4 Experimental Results

Three versions of the *QuaSim* game suppporting the three *nhint* modes (*nohint*, *a-hint*, and *sa-hint*) were played by 81 players that included 20 females and 61 males, 68 graduate students, 2 seniors and 1 freshman and 10 cybersecurity professionals. The *QuaSim* was played in a media lab on individual desktops with Intel i7 @ 3.40 GHz processor, 16GB RAM running Windows 10 Enterprise 2016. The NVIDIA GeForce GT 730 graphic card was available on each machine to support the Unreal graphics. After an IRB consent for data collection, players register with a given anonymous id and email address and login to play the game scenarios for about an hour. The *QuaSim* assigns each player a unique player id and logs every action of the players in the *QuaSim* database (SQLite3). See 1(b) for a sample of the collected data. Students were also given a post-game qualitative survey regarding their engagement levels, and hints. The main objective of our experiments was to study player proficiency and engagement in scenarios and whether these two aspects can be improved by using the *nhint* procedure. Player proficiency ratio, $Pr = \frac{pc}{|C|}$ where pc is the number of concepts where a player is proficient and C is the total number of concepts in a scenario was used to track proficiency. Player engagement was measured qualitatively through post-game surveys as well as quantitatively using the number of exercises attempted and the play time. The proficiency to effort for a scenario, $PE = \frac{Pr}{|E_s|}$ was used to measure the proficiency attained by a player with respect to the

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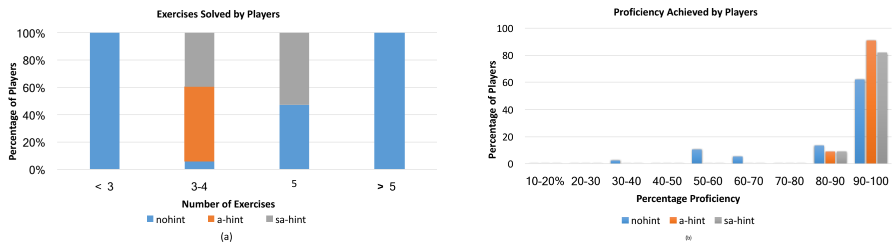

Fig. 2: Proficiency and Engagement: a) Percentage of exercises solved, b) Percentage Proficiency achieved.

number of exercises that they solved (E_s). Our results regarding the number of exercises solved by players, the proficiency achieved by them in the qubit scenario, as well as the proficiency to effort ratio across the three versions of the game are depicted in Figure 2. The X-axis in Figure 2(a) is the number of exercises solved by the players and the Y-axis is the percentage of players that solved those many exercises. We grouped the number of exercises solved into 4 buckets to highlight the difference across the three modes. As evident from this figure, *a-hint* version players solved 3-4 exercises. The *sa-hint* version players solved 3-5 exercises whereas only the *nohint* players greater than 5 exercises. Thus, we can conclude that in general, the effort of *nohint* version players was greater than the *sa-hint* players which was almost the same as that of *a-hint* players. Further, only the *nohint* players solved less than 3 exercises indicating that this version was not engaging enough for them to persist. Figure 2(b) depicts the proficiency ratio Pr (as a percentage) achieved by players. The X-axis is the Pr percentage and the Y-axis is the percentage of players. It is clear from this figure that all *a-hint* version players achieved over 80% proficiency (in fact over 90% of these players achieved 90-100% proficiency) whereas around 90% of the *sa-hint* players were able to achieve such proficiency. On the other hand, the proficiency achieved by the *nohint* players peaked around 60% that was well below those of the other two groups. The left side of Figure 3 depicts the PE results for these three groups. The X-axis the PE percentage and the Y-axis is the percentage of players. It is clear from this figure that the proficiency to effort ratio for *a-hint* is the highest followed by that of the *sa-hint* players, and both these player groups performed much better than the *nohint* version players. From this figure, we conclude that the *a-hint* and *sa-hint* versions are promising in helping players achieve scenario proficiency while maintaining engagement measured in terms of the player effort.

The *nhint* procedure is designed to choose exercises based on their concept freshness *i.e.*, concepts that players have not encountered in earlier exercises. We studied the effect of such a choice on players solving a problem on their very first attempt. The results are depicted in the right side of Figure 3. The X-axis consists of the 12 exercises in the qubit game scenario and the Y-axis is the percentage of players who solved the exercises correctly in their first attempt. It

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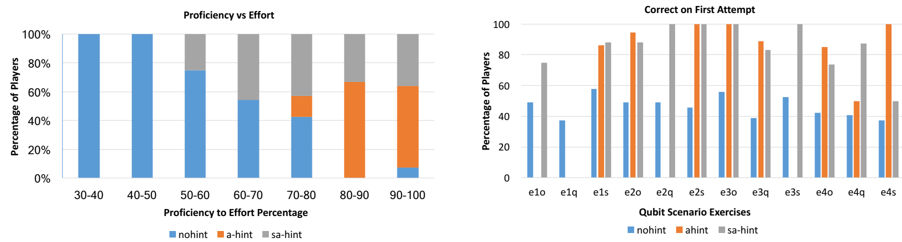

Fig. 3: Correct on First Attempt with and without hints

is easy to see that players using the *a-hint* versions outperformed those playing the *nohint* version by a wide margin in all the exercises that they played. Note that some of the exercises such as e10, e1q, e21 and e3s have zero *a-hint* players since the *nhint* procedure did not assign them these problems. This is because the relevant concepts in these exercises were already covered elsewhere. The result for *sa-hint* version players are very similar to those for the *a-hint* players.

5 Conclusion

We have described a novel approach for players to achieve the learning objectives in an engaging gaming environment while avoiding potential distractions due to game elements. The proposed approach observes player performance in the game exercises and automatically suggests other unexplored exercises to the player. The exercises suggested are selected using a value which is computed based on the uniqueness and the freshness of the concepts underlying the exercises. The approach was incorporated into a quantum cryptography game, *QuaSim* and was played by 81 graduate students and cybersecurity professionals. Our results show that the proficiency achieved by the players can be improved by the use of these hints while retaining their engagement measured in terms of their persistence in the game. While user choice of acting on hints (*sa-hint*) was preferred over fully automated hints (*a-hint*) by players in the post-game survey, both these forms of hints enabled players to solve many more problems correctly in their very first attempt when compared to the version where no hints were available.

6 Acknowledgement

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Workshops

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Summer Programming Camps Workshop

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1 Introduction

Summer programming camps have been established in urban areas for quite some time now, but there is a great need for them in rural and suburban areas. These camps must be self-sustaining and provide an experience that combines fun and learning. Camp leaders can create a social environment where those who participate feel welcome, regardless of their background. By focusing on "gamification," along with social interaction, we can create a place of belonging that might not exist anywhere else. Summer camp is about much more than just offering programming skills to interested students. It is about creating an experience that the camper, as well as their parents, will remember.

In this workshop, we will give specific logistical and practical examples, based on years of experience, of how to plan and implement a week-long summer programming camp. We will show how to successfully "gamify" the camp, using tools such as a leaderboard, mini-competitions, and other games to keep campers positively motivated throughout the week. We will also talk about how to implement outdoor activities that encourage participation by all campers and help increase social belonging. We will discuss several programming languages covered in our camp and how each builds upon one another. Participants will receive a sample planning checklist, an outline of the suggested activities, techniques to recruit volunteers, and tips on how to make the camp self-sustaining. This workshop will help prospective camp leaders of all ages to create their camp successfully.

The goal of this workshop is to share experiences with other educators who are interested in creating their camp. The workshop will cover the logistics of creating and running a successful camp in their area. Attendees will get hands-on experience working with an expert who has run a camp for over seven years in rural Montana learning how to not only run the camp but also understand the logistics of creating a camp that is self-sustaining while using local vendors and involving the community. Attendees will also create a network and collaborate with other educators and share ideas. Attendees will also have access to their version of an online web system that visually tracks the gamification aspect of their camp. The turn key system will be free of charge to all attendees so that they can have a web-based system without having to either create it on their own or pay for another developer to create it for them. Historical experiences will be shared including what has worked well and what pitfalls to avoid with all who attend the workshop with the

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goal of being as successful as possible right from the beginning. Finally, those in attendance will have a chance to present their curriculum with the larger group continuing the goal of sharing everything with all those who attend.

2 Expected audience

Late secondary and early post-secondary CS educators who are interested in starting a camp or exploring how to expand their current offering. Since this is the first offering of this specific workshop, we expect anywhere from 15-30 people to be interested.

3 Space and Enrollment restrictions

Enrollment could be limited to 30, with six teams of 5 interacting with one another.

4 Take away skills

Attendees of this workshop should be able to successfully start and run a gaming programming camp focused on middle school aged students. They should be able to prepare, market, and garner interest from students from a wider geographical location. Attendees will also be able to teach the programming languages that are introduced in the workshop. They will have an opportunity to learn up to seven different programming languages and determine which ones they will incorporate into their camp. Finally, those in attendance will learn how to run the end of camp showcase that displays the student's work for their parents, guardians, and friends.

5 Audio/Visual and Computer requirements

Ideally, participants will have wireless internet access and laptop power at each seat as these tools would help facilitate the participants when creating their mini-camps. We will also need a digital projector (for presenters). Support for Windows and Mac laptops are essential. Laptop Required: All participants will need a laptop for creating and storing their mini-camp and for creating their camp web portal.

6 The expertise of Presenter

Michael Cassens holds a Masters in Computer Science from the University of Montana and has been running summer camps for middle school and high school students over the last seven years. His camps often have maximum enrollment along with waiting lists. He was instrumental in starting one of the first summer camps of this kind in the state of Montana, bringing more computer science education to young people. He continues to adapt and evolve his camps to meet the needs of new and return campers alike. He looks forward to talking to others in rural and suburban areas who are interested in starting their camp and hopes to share and collaborate with anyone who is interested.

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Streams of Inspired Thinking--The Confluence of Civic Engagement

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[1]Inspired Classroom

Inspired Classroom is an interactive distance learning and civic engagement company bringing world class collaborative experiences into the classroom or organization—in real time. We connect the experts and role models with students, educators, and professionals who hunger for authentic learning opportunities.

During this hands-on session educators, researchers and entrepreneurs will come together to experience the IC Challenge Platform as a tool to engage your community in real-world problem solving and critical thinking. You will work in teams to collaborate, research, discuss, and plan relevant immersive projects to take home to your community or school. The platform develops digital literacy skills and provides a forum for you to communicate your decisions about chosen solutions with the group.

Participants will walk through a demonstration problem based on community water issues using this opportunity to become familiar with the platform and the process of problem solving. Additionally, participants will explore different resources available through the IC Challenge platform to help teach the process of problem solving and presenting. We will also share websites and resources outside the platform that other educators find helpful.

At Inspired Classroom we believe that collaboration IGNITES learning and action!

Workshop Objectives
As a participant you will:

1. Discuss the importance of problem based learning and civic engagement in the classroom.
2. Experiment with the IC Challenge platform as a tool for community and student engagement.
3. Collaborate using the IC Challenge platform with local and visiting experts to produce an action plan for teaching problem based, environmental education.

Posters

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Lucid Learning: a Theory of Learning in Mentally Enriched Virtual Realities

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Abstract. This paper focuses on the question of how human learning is influenced when a learner is able to mentally create or enrich his or her learning environment in a Virtual Reality. A definition of this process called Lucid Learning as the acquisition of new skills through problem solving in a mentally created or enriched world in which the learner feels physically, socially and self-present is given and its phases *Brainstorming the World*, *Exploring the Mind* and *Building the Knowledge* are depicted.

Keywords: Lucid Learning · Virtual Reality · Neurofeedback · Lucid Dreaming · Learning Environment

1 Lucid Dreaming in VR

When thinking of the ultimate experience of presence in a virtual environment, Calleja depicts Virtual Reality (VR) as "lucid dreaming on demand" [1]. We are at a point where we can control our own movement in VR through our thoughts, using neurofeedback technology [2]. Through further research, possibilities of not only moving in but creating the whole virtual reality through the users thoughts will emerge. The use of a neurofeedback system linked to a Head Mounted Display could bring us to the next level of learning, where we will be learning in the virtual environment that feels like a lucid dream: Lucid Learning. The feeling of lucid dreaming refers to an experience similar to "dreaming while being conscious that one is dreaming" [3]. Thus, the feeling of lucid dreaming in this paper refers to a conscious experience within the process of creating an individual world using only your own thoughts.

First, we need to discover a way to create the feeling of lucid dreaming using VR in order to think about the effects on learning processes. For Calleja, the lucid dreaming VR experience is described as "a pay-per-act performance inside a virtual world so compelling it is challenging to distinguish it from reality itself" [1]. The concept which is addressed here is called presence, which is widely explained by the feeling of being there. Beyond the physical presence, Biocca depicts social and self-presence [4]. The process of trying to solve a problem (para-authentically or artificially represented by a physical component, a social actor or a modification of the self) through in VR visualized imagination is what will be called Lucid Learning. I define Lucid Learning as the acquisition of new skills through problem-solving in a mentally created or enriched world in which the learner feels physically, socially and self-present.

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2 Stages of Lucid Learning

On the basis of constructivism with its understanding of forming knowledge inside the learner [5], constructionism as a learning-by-making [6] and imaginative learning as creative exploration of an environment [3], we can form an understanding of Lucid Learning by separating three steps which are initiated by feeding the learners brain with a problem. In the beginning, the learner deals with an issue by using a brainstorming process which results in mentally constructing or enriching an environment. This *Brainstorming the World* process can be referred to the learning-by-making approach of the constructivists [3].

Secondly, the learner explores this environment in a creative way (*Exploring the Mind*), using the capacities of imaginative learning [7]. In this phase, the learner performs a continuous try and error process with the aim of finding a valid solution to the problem. This is the hard part since it requires thinking about every single aspect of the given problem and may require help from outside, for example from a teacher or from tutorial software.

By doing so, the learner gets to the third and final step: the creation of new knowledge, coming from own thoughts in a mind-built or mind-enriched world over a given issue. This is the lived constructivists perspective: The only part that comes from the outside of the brain is the specific problem and the conditions. Every component of the problem-solving process itself (additional environment, actors, and methods) is created by the brain. By doing so, the new knowledge is something the learner could discover by himself during the process of *Building the Knowledge*. Note that this can be an iterative process, so the created knowledge may not be perfect at the first attempt but when enriched with further questions, it may develop and grow into its assumed form.

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ARPiano: Efficient Music Learning Using Augmented Reality

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Abstract. ARPiano uses a MIDI keyboard and a multi function knob to create a novel mixed reality experience that supports visual music learning, music visualizations and music understanding. At its core, ARPiano provides a framework for extending a physical piano using augmented reality. ARPiano is able to precisely locate a physical keyboard in order to overlay various objects around the keyboard and on individual keys.

Key words: Augmented Reality · Piano · Learning · Education · Music

1 Background and Related Work

Traditional music learning focuses on reading symbols in the form of sheet music. However, these symbols are abstract and there is no intuitive correlation between the symbol and the note that it represents. Additionaly, when playing piano the feedback is mainly auditory, not visual. Current theories of learning show that using multiple modalities (ie auditory and visual) in learning is an effective strategy to form mental constructs and schemas [1–3].

Current software like SmartMusic [4] and Synthesia [5] try to facilitate music learning by creating visuals and providing performance statistics. SmartMusic

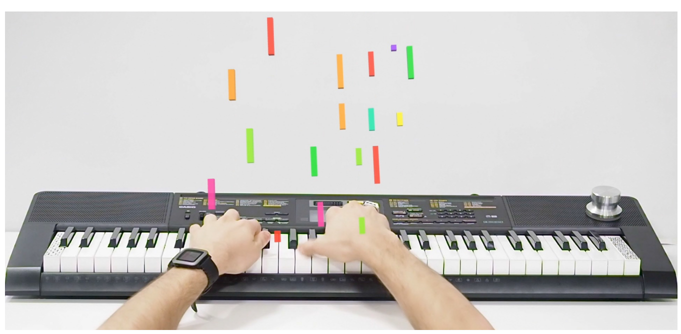

Fig. 1. ARPiano can provide a visual representation of played notes.

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uses a microphone to analyze a player's perofrmance, but it relies on sheet music and does not offer a more intuitive musical representation of the song. Synthesia, like ARPiano, renders songs in the form of a piano roll but does so on a traditional 2D display, requiring the user to look back and forth between the keyboard and the display.

1.1 ARPiano

ARPiano supports music learning, visualizations and understanding by using Augmented Reality to precisely overlay useful sprites an annotations on top of the piano. ARPiano aims to facilitate visual music learning by providing a deeper connection between the song the user is learning and what they are seeing. ARPiano visually renders a song in the form of a sequence of cuboids where the length of the rectangle represents the length of the note and the position relative to the keyboard represents the note value (similar to popular music rhythm games like Guitar Hero). This piano roll representation of a song allows users to play simple melodies without needing to learn sheet music.

ARPiano also allows for music visualization and music understanding. Music visualization is accomplished by emitting a sprite from the physical key location whenever the key is pressed. This provides the user with a visual counterpart to what they are hearing and allows them to better see patterns in the music. Additionally, while the user is playing, ARPiano is able to augment the interface to point out specific musical artifacts, such as chords, which aids in music understanding.

2 Conclusion

Before augmented reality, adding visual learning functionality to instruments required expensive hardware and visuals were limited to that hardware. With augmented reality, there is no limit to the type and position of objects that can be rendered on the keyboard. We believe this opens the possibility to rethink the way we approach music learning.

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Group Immersion in Classrooms: A Framework for an Intelligent Group-Based Tutoring System of Multiple Learners

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Abstract. This paper presents a short introduction into an Intelligent Classroom Tutoring System, which seeks to extend the classical individual based Intelligent Tutoring System into a Multilevel Tutoring System.

Keywords: Group Based Intelligent Tutoring Systems · Multi Level Group Analysis

1 Intelligent Classroom Tutoring System

1.1 Introduction

The Intelligent Classroom Tutoring System (ICTS) model is an attempt to extend the Intelligent Tutoring System (ITS) model from a single learner to a group of learners. The aim is to take the current traditional physical classroom and use that environment to assist a human teacher in delivering knowledge to the leaner. The model is split into two components, the individual ITS component, which is the existing ITS model, and a group component. The feedback loops within the traditional ITS and this ICTS model, which is where the learner, individually and/or as part of a group, is instructed through a series of teaching techniques transferring the domain knowledge via a communication interface and updating the learner model.

1.2 New Components Outlined

First, Second and Third Teacher The ICTS utilises the terminology of the Reggio Emilia approach [1] where the environment in which the education takes place is named the Third Teacher. This environment as teacher is used to inspire and direct learners through the use of external stimuli[1]. Within the ICTS Framework the Third Teacher is the AI that manipulates the environment, the group user interface, adjusting the environment to the emotional state of the room, but also defining the narrative of the lesson via the Group User Interface. The First Teacher is the classroom teacher and the Second Teacher is the ITS AI for individual learners.

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Group Model The Group Model is an attempt to capture and manipulate Group Cognition (GC). GC is different from Individual Cognition (IC). While GC is dependant on IC, a higher level of argumentative structure combined with a greater zone of proximal development can be observed within a group than within the IC of members[2]. Each group is unique based on the individuals involved within each group and the strength of group cohesion based on relationships and power structures within that group[3]. Group cohesion is dependant on the creation of group practises, which are adopted or rejected by the GC[4].

Group Pedagogy Educational researchers have tended to agree that group learning is superior to individual learning[5]. The direction of the knowledge flow, either from the teacher directly or via self learning and other learners, can be expressed as a continuum, where a teacher transfers the responsibility of generating ideas and knowledge towards the learner [6]. The ICTS Group Pedagogy Module is based on how the First Teacher wishes to construct the lesson, depending on how the groups are formed as part of the Group Model. Emotional and academic profiles of groups and individuals are passed back to the First Teacher during learning sessions. The First Teacher can then decide on how to best act upon that the information they receive.

Classroom as interface The premise of the Classroom as a Group User Interface is the idea of an invisible or transitory user interface that allows the transfer of knowledge to a group of learners. This interface is the physical component of the Third Teacher, modifying the environment of a room to either stimulate learning outcomes, act as an intermediary between knowledge and the learner, assist the First Teacher direct learner attention and support the lesson plan.
Future work includes the creation of a group matrix to identify types of groups, and an experiment utilising light as a medium for lesson structure.

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ELLE the EndLess LEarner: A Second Language Acquisition Virtual Reality Game

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Abstract. Our team has developed a virtual reality (VR) videogame, *ELLE the EndLess LEarner*, designed to enhance second language acquisition (SLA). The game is an endless-runner style (the avatar is always in motion), which results in fast-paced, engaging gameplay that we predict will motivate learners to increase out-of-class vocabulary practice. Terms are added to the game database through a user-friendly website, and the flexible game design affords it much opportunity for research on a variety of elements influencing SLA including term types (visual, auditory, textual), learner study habits and platform preferences (the game is playable on a variety of VR, PC, and mobile devices).

Keywords: VR · Second language acquisition (SLA) · Learning game · Portuguese

1 Description

Language learning can be difficult and time-consuming, especially when it comes to vocabulary retention. Second-language learner motivation often wanes when presented with a foreign lexicon they cannot easily map to prior knowledge. To alleviate this issue, our team has developed a virtual reality (VR) videogame designed to make vocabulary practice fun. *ELLE the EndLess LEarner* is an endless-runner style game (the avatar is always in motion), which results in fast-paced, engaging gameplay.

ELLE draws vocabulary terms from a database with a user-friendly front-end website where instructors can input new "packs" of vocabulary terms (organized by a theme or chapter if they choose). Students can enjoy the autonomy of selecting which "packs" to download and include in their game, monitor their progress by looking at their player data (total time played, highest score, etc.), and choose how long and how often to play.

In conjunction with these learner-centered game features, *ELLE* is designed to be simultaneously a robust language acquisition tool as well as a research instrument. The flexibility of the game will allow the research team to study the learning outcomes from players who are presented with different combinations of input (text, image, audio, etc.), as well as other aspects of language learning games such as learner self-efficacy, autonomy, and the logistics (frequency, duration, and location) of student-selected play.

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It is our intent to scrutinize a variety of aspects of language learning to determine whether or not there are more effective paths for second language acquisition for different groups of learners.

In its current iteration, *ELLE* is engaging and motivating; however, it is not very culturally immersive and does not fully capitalize on the affordances of the VR platform. For example, in this version, players have to point and click the handheld VR controller to operate the game (Figure 1). This is a scope constraint that we seek to remedy. The demo at *iLRN* 2018 will afford us opportunity to discuss ways for improving the game's design to enhance its immersive nature to more effectively facilitate language learning.

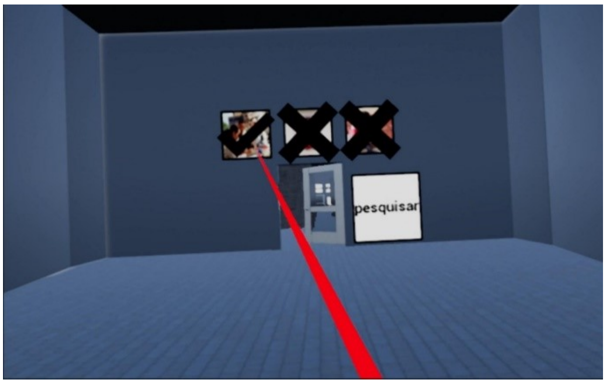

Fig. 1. Player points a laser from the Vive handheld controller to select the matching term.

ELLE is also playable on a PC or laptop in two different player perspectives (Figures 2 and 3), and a mobile prototype is also under development. We have just concluded a research study comparing the three versions to a control game. Several participants who had never experienced a VR headset were preoccupied with the non-learning elements, especially dodging the virtual brick walls. Even experienced VR players commented in post interviews that the walls were a major distraction to their ability to concentrate on the game. Work is underway to replace these walls with shorter, less intimidating obstacles; the research team views this as an opportunity to replace distracting game elements with meaningful interactions that will increase the player's learning opportunities and/or the cultural context of the game.

We have made plans to implement *ELLE* as a required assignment in a language class next Spring and are eager to study its efficacy when utilized in conjunction with a post-secondary language course. Students will be given autonomy to select which of the four versions of the game to play as well as the frequency, duration, and location of their gameplay. By studying these behaviors, we will be able to better understand student preferred methods of utilizing learning games and further iterate the game's design accordingly. We believe this information will be valuable to the field of educational technology in general and immersive learning in particular.

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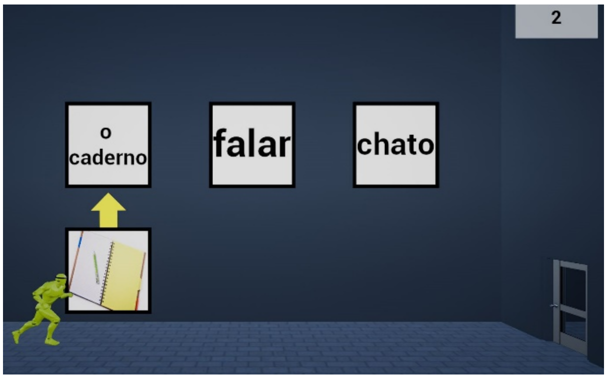

Fig. 2. The PC version of ELLE showing the side-scroller player point of view.

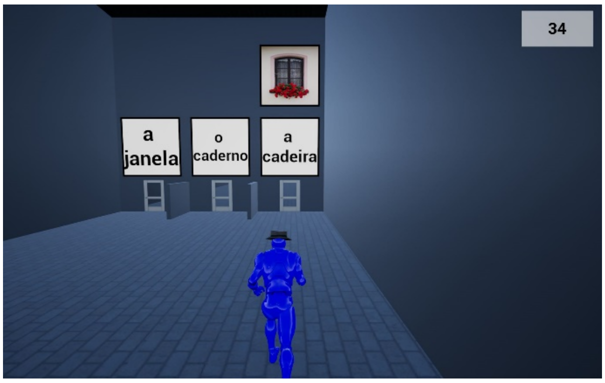

Fig. 3. The PC version of ELLE depicting the over-the-shoulder point of view.

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Visualizing Tsunami Threats to Coastal Communities with Immersive Technologies

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Abstract. Immersive technologies could help prepare coastal communities by simulating and visualizing threats posed by natural disasters and a changing climate. We have been developing a tool to help the coastal community of Port Alberni (Canada) to prepare for a tsunami. The long-term goals of the project are to help communicate, plan, and eventually coordinate the response to a tsunami.

Keywords: Tsunami · Emergency management · Disaster planning · Virtual reality · Augmented reality · Immersive technology

1 Background

Immersive virtual environments (IVEs) are increasingly being leveraged for disaster preparedness and response training [1]. Virtual reality enables accessible representations of complex scenarios that could affect communities; while augmented reality provides a means to overlay critical information on the real world environment for effective planning and decision making. Virtual reality has been effectively used to simulate sea level rise related to climate scenarios [2] and flooding [3]. These can be persuasive approaches for communicating and training communities [4]

We have been developing an IVE to help the coastal community of Port Alberni in British Columbia, Canada, prepare for a tsunami. The town is considered highly vulnerable as the Alberni Inlet would funnel and concentrate waves produced by offshore seismic activity and amplify their impact on the community. A tsunami in 1964 caused widespread physical damage and an earlier event in 1700 was even more devastating.

1.1 Goals

- Communicate the threat to the community, using immersive technologies and the sense of presence to make that threat personally relevant
- Help stakeholders plan for a disaster using the latest in earth observation data, layered with sensor data
- Provide support via a virtual emergency operations (EOC) center during the disaster.

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Fig. 1. Virtual representation of Port Alberni for tsunami preparedness

1.2 Approach

Our initial priority is to develop an IVE for tsunami education and planning for community members and students; the IVE will eventually be expanded to develop a virtual EOC for emergency managers.

The virtual model was developed by combining digital elevation models of the region with relevant geospatial layers to capture social vulnerability, critical infrastructure, transportation networks, and response assets. These layers were combined into a virtual representation of region to enable users to envision the impact of tsunamis of varying magnitudes.

The system layers disaster assets with simulations informed by earth observations and sensor data. This architecture bridges virtual benefits with real world observations, and positions the tool to be used for visually interpreting complex data and models. The sea level simulation was developed in collaboration with Ocean Networks Canada, their offshore sensor network measurements are used to extend the spatiotemporal range of tsunami detection. Immersive visualizations can help facilitate the interpretation and communication of these complex measurements and models to stakeholders

Virtual representations of the community, wired to observation data, and mapped to disaster response assets could eventually power a virtual EOC, allowing emergency managers to virtually position assets and personnel, reroute traffic, issue alerts, and coordinate the overall response. Critically, access to these capabilities via commodity headsets and devices, coupled with satellite communications, could distributed and enhance the flexibility and resilience of the emergency response.

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Debugging Computational Design: A Pedagogical Approach to Introducing a Visual Programming Platform

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Abstract. Debugging or encountering and resolving bugs is a practice embedded in computational design processes. In this study, we explored how debugging can be leveraged as a pedagogical approach to introduce youth to a visual programming tool as part of a computational design process. In partnership with a local makerspace, we conducted a workshop with seven youth (6 girls, 1 boy) ages 9-15 during which they created their own mobile games. Our findings offer insights for thinking about debugging as a productive tool not only for learning and assessment but also for instruction.

Keywords: debugging, computational thinking, visual programming, pedagogy, mobile games

1 Introduction

Encountering and resolving bugs is a practice embedded in the computational design processes. A "bug" can be defined as a minor problem that is wrong within the computer code which is easily fixable [1]. Griffin and colleagues [2] introduced "debug'ems" to describe a process of intentionally creating a bug or error in a coding language as a tool to scaffold students' learning. By intentionally creating a known error the teacher can pinpoint a desired competency that will ensure a student will practice and eventually gain mastery over the skill set, which might otherwise be overlooked during exploratory experiences [2]. In this study, we explored how debugging can be leveraged as a pedagogical approach as part of a computational design process. Specifically, we examined how a debugging activity can introduce and orient learners to the Augmented Reality and Interactive Storytelling (ARIS) platform [3], a narrative-based visual programming tool for non-programmers to build their own mobile games and experiences. ARIS consists of a web-based editor with which games are created and a client-based app with which games are played. Our inquiry was guided by the following research question: How can we leverage debugging activities as a pedagogical strategy to introduce novice programmers to a visual programming tool?

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2 Methods

In partnership with a local makerspace, we conducted a workshop with seven youth (6 girls, 1 boy) ages 9-15 during which they created their own mobile games. We introduced participants to the ARIS platform by giving them an example game to explore on an iPad, which was embedded with strategic bugs predominately focused on “locks” a key element of ARIS that controls logic. After playing this game, we introduced youth to the ARIS editor by showing them the code to the game and challenging them to debug the logic issues. We collected a range of qualitative data including field notes, interviews, video observation, screen recordings, and audio recordings. In our analysis, we examined the method of creating intentional bugs for students to resolve and how that influenced their understanding of the platform of ARIS. We collaboratively developed a codebook that utilizes iterative open (bottom-up) and elaborative (top-down) coding methods [4]. In this poster, we present key themes that we identified across participants to help shed light on debugging as a pedagogical tool for introducing novices to visual programming.

3 Results

Our findings indicate the successes and challenges of leveraging debugging as a pedagogical tool. On the one hand, participants reported that the debugging activity was an effective tool with which to familiarize themselves with the ARIS jargon and interface. For example, when asked about debugging, Jane, an 11-year-old girl, elaborated, “They [bugs] were easy to fix once you figured out what the problem was, and it was really rewarding to fix them” (Interview, December 7, 2017). Moreover, MacKenzie, a 12-year-old girl, reflected on this process and claimed, “that debugging was a good way to get introduced to ARIS” (Interview, November 28, 2017). On the other hand, some participants found the activity overwhelming. For example, Sarah, a 10-year-old girl, further expounds this idea, “Um, I didn't know where to find anything because it was my first time using ARIS,” and that “there were too many things happening at once” (Interview, February 5, 2018). A key challenge with the debugging activity was that the bugs we integrated into the code were exclusively logic bugs.

4 Discussion

These findings provide insights for thinking about debugging as a productive tool not only for learning and assessment but also for instruction. By allowing participants to search and seek out to diagnose and resolve bugs, they were authentically immersed in the platform and developed proficiency in computational design. Though some participants thought the debugging activity was helpful in starting in an unfamiliar visual programming platform, other participants were overwhelmed it. Thus, additional research is need to explore whether varying the type of bug might reduce the overwhelming response some participants had to the activity. Building on recent work exploring debugging as an assessment tool [5], our study provides evidence for using debugging activities as a pedagogical approach. Further research is needed to empirically examine

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how these debugging approaches impact specific learning outcomes in computational design activities.

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Using a wearable EEG to promote mindfulness in an adolescent with autism spectrum disorder

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Abstract. This study investigated the use of a wearable EEG that provides neurofeedback to promote an adolescent with autism spectrum disorder (ASD) to be mindful. Adolescents with ASD can have an increased risk for developing mental health disorders and mindfulness is one strategy that can help treat these disorders. Results of the case study demonstrate the wearable EEG is a promising tool to promote an individual to be mindful; however additional research is needed to further our understanding of how this device can be used for this particular population.

Keywords: autism spectrum disorder, mindfulness, wearable EEG

1 Introduction

Individuals with ASD can experience deficits in social-emotional reciprocity and nonverbal communicative behaviors across multiple settings [1]. One health concern that individuals with ASD can have is an increased risk for developing mental health disorders [1]. These disorders can include anxiety and depression and can originate in early childhood or adolescence, which is why it is essential to promote the mental health of adolescents with ASD [1].

One current strategy designed to support the mental health needs of adolescents with ASD is mindfulness. Mindfulness is the ability to be in the present moment in a non-judgmental manner and can enhance self-regulatory skills [3]. However, adolescents with ASD are generally not mindful and need additional support or other innovative methods to help cultivate the practice, especially when first learning how to be mindful [2].

A novel approach to promoting mindfulness in adolescents with ASD is the use of wearable electroencephalography (EEG) devices. Wearable EEGs may help promote mindfulness practice among adolescents with ASD and further our understanding of how mindfulness can support this underserved population. Therefore, the purpose of this study was to investigate the use of a wearable device in an adolescent with ASD designed to promote mindfulness through neurofeedback.

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2 Methods

One male adolescent diagnosed with ASD, age 16, participated in the study. The MUSE™, a wearable EEG, was utilized that provides continuous neurofeedback that is displayed in a smartphone or tablet via Bluetooth connectivity. The device detects individual brainwaves and promotes an individual to be mindful by translating brain signals into the sounds of wind, and provides how mindful the participant was as time spent being mindful. Baseline consisted of the participant wearing the MUSE™ without listening to the neurofeedback and the intervention consisted of the participant wearing the device and listening to the neurofeedback to be mindful. All sessions were three minutes each and used the ocean soundscape.

3 Results

The results are displayed in Figure 1. The first three sessions were baseline and the rest consisted of the intervention. The results suggest that mindfulness can be promoted with the support of a wearable EEG for an adolescent with ASD.

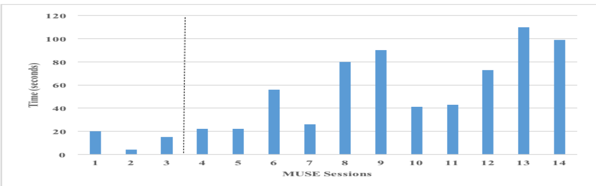

Fig. 1. Time spent being mindful in seconds during the three minute sessions

4 Discussion

The use of wearable EEGs that provide neurofeedback may be a promising tool to promote those with ASD to be mindful, due to their accessibility and inclusivity. However, future research is needed, such as larger sample sizes and replicated studies, to establish this construct as evidence-based. Longitudinal evidence is needed to further explore how wearable EEGs can help those with ASD cultivate the practice and be used for certain mental health disorders.

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Investigating the promise of the virtual field trip: Capitalizing on the advantages of virtual reality for conveying field site information

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Abstract. In education today, technologies enable learning far beyond actual boundaries. While students of yesterday went on physical field trips, today's students can experience virtual counterparts. Recent developments in immersive technologies are finally reaching a broad audience, entering the mainstream, and enabling us to deliver on a long-held promise: high-fidelity, immersive virtual field trips that can find their rightful place in education. There is still, however, little known about the effectiveness of virtual field trips compared to actual field trips. We present our research approach to study an introductory geosciences course utilizing virtual field experiences compared to an actual field trip.

Keywords: Virtual Reality. Field Trips. Geology. Higher Education

1 Introduction

Overall there are inconsistent results with virtual reality in education [1] and previous research findings on learning through virtual field trips found they enhanced actual field experiences when used in tandem, highlighting favorable student perceptions [2, 3]. Little research measures the effectiveness of virtual field trips in comparison to their actual counterparts. One study [4], provided mixed results where the virtual enhanced knowledge yet the actual trip resulted in better long -term retention. In another study [2] however, there was no significant difference in knowledge gained from virtual or actual field trips]. With a lack of consensus on the effectiveness of implementing virtual field trips compared to actual field trips, additional research is needed.

2 Developing a Research Approach

We developed a research approach to address whether virtual field trips are suitable proxies for actual field work. To explore this question, we developed a series of empirical evaluations focused on introductory geoscience field exercises in a course. We formed a three-category taxonomy to guide our experimental design: basic, plus, and

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advanced immersive virtual field trips (iVFTs). *Basic* replicates a physical environment comparable to actual field trips. *Plus* replicates the physical environment while adding access not possible in the physical world (i.e. overview perspectives through drone imagery). *Advanced* adds simulation features like interacting with a site over time.

2.1 Virtual Field Trip Development

Our approach uses head-mounted displays, HTC Vive, to deliver virtual content (contrasting from desktop experiences to create a basic iVFT. We used 360° images, 3D models from structure for motion mapping, high resolution SLR (single lens reflex camera) images, lab manual diagrams, and audio recordings narrated by a teaching assistant to replicate actual field experience. We implemented basic tools for field work such as measuring and recording the thickness of rock layers.

2.2 Iterative Experiments

The first experiment compared our basic iVFT to the actual field experience. The results indicated a positive reception of the iVFT and significantly higher learning, enjoyment, and lab grades. From these results, we generated a list of updates to address in a second experiment: 1) Image Resolution through high-resolution 360° images, 2) 3D Resolution through drone footage to create higher resolution 3D models, and 3) Elevated Perspective from high-resolution 360° images taken with a 27' tripod. The ongoing experiment uses an AB design where students participate in both the iVFT and the actual field trip. This experiment seeks to investigate the following hypotheses: 1) higher fidelity, resolution of images and 3D models, will improve the overall experience, 2) multiple perspectives, 27', will improve formation of a spatial situation model, and 3) the plus iVFT will show higher learning outcomes than basic iVFT.

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Special Tracks

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Special Tracks Preface

The field of immersive digital learning is a rising topic of research. One of the fantastic difficulties of this intricate and developing exploration field is its interdisciplinary and expansive nature. Immersive learning comprises of an extensive variety of research and fields and encourages joint effort amongst scientists and professionals from various disciplines. After our successful involvement with iLRN 2015, we have presented tracks for quality research in unique disciplines. The mission of these engaged tracks is to unite experts from different disciplines to empower an interdisciplinary cooperation and exchange of information.

This year, we welcomed experts from various research fields to submit focused tracks for this journal to feature different area of immersive learning. iLRN 2018 highlights four special tracks covering subjects:

- In the special track "Environmental Science and Immersive Learning", the track chairs Amy Kamarainen and Shari Metcalf from the Harvard Graduate School of Education invited participants to explore and discuss the process of designing learning experiences to support understanding of environmental science and to explore opportunities and challenges associated with blending immersive technologies with environmental science themes.

- The track "Climate Change and Disaster Management Immersive Analytics" is chaired by Jalel Akaichi from the King Khalid University. The aim of this track was to gain insights into innovative research that treats climate change and disaster management fields with immersive analytics methods and tools.

- In aim of the track "Immersed in Cultural Heritage", chaired by the track chairs Alan Miller and Catherine Cassidy from the University of St Andrews (UK), as well as Jonathon Richter from the Salish Kootenai College (US), was to explore and discuss the use of immersive learning environments for understanding cultural heritage.

- In the track "Immersive and Engaging Educational Experiences," the track chairs Johanna Pirker from Graz University of Technology (AT), Foaad Khosmood from California Polytechnic State University (US), and Kai Erenli from University of Applied Science BFI Vienna (AT) invited participants to discuss the potential of immersive and engaging learning environments as teaching and training tools.

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For the special tracks, 25 submissions were received, and 7 were chosen as full papers to be published in the Springer proceedings, for an overall acceptance rate of 28%. We want to offer sincere our thanks to all Chairs and reviewers of the special tracks and their commitment and commitment to making the tracks an indispensable piece of the conference by giving a wide assortment of high quality presentation with an in-depth overview of the different research topics on immersive learning. We thank every last individual who contributed toward making the special tracks to such to an essential and successful part of the conference.

Johanna Pirker
Allan Fowler
Special Track Co-Chairs

Special Track

Environmental Sciences and Immersive Learning

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Immersive Virtual Environments and Climate Change Engagement

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Abstract. Climate Change will affect our lives, yet communicating about climate change has proven to be more complicated than initially thought. Recent attention has turned to the potential affordances of immersive virtual environments (IVE) to support public engagement around climate change. We offer theoretical arguments for ways that IVEs may influence understanding, emotion, and behavior related to climate change, and we present a systematic literature review covering IVE applications to climate change. From 619 papers, 55 were fully reviewed. The findings were analyzed and discussed according to how IVEs may influence understanding, emotion, and action related to climate change. Findings suggest that IVE has a positive outcome in climate change engagement and the use of IVEs in the context of climate change warrant further investment of resources toward design and research.

Keywords: Climate Change · Immersive Virtual Environment · Virtual Reality · Augmented Reality · Mixed Reality

1 Introduction

1.1 Challenges in communicating about climate change

Although the effects of climate change are evident [1] it remains a struggle to communicate about causes and outcomes associated with climate change. Scientific articles that use numerical projections and text-based descriptions fail to capture the character of anticipated changes and possible futures. Climate change will affect all our lives [2], but the effects seem remote when reported at national or global scales.

In efforts to communicate about climate change, messages used in mass media tend toward stories that are emotionally charged, in efforts to grab attention. Yet, research shows that invoking fear can be counterproductive [3], and that effectively communicating about climate change is more complicated than initially thought [4]. Sparking awareness is only a start, and changing attitudes is still not enough; current thinking suggests that meaningful impact requires public engagement with climate

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change. Engagement is considered to have three components 1) understanding (knowledge), 2) emotion (interest and concern), and 3) behavior (action) [5].

Recent attention has turned to the potential affordances of immersive virtual environments (IVEs) – including virtual environments, virtual reality (VR), augmented reality (AR) and mixed reality (MR) - to support public engagement with climate change. Below we outline a theoretical rationale for the potential of IVEs to impact this space, and we provide a review of work that is represented in the literature.

1.2 Theoretical framework for the use of immersive virtual environments to support climate change engagement

Immersive virtual environments offer fundamentally new ways to communicate the causes and consequences of climate change. Building on the components of engagement, we outline theoretical arguments for how IVEs may influence understanding, emotion, and action related to climate change.

Supporting understanding. Prior work on the use of AR shows that vision-based AR can support student understanding of concepts that require interpretation of complex spatial relationships – concepts for which visualization is a useful tool [6]. For example, Shelton & Hedley [7] report on improvements in conceptual understandings of complex spatial concepts associated with earth-sun relationships while vision-based AR used in physics and astronomy laboratories had positive effects on students' attitudes, skills and conceptual understanding [8, 9]. The application of IVEs in K-12 educational contexts reveal other theoretical and empirical benefits of using IVEs to support reasoning about causal dynamics embedded in complex systems. Prior work on the EcoMUVE project, which uses a multi-user virtual environment as part of a middle grades ecosystem science curriculum, demonstrates that student use of the IVE supports new forms of thinking about time and scale as they relate to ecosystems [10], supports adoption of process- instead of event-based reasoning [11], and engages students in practices, like modeling, that align with expert approaches for understanding complex systems [12].

Engaging emotions. IVEs offer the potential to elicit emotional states through manipulating the visual, auditory and haptic stimuli presented to the user, and the strength of the emotion is linked with the users sense of presence [13]. By invoking a sense of presence, IVEs can support intense feelings that make a user think, feel and behave as though they are really embedded in the place represented by the computer-generated virtual space [14]. It is possible that such affordances of IVEs may be applied to climate change in order to position users in a context that elicits specific emotional responses, like a sense of wonder about the natural world or horror at the destruction caused by coastal flooding. However, design and use of IVEs to elicit emotional response remains poorly understood, and while some constrained designs systematically elicit intended user emotions [15], it is also common for users to have diverse emotional reactions to the same experience (J. Bailenson, pers. comm.).

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Inspiring Action. A core theoretical domain related to IVEs is that of embodied cognition. We interact, communicate and learn through movements, gesture and physical activities [16]. Research shows that designing learning activities that encourage actions that are linked with concepts can support the formation of memories, prepare users for future learning, and help people link observable and unobservable phenomena, but these interactions must be designed carefully for these purposes [17]. IVEs for kinesthetic training suggests that the medium can be particularly powerful when users have opportunities to practice movements and decisions that mimic those that will be made at a later time in a more complex context [18]. For example, in his book, Experience on Demand, Jeremy Bailenson recounts how quarterbacks in the US National Football League are using VR to train for games, and experiencing improvements in performance. Such affordance of IVEs to elicit movement, gesture and interaction might offer possibilities for encouraging embodied understanding related to climate change or supporting the habituation of pro-environmental behaviors.

2 Research Methodology

2.1 Search Strategy and Terms.

This review was based on published research papers available until early March/2018. Terms and databases used are described as follows. The terms used in the search were: Immersive Virtual Environment, Virtual Reality, Augmented Reality, Mixed Reality and Climate Change. The search thus used the following string in each online database, composed of Boolean operators (AND/OR): *(("immersive virtual environment" OR "virtual reality" OR "augmented reality" OR "mixed reality") AND "climate change")).* The online databases used and number of articles found (n) were: ScienceDirect (n=499), Scopus (n=78), Web of Science (n=29), IEEE Xplore (n=7), ACM Digital Library (n=5) and ERIC (n=1). These databases were chosen to cover the multidisciplinary nature of the use of IVE in climate change engagement. Papers were further subject to the inclusion and exclusion criteria below.

Inclusion Criteria.

- Peer-reviewed research papers written in English
- Studies directly investigating the research questions
- Papers describing the outcomes of using IVE in climate change

Exclusion Criteria.

- Papers not describing outcomes of using IVE in climate change engagement
- Papers not answering the research questions
- Papers not available through our institutional access and not available after requested to their authors (not retrieved)

2.2 Research Questions

1. How are the studies distributed geographically and temporally?

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2. What types of immersive medium are used?
3. Which topics and population are investigated?
4. What are the outcomes reported of using IVE in climate change?
5. What are the suggestions for future studies reported by the authors?

3 Results

The 619 total papers were evaluated according to the title and abstract. Of these, 55 were selected and fully evaluated. They were classified into 3 categories: Education and Communication (EdCom), Analytics, and Plan. "EdCom" focused IVEs for climate change communication, education and awareness; "Analytics" focused on IVE for analytics, modeling and data visualization; and "Plan" focused on IVE for environmental or urban planning and decision making at a community or landscape scale. After full evaluation, the papers were categorized according to their topics and outcomes (Understanding, Action and Emotion), as can be seen in the Table 1.

Table 1. Results

Topic / Outcomes	EdCom			Plan			Analytics		
	U	E	A	U	E	A	U	E	A
Animals	[19, 20]								
Carbon footprint	[21]						[22]		
Concepts about Climate Change	[23–28]	[29]		[30]					
Energy consumption			[31, 32]				[33, 34]		
Heritage Sites	[35, 36]								
Land use and Urban Planning			[37]	[38–40]	[43]	[38–43]	[44, 45]		[45]
Landscape visualization	[46–48]		[49]	[50–53]		[51, 53]	[47, 54, 55]		
Multiple environmental scenarios	[56, 57]						[58–64]	[60]	
Risk assessment / management		[65]	[65]	[66]			[67–70]		[69, 70]
Sea rise		[71]		[72]		[72]	[73]		

U:Understanding; E: Emotion; A: Action.

3.1 Distribution, Target Audience and Medium

Most of the studies are from US institutions (12 papers), followed by United Kingdom (11), Australia (9) and Canada (6). Germany and The Netherland count with four publications each. The following countries count with two publications each: Austria, China, Hong Kong, Israel, Italy, New Zealand and Spain. Finally, there is one publication of each of the countries: Denmark, France, Greece, Norway, Portugal, Republic of Korea and Sweden. The papers' publication date ranges from 2005 to 2018,

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with a peak of publications in 2010 (9), followed by 2015 (11), as showed in Figure 1. Maybe the increased interest EdCom in Climate Change in 2009 is due to the Copenhagen Climate Change Conference held in December by the United Nations.

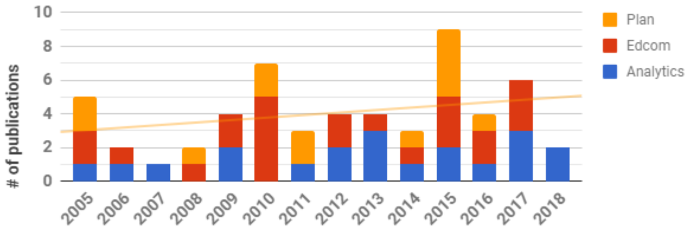

Fig. 1. Publications' year

Most of the studies in Plan target researchers and/or decision makers, as expected. Studies in EdCom target mostly students, with a balanced distribution among the school levels. Many studies focus in technological solutions and outcomes and do not specify the audience for which they are intended. Figure 2 shows the Target Audience distribution.

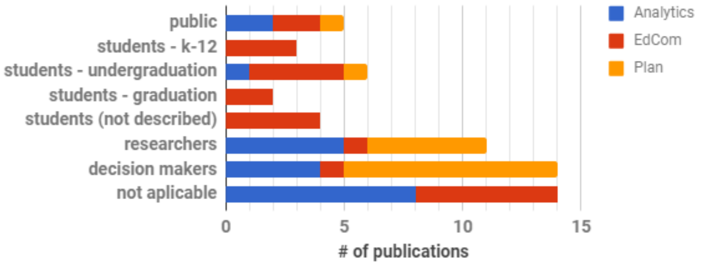

Fig. 2. Target Audience

Most of the studies used single screen (as desktop monitor) as the medium to project 3D images or animations, followed by Augmented Reality and HMD (Figure 4).

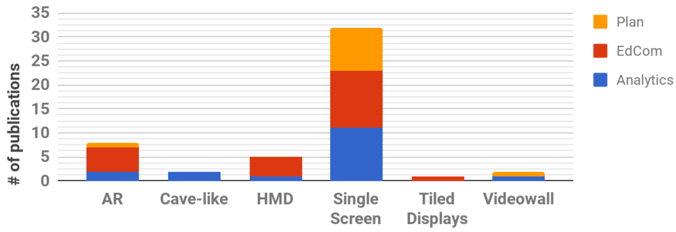

Fig. 3. Medium

3.4 Outcomes

Outcomes are summarized according to: Understanding, Emotion and Action.

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Understanding: studies reveal positive outcomes in climate change understanding, especially direct and indirect impacts and awareness of strategies to mitigate climate change [20, 28, 47, 57], higher engagement on the topic [19, 23, 25, 27, 46] and on related community problems [25] and greater ease in collecting and correlating data on climate change when using AR applications [47]; with the Plan category, papers prior to 2011 [30,38-40,43,53] focused on describing the technical infrastructure and value of using advanced forms of visualization of spatial data and information to support land use planning, landscape design and scenario exploration, with minimal attention to the describing or measuring the utility and value of these visualizations to the users, with the notable exception of [52]. From 2014 onward [41-42,50-51,66,72], the papers related to land use planning and landscape design bring up theoretical areas like "presence," which demonstrates co-development with theories in the field of immersive technologies. IVEs have the potential to advance climate science through immersive and interactive interfaces that democratize access to data models and simulations to scientists from a broad array of discipline and beyond, to the general public and citizen scientists. This utility has been demonstrated through a range of applications spanning health care, business, climate change, and natural disaster [61]. Broadly, they allow users to interact with complex scientific models without prerequisite training with the background and tools necessary to convert raw data into visualizations. The feeling of realism, demonstrated by examples such as VR-Ocean [73] allow users to gauge the impact of melting ice from complex global data sets such as altimeter and ice surface data. Furthermore, 4D models allows users to understand the past through climate reconstruction models [55] and to 'live' the future effects of sea level rise on their communities [70]. However, the current state of the science is biased towards Western, English speaking nations and powerful interests that shape our mediated experiences of climate change through the media [60].

Emotion: the use of IVE promotes occupant engagement in energy-saving building design [31]; also, people demonstrate increased willingness to engage with climate change issues in conjunction with rich media visualization[29]; Although virtual field trips can be expensive they generate positive engagement and feedback from students [23]. Teachers and students report that AR authoring is motivating and engage students beyond climate change issues, to issues within their communities [25]. An interactive flooding 3D simulation increased the motivation to evacuate from the virtual polder (low-lying, flood-prone, tract of land protected by dikes) as well to buy flood insurance [71]. The use of immersive and virtual environments for Planning addressed understanding and action, but emotion was not raised as a focal dimension. The emotional impacts of these visualizations can be mixed, on one hand they provide a lens to the scientific state-of-the art for laypersons without formal training; however, reports describing frightening case studies in sea level rise can be alarming to observers [73]. For instance, a thirty-five year simulation of sea level rise presented 348 South Florida home homeowners revealed that 75% of the participants were willing to support the costs of adaptation projects; however, many of the participants reported an interest in moving out of the region in an emotional response to seeing potential climate impacts [70].

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Action: an experiment done in an immersive virtual environment (HMD) using vivid images suggests that it can elicit pro-environment behavior[32]. A study comparing avatars to voice and text found that avatars in the IVE are more effective than voice and text to promote pro-environment compliance [37]. Also, a study suggests IVE may increase awareness of strategies to mitigate negative impacts of climate change [56]. Our theoretical concept of action was introduced from the perspective of an individual, but the papers also described VR and immersive visualizations as a way to engage stakeholders in process oriented VR experiences that were participatory and collaborative [41]. Platforms such as SUNPRISM [62] add an additional level of interactivity by allowing users to visually design application scenarios with limited or no coding experience.

Others reported that these interactive and extensible platforms would allow scientist to spend more time on their core research interests rather than database and processing challenges [61]. Among sectors that stand to mitigate or reduce the potential impacts of climate change, advances in IVEs are allowing designers to simulate and control energy chains via IVEs at the district level, coupling real time data from sensors with advanced simulations to assess the energy performance of buildings [33] Across the building sector, 4D IVEs are facilitating prototyping during project planning for construction projects to minimize carbon emissions [22] Again advances in IVEs are democratizing complex 3D building and power grid modeling, simulation, and logistics exercises for a wide range of users in sectors critical to mitigating climate change.

3.5 Future Studies

With regards to the technical medium used, some studies suggest the use of VR headsets to richly communicate cultural paradigms and important contextual factors [23]. For visualizations and imagery, it is suggested that additional psychological research on climate change perception and behavior is necessary, using controlled visual landscape imagery[49] and emotional, social and intellectual support to lead to deeper behavioral changes [24].; standardization across platforms[36, 46]; to investigate what kind of images best represent the scientific information to be communicated, how the audience is influenced by these images [29] and what scientific monitoring of real-world projects would help model future scenarios [49]. Also, one study suggests developing a low-cost VR platform for displaying forest monitoring data to support analytical reasoning and decision making [48]. When using IVE for energy-saving building, authors highlight the importance of future studies to identify prospective occupants [31], using avatars to enhance the communication between buildings and their occupants to support pro-environmental behavior [37]. Finally, others recommend integrating AR games into the daily life of students [25] and the need for strategies to compensate for GPS failure in dense vegetation locations [47].

In planning, considerations of realness, verisimilitude, and uncertainty were cited as focal points for future study [52-53]; Variability in the availability of VR hardware, and lack of standardization were listed as barriers to wider use of VR in environmental planning [41]. A number of studies cited the need to increase access to objects data and code [62] to facilitate extending the tools to other research and applied domains. Others stated that the tools they were developing could be readily extended to interdisciplinary audience if the codebooks for were made more accessible [60]. While many studies

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employed commodity hardware, there was the sense that new tools and algorithms would advance the state of the experience, the ability to extend the capabilities, incentivize climate investigation through gamification, and introduce semi-automation to shift data generation and analysis beyond form-filling and selective technologies with a high technical barrier to entry [47].

4 Discussion and Conclusions

There was a relative paucity of papers on the design and testing of IVEs to support climate change awareness, mitigation, and adaptation (n = 55), and only twenty two related to education and communication. Engagement and motivation were key outcomes in many of the studies. The limited number of publications indicates the need to understand how IVEs may be leveraged to support public engagement with climate change.

Ockwell, Whitmarsh & O'Neill [5] speak of engagement as a three-part construct (understanding, emotion and action), and argue that all three parts are necessary to elicit change in public perspectives related to climate change. There are compelling arguments how IVEs might influence all three; some of the research papers evaluated more than one of these dimensions [38–40, 43, 45, 51, 53, 56, 60, 65, 69, 70, 72], but none studied all three parts. Could rich immersive virtual experiences potentially tap into all dimensions?

A number of studies focused on the potency of visual aspects of the experience, especially images and details in the visual display. This is not surprising, given that IVEs tend to be richly visual spaces. More innovative are the studies that focused on new forms of interaction that are enabled by IVEs. A number of the experiences drew on user input and interaction, requiring users to interact with virtual objects or data, thus activating a sense of agency in the virtual space. Also, in some cases, designers integrated forms of simulated social interaction by using avatars to personify data. These forms of kinesthetic and social interactions warrant further research, as the work presented here suggests these can provide powerful contexts for eliciting motivation, self-efficacy, and action.

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Postropolis Learns?

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Abstract. The primary objective of this roundtable is to launch and continue a discussion of the Postropolis concept—which is manifesting as both an iterative book project and an immersive digital learning platform—especially concerning the relevance of this Postroplis concept as a learning and assessment space, driven by interactive data visualization for the purpose of individual and collective behavior change through better decisionmaking over time.

Keywords. Learning, platform, environment, sustainability, behavior, decisions, interactive data

1 Postropolis

Postropolis is the conceptualization and planning for what comes after cities in human civilization. Let us conceptualize and build one big "after-city-state" of networked nodes of dynamic human habitation distributed appropriately across the planet according to natural physical boundaries. Pragmatically, Postropolis is a watershed-driven network of dynamic urban core districts connected through a resilient human transportation network. Postropolis is a platform, a learning system, and a commons, fostering systems thinking and wisdom for all people, *by doing what we do*: living, working, interacting with machines and natural environments—all within an eco-socio-technical system: environment subsumes people, and people build/control technology in service of both.

The book initially contains nine chapters:

1. Introduction
2. Why Postropolis?
3. Systems Wisdom and the Ecology of Postropolis
4. Postropolis As Platform: Deep Shifts in Experience through Critical Data Analysis
5. Postropolis Learns
6. Postropolis Sleeps: Urban Core Districts
7. Postropolis Moves: Human Transportation Networks
8. Postropolis as Commons
9. Loving Resistance: Eco-Socio-Techno-Postropolis

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Each of these areas of Postropolis can be discussed in terms of their relevance to immersive learning/assessment and research, both in terms of process and content. *Clearly, a focus on Postropolis as platform and learning/assessment system (chapters 4 and 5) will be the forefront of the discussion.*

In chapter 4, Postropolis is conceptualized as a platform for understanding change and growth in humans and non-human species through their behavioral patterns and relationships with each other, machines (both real and virtual), and information. Schwab's deep shifts of the fourth industrial revolution (such as implantable technologies, Internet of Things, driverless cars, big data, artificial intelligence, sharing economy, and 3D printing) are critically analyzed through the lens of ecological literacy and principles of systems wisdom, informing ways Postropolis—especially as a platform—can support these shifts in ecologically appropriate ways. Postropolis as platform is further explored and articulated using fundamental aspects outlined in The Platform Revolution (and its precursor, Platform Scale), such as architecture, disruption, monetization, openness, governance, metrics, strategy, and policy. Interactive data visualization as the key language of Postropolis as a platform is investigated in terms of how to build and deliver visualizations in ways most useful for stakeholders over time, especially as the basis for lifelong learning, decisions, and behavior change (growth) within Postropolis. Finally, Postropolis is conceptualized as a hybrid simulation (in terms of the informational relationships articulated above), measured, assessed, and evaluated using an xAPI-based simulation relationship assessment data framework. Functional individual, community, organizational, and infrastructural perspectives of this framework in action will be explored, including interspecific interactions.

The framework established in chapter 4 leads into an understanding of Postroplis as a learning system (chapter 5), conceptualizing Postropolis as one dynamic digital-hybrid school across human generations and interspecific relationships, as well as how to design relationships between humans and information across time and space for the sake of continuous learning. This is followed by an articulation of this learning system design through the lens of evaluation, assessment, and measurement, in terms of evidence-centered assessment design and its four-process architecture of assessment delivery, and the four-space model of simulation-based assessment—based on the "Postropolis as simulation" argument made in the previous chapter. Individual, organizational, and interspecific interactions (conceived as learning activities) are explored as functional, cultural, and critical phases of growth in ecological literacy, as well as modes of belonging—engagement, alignment, and imagination—in communities of practice. Finally, interactive data visualizations are revisited and explored in specific service of these learning activity interactions.

Goals and outcomes of this discussion include: increased awareness of the Postropolis project, continued articulation of chapter contents and structure, discovery of additional relevant examples for inclusion in v1.0 of the book, understanding the value of Postropolis as curriculum for more traditional learning environments, and building of

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relationships with potential digital platform collaborators and future co-authors or contributing authors.

Special Track

Climate Change and Disaster Management Immersive Analytics

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Immersive Analytics for Floods Management Semantic Trajectory Data Warehouse Ontology

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Abstract. Semantic Immersive Analytics is a new paradigm that has the capability for visualizing ontologies and meta-data including annotated web-documents, images, and digital media such as audio and video clips in a synthetic three-dimensional semi-immersive environment. More importantly, it supports visual semantic analytics, whereby an analyst can interactively investigate complex relationships between heterogeneous information and supports query processing and semantic association discovery. In our previous work we proposed a Semantic Trajectory Data Warehouse Ontology (STrDWO) [15], a tool supporting designers at the modeling of ontology-based trajectory data warehouses. In here, we intend to integrate our aforementioned tool with augmented Reality (AR) technologies to provide multi-sensory interfaces that support collaboration and allow users to immerse themselves in their data in a way that supports real-world geo-space analytics tasks. To do so, we present a Semantic trajectory data warehouse having an ontology-based multidimensional model. We illustrate our approach by a case study dealing with floods management.

Keywords: Data warehouse, trajectory data, ontology, floods management, immersive analytics, augmented reality

1 Introduction

The leapfrog of remote sensors and sensor networking technologies is leading to the eruption of disparate, dynamic, and geographically distributed mobility data. For a long while, location sensing devices such as (pda, smartphone, tablet) and sensor networks such as (WIFI, fiber optic,3G-4G networks) started becoming untethered. As a result, different structures of mobility data sources revealing the details of instantaneous behaviors conducted by mobile entities can be constructed.

Note that, trajectory data, which is a record set of gathered mobility data, can be associated to different domain-specific information. Trajectories are naturally represented as *raw trajectory* denoting a sequence of temporally-indexed positions. For example, a flood is defined as an overflow of water resulting from

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different bodies of water such as a river, a lake or an ocean. it moves with a varied speed and a depth that change instantly. Indeed, flood move in a geographical areas located near this river. In this case, we refer to flood waves as the moving object that moves in time and space and to flood movement as flood trajectories. In the other side, ontologies have emerged as more flexible, reusable and manageable modeling solutions. It may provide common model for different representations of flood trajectory data where designers can pick the appropriate knowledge to define flood trajectories in view of share, exchange or integration [15]. Alongside, data warehousing techniques are expected to analyze and extract valuable information from different flood trajectory data sources [14].

For this purpose, this paper throws light on a Semantic Trajectory Data Warehouse (STrDW). We emphasize a geometric module in order to represent common structures encountered in trajectories associated with links to application and geographic modules in order to maintain semantic interoperability. Furthermore, our model serves to define the STrDW conceptual model. Our proposal permits to save too much designers efforts and time needed to acquire domain knowledge since the latter is extracted from the floods ontology. This will mainly highlight the trajectory to be seen as a first class semantic concept, providing an ontology-based multidimensional model.

Immersive analytics represents a set of novel visualization techniques of big sets of data. The former investigates new display and interaction technologies for supporting analytical reasoning and decision making. Accordingly, we later use the aforementioned techniques to generate a STrDW for floods managements encompassing floods data from different data sources. And to facilitate data analysis and management we use immersive analytics technologies to introduce our vision of an AR tools for floods data visualization.

Therefore, this paper is organized as follows. First, we'll give an overview of STrDW modeling. Then we'll introduce the floods data ontology and the STrDW used for floods management. After that, we ll review previous works on immersive analytics. We'll introduce our vision of the future visualization system for our flood management STrDW. Finally, we'll conclude this work.

2 Semantic Trajectory Data Warehouse: Overview

Trajectory Data Warehouse (TrDW) is considered as an efficient tool for analyzing and extracting valuable information from heterogeneous trajectory data sources. A TrDW is the application of data warehousing techniques on trajectory data [13, 22]. Before getting to the TrDW, research communities were interested in analyzing spatio-temporal data in Spatio-Temporal Data Warehousing (STDW). There have been various proposals of multidimensional models for STDW [25] aiming at the integration of various data sources containing spatio-temporal data. Trajectory data is a particular case of spatio-temporal data characterizing objects mobility. Then, a TrDW is obviously a particular case of STDW where trajectory is the fact [13, 4]. However, obtaining an implementation of the DW is a complex task that often forces designers to ac-

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quire wide knowledge of the domain, thus requiring a high level of expertise and becoming it a prone-to-fail task. The first attempt to set a Semantic Spatio-temporal Data Warehouse is given by authors in [8] which annotate the datacube elements with domain ontologies as well as mathematical ontology. Data Warehousing works analyzed above present some limitations in the fact of managing trajectory data, especially when dealing with the semantic aspect of trajectory data. Several works in the literature consider the trajectory concept is beyond a record set of time stamped positions. Indeed, a trajectory exceeds its classical definition to be considered as a semantic entity related to a semantic layer of thematic information. So, the need to emphasis the trajectory to be seen as a first class concept motivated us to propose throughout this work a multidimensional model of TrDW, namely a Semantic Trajectory Data Warehouse (STrDW) model, which is meant to be more than a classical trajectory data repository for storing and querying raw mobility data. Recently ontology building attracted researches aimed at supporting TrDWs with semantic models [18, 14]. The multidimensional model presented by a STrDW conceptual model, inspired from an existing ontology model. This will emphasis the trajectory to be seen as a first class semantic concept, not only a spatio-temporal path. Thus, the semantic multidimensional model is meant to be more than a spatio-temporal data repository for storing raw mobility data. By exploring the literature, we find little concrete work on conceptual design of TDW considering the semantic aspect of trajectory data. Taking a brief overview on similar works, the closest and the only true design of TrDW using semantic concepts that can be recalled, is the solution discussed in [18]. In this paper, authors proposed an ontology-based TrDW related to the marine mammals field. The design methodology they propose deals with a specific domain ontology and a specific structure of trajectory data valid only for the case of marine mammals and didn't propose a generic methodology to extract the semantic TrDW model from a semantic representation of common structures of trajectories.

3 Floods Trajectory Data

A flood is defined as an overflow of water resulting from different bodies of water such as a river, a lake or an ocean. A flood therefore moves with a speed and a depth that change continuously. In addition, these movements generally affect the geographical areas located near this river or this lake or ocean with variable degrees. For this fact, we refer to flood waves as our moving object moving in time and space. We are looking through this topic to detect flood trajectories in real time in order to plan the paths of rescue agents to ensure the rescue task in optimal time. In this work, we'll opt for an ontological solution to model floods trajectories to help in their management, especially that ontologies really offer a great semantic richness (Figure 1).

We first identify the classes forming our ontological model. There is mainly the *Flood waves*, the highest node that inherits from the *Thing* class. Several other subclasses are related to the class *Flood waves* such as *Side, Flooded area,*

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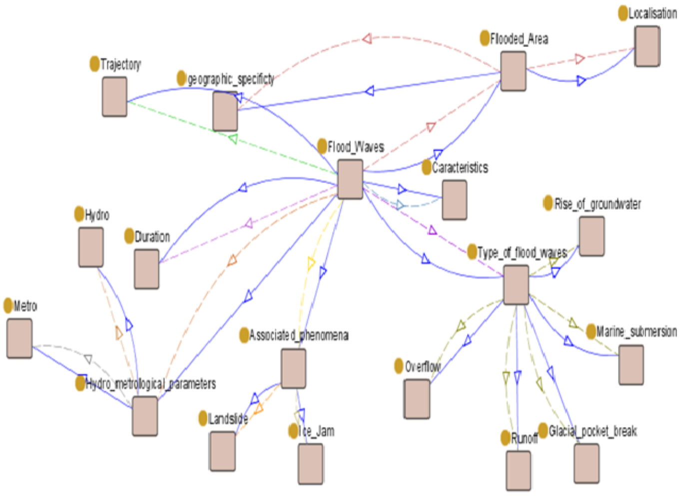

Fig. 1. Ontological modelisation of Flood wave

Time, Characteristics, Associated phenomenon, Hydro-metrological parameter, etc. Most of these subclasses themselves contain other subclasses for example: the subclass *Duration (Start date, End date)*, *Associated Phenomenon* subclass of *(Burrowing, Icebreaking, Icebreaking, Landslide, Gully)*, the subclass *Flooded Area (Geographic Specificity, Localization)*, the subclass *Type of Flood* itself includes other subclasses and sub-subclasses *(Overflow (Snowflood, Rainfall), Runoff (Rural Runoff, Urban Runof), Breakage of work (Dam, navigation channels, Reservoir, pumping station,etc), Marine submersion (Tsunami, Sea / Tide, and wave actions, ...)*. The subclass Type of floods will be detailed in the (Figure 2). Our model presents different types of interrelationships between classes, some of them are defined through our proposed model (Figure 3). We note for example:

- The *hasTrajectory* relation connects between *(Flood waves and Trajectory)*.
- The *is-a* relation connects between (*Flood waves* and *Type of flood waves*).

Later in the next section we'll integrate this model into a more general and generic model with more detail on trajectories and geographic specifications, the STrDW, to improve response time and emergency process in case of disasters.

4 Floods Management STrDWO

With the increasing use of ubiquitous localization and positioning technologies such as remote sensing, GPS and mobile technologies, huge amounts of data are

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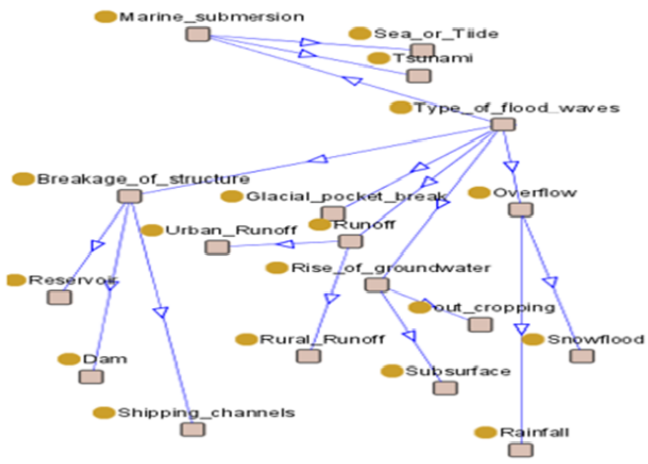

Fig. 2. Subclass modelling of Type of flood

being collected every moment. These location data are defined as the trajectory data. Typically, these types of data are in the form of a triple (x, y, t) where x and y form the geographic coordinates and t supports the moment when the moving object occupies that location [3]. Indeed, these voluminous data need to be stored according to the most appropriate model to ensure their best interpretations. For this fact, in this work ontology modeling is used for the proper representation of the floods management issue which encompasses big set of data. In this paper, we are interested in highlighting the STrDWO for floods management based on a work recently proposed by [14] and on the basic model initially developed by [24], consisting essentially of three ontologies (ontology of trajectories, a geographical ontology and a domain ontology). The model that we assume is made up of a generic ontology composed of four types of resources: fact, thematic, temporal and spatial are respectively represented in the following sub-ontologies modules :

- GTO: contains different concepts spatio-temporal necessaray for the geometric description of trajectory.
- FMO and GO:
  - FMO: describes domain ontology dedicated to represent the concepts necessary to understand the field of floods FMO: describes domain ontology dedicated to represent the concepts necessary to understand the field of floods
  - GO : specifies the geographical concepts related to undrestanding a trajectory.

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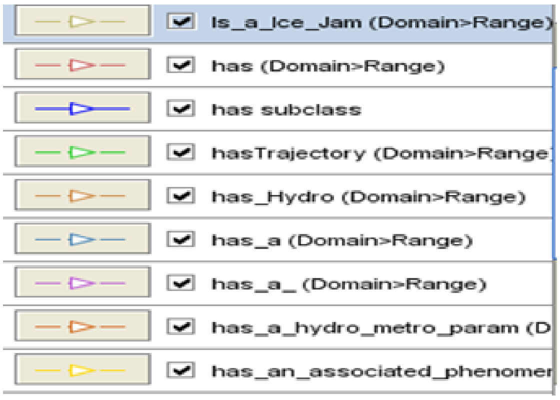

Fig. 3. Some types of relationship between the classes

- Temporal Ontology: Temporal concepts and roles are based on the standard Time-owl ontology3 developed by W3C.
- Spatial Ontology: Spatial concepts and roles are based on Geo ontology4developed likely by the W3C standard.

In addition, this model offers in parallel the different relationships and links connecting the different concepts. Among them, we quote (Figure 4):

- *hasAffected* is a property between the concepts Flood waves and Geographic Area means the area affected by this flood.
- *isLocatedIn* is a property between Flood waves and Trajectory describes the trajectory followed by the flood.
- *hasSpecificity* is a property between Trajectory and Geographic Area specified the trajectory specificity for each geographic area.

5 Immersive Analytics: State of The Art

Nowadays, with advances in immersive technologies used for interaction and display such as tangible screens and headsets they became widely used to analyze and explore data. In fact, such immersive environments support collaborative work for data exploration and leverage users' actions in such tasks. Also, the affordance of display devices used for analyzing data effects strongly the experience of user while interacting with these systems which effects, consequently, users' degree of productivity. Immersive Analytics (IA) is a new and emerging initiative defined by providing a set of techniques to augment human ability of making sense of noisy, massive, heterogeneous and multifaceted datasets and deriving insights from it based on high resolution and immersive environments. It is multidisciplinary research thrust representing an interaction of technologies for data analytics as it brings together researchers from visualization disciplines

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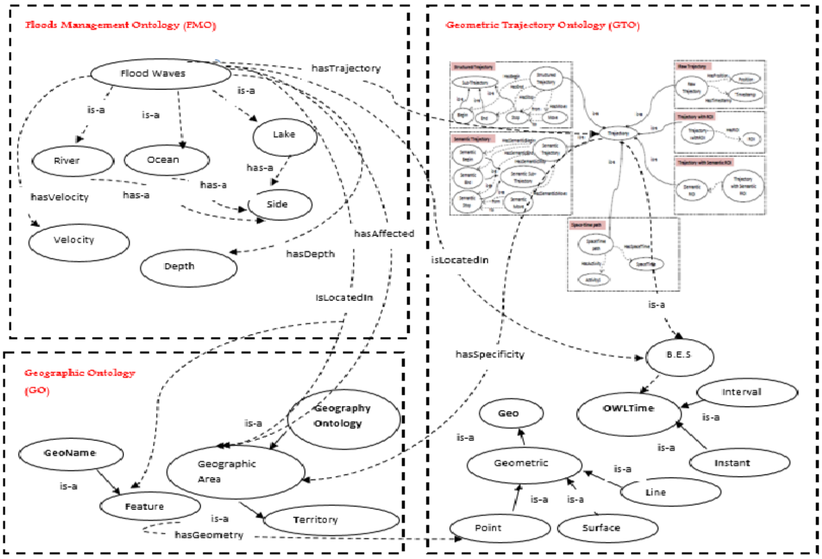

Fig. 4. STrDWO for floods management

in data science including visual analytics mainly, information visualization, scientific visualization, 3D natural user interfaces, hybrid, virtual and augmented reality. Visual analytics provides analytical reasoning facilitated by visual interactive interfaces [12]. IA, then, investigates how the emerging and powerful visualization, display and interaction technologies could be used for creating seamless data visual analytics and supporting analytical reasoning and decision making [5]. Since the rise of this research field, a lot of work has been done to visualize in immersive systems data coming from different applications and case studies such as: crisis management, animals tracking, medicine, etc [21, 11, 1, 7]. Actually, classical data visualization, despite its long history, has not gone much beyond tradition devices: keyboard, mouse, flat screen, etc. Which is not the case for IA as it supports data analytics in many ways by the usability and design of its user interfaces in such systems. For instance, immersive technologies permit to show many views at the same time. In fact, nowadays, rather than its complexity, data is considered as widely available. Such big datasets are difficult to precess. Indeed, decision making relies on computer processing of data. Otherwise, visual methods are advantageous for the exploration of large datasets, their understanding and then propitious decision making. In fact, big datasets need to be visualized in more than one view. IA allows people to organize views, make sense of data and reach collaborative conclusions based on a shared information space. Furthermore, it helps showing larger information spaces than desktop computers. Such interactions could allow movement within the views. Other works subdivided display space into multiple views, each presenting some aspect of the data. This requires to organize the visualized data within a single

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large view [12]. Emerging IA works focus on binding entities movement with data exploration process. For instance, in the work of [10] authors introduced a tool for data exploration based on the user location since Human Computer Interaction (HCI) relies on binding between user actions and system's response. This tool relies on mixed reality (MR) and virtual reality (VR) tracking techniques to detect their users movements and interact later with data exploration system. MR is the interaction between virtual and physical world. Hands movements are also detected and used to manipulated and select the data. Furthermore, in the work of [16] IA was applied to an animals tracking case study. I-Flight, a visual analysis system based on virtual reality for insect movement data is proposed. This system helps to understand flights movement and then its behavior in a simulated environment. I-Flight permits to visualize insects trajectories in their natural 3D geospatial context. In fact, such visualization system complements existing scientific methods and tools for analyzing and understanding data. Most of the work in the literature that visualized movement data used conventional desktop displays. From another side, immersion is beneficial in the acquisition of spatial knowledge. Also, virtual reality headset natively supports position tracking to allow users to move and look around naturally in the 3D environment. Differently, in other works IA was applied to environmental case studies. For example, researchers in [17] explored data recorded from approximately 18000 weather sensors placed across Japan in local and global contexts in a VR visualization system developed using the HTC Vive and the Unity engine. Originally, sensor data was visualized by the public via a simple web interface through a list of small maps with links for sensors. Accordingly, it was hard to get a global idea of the sensors at the national level, to respond to large scale natural disasters (floods, storms, etc). In this work authors went farther by investigating a variety of methods for user interaction with data: flying around the map, open an interactive window for any sensor, seek their position in time. Also, the VR provided a country-wide view of data and allowed querying of each sensor. To display the sensors in the 3D map of Japan, vertical bars are used, they change in height each time their value is updated to ensure a flexibility in data analysis and interpretation. In the work of [9] a prototype is implemented introducing an interaction methodology of MR immersive visualization for better decision making in maritime environments. Actually, in such environments large amounts of data are generated by ship-mounted sensors, radar, sonars and ground stations. This work combined 3D visualization in AR head-mounted displays with 2D visualization in tangible table top. It also permits to share updates with collaborators in their tablets and shared wall display. AR displays allow users to overlay information in the real world. The prototype supports also interaction techniques that allow direct manipulation and selection of data to facilitate collaboration. Also, in the work [19], an IA tool for exploring the output of a Dynamic Integrated Climate-Economy (DICE) model is introduced, since it is difficult to visualize such model with complicated data with complex relationships between variables in 2D.

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6 Immersive Analytics for our floods management STrDWO

Our subject of study is characterized by massive data sets as well as uncertain data in time and space which makes our problem rather complex. The generated STrDWO for floods management provides tools to store this big data sets and to analyze them. However such tools are dedicated to computer science experts. In fact, domain expertise have to be integrated to analyze floods data and overcome related problems that arise. Although, domain experts do not know how to manage such tools. Therefore, adapted visualization tools might be developed to not only permit domain expert to visualize data but also immerse in it using advanced immersive analytics technologies. In this paper, we propose a solution in order to know how to properly manage floods data, once a geographical area has been affected by a natural disaster. For this fact, we intend to implement an AR tool to support an interactive visual analytics through a 3D visualization to ensure a better decision-making in this field. This makes it possible to visualize the data and meta-data within the proposed STrDWO. In addition, it also supports visual semantic analysis. This analysis provides the analyst with the advantage to investigate and treat in an interactive way the various complex relationships between different heterogeneous information that exist within our model. Indeed, the reasons behind the use of AR technology is its potential to superimpose real-time live or indirect real-time environments to computer generated virtual imaging information. AR is defined as a technology that allows computer-generated virtual imagery information to be overlaid onto alive direct or indirect real-world environment in real time. Differently from VR, that permits to people to visualize data in computer generated virtual environment, AR bridges that gap between real and virtual worlds in a seamless way. That's why AR will impact potentially the future of many application domains including our case of study. Accordingly, our proposed approach is detailed as follows :

- Various GPS sensors, as well as tracking cameras are located in a real-world environment, at different POIs in order to group the images at every moment, also to track any developments that may alter the steady state for each type of flood waves.
- These real images are transformed into virtual images, once they will be recorded and seen on our system. Indeed, they will be visualized in 3D and in real time on our interactive screens. In addition, these computers have an AR system.
- Once, we detect a change in the visualized image presenting the captured object as a quadruplet (x, y, z, t): where x, y, z are the geographic dimensions at time t of each type of flood waves put under control. It is necessary to initiate interactions with the data stored on the computer that are described according to the model STrWDO to carry out the necessary reasoning about the situation.
- Analysts have the possibility to act collaboratively with the system during the disaster event to launch an alert that calls to the entire environment that

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may be affected by the disaster in order to ensure that the rescue process is in a timely manner. Hence these new visualizations can contribute to solving such issues thanks to augmented real objects.

Our current work represents first steps towards an IA tool for floods management. Understanding floods multidimensional data is of paramount importance and can give insight on future floods management scenarios. IA promise to be more effective than traditional techniques of visualization. We opted for IA also since immersive environments has been successfully used especially for understanding spatial data, letting users visualize large sets of information at once. This was also facilitated with the revolution in low cost immersive AR. We present inhere early work on the visualization system. Our approach is introduced in the figure 5.

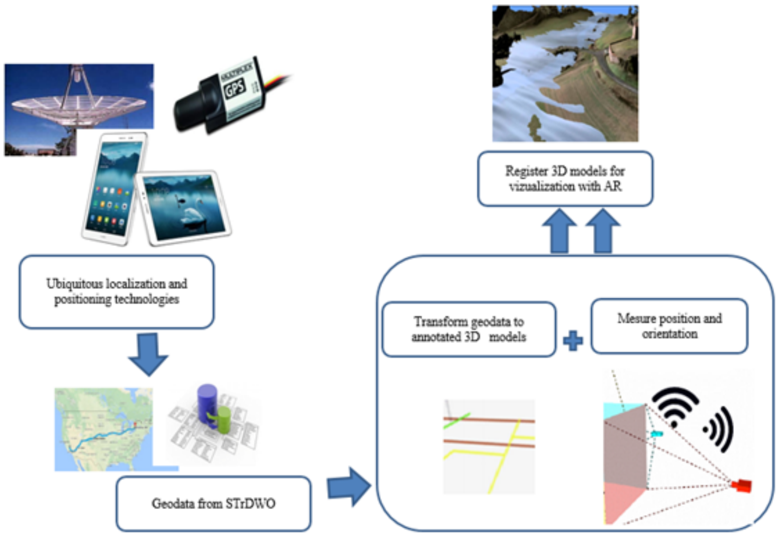

Fig. 5. The approach of visualization of flood trajectory data via AR

From another side, such system is even more informative for environmental decision making and policy analysis. This is because our IA tool supports visual semantic analytics by presenting a new visualization technique making the semantics of this data comprehensible by experts and different stakeholders and more readily communicable to them and facilitating then understanding and engagement of novice users. In fact, the set of data produced in this context is considered as complex and multi-layered. And our tool leaps ahead of this complexity in two phases. Firstly, the back-end of our system, consisting in the proposed STrDWO model, presented data in a semantic way that permit the visualization of additional information including meta-data and aggregated

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summaries of floods data added to relationships between them. Then the AR visualization tool gathers data and different related information in a one encompassing view. And as the AR is a highly interactive technology it permits the investigation of heterogeneous information about floods data and discovery of association between them. The system can display trajectories of the floods among places and on real time and users can interact with it by pointing out locations or points of interest to zoom in and out and then have a view on more or less aggregated data. Users can also launch an alert messages to local competent authorities to take the necessary measures. Also users can execute queries based on the semantic information related to location (streets, cities, etc), time, depth and speed of the flood waves and other parameters. A ranking of the results is also possible. This actually facilitates the search, analysis and comprehension of the presented information and gain in time and accuracy.

7 Conclusion

In this article, we presented a model based on the concepts and the semantic relationships between these concepts, in a subject that takes into account one of the most horrific natural disasters, which is in particular floods. Large amounts of data are generated in this context. Indeed, to obtain the most relevant data related to this domain, we proposed to STrDWO for floods management. Therefore, this problem needs to be solved in real time in order to save as much as possible because time presents here a critical factor. Inspired by recent work in IA, we'll also opt to explore the possibilities offered by new immersive display and interaction technologies. We discussed the possibility of developing a tool based on AR to address this topic by reinforcing the information captured on the affected areas. Implementing this technology would require additional time and is an important aspect of future work for this application. This would allow disaster management professionals to maintain a global and localized view at the same time when viewing the data and making decisions. In addressing many of the challenges, we believe this work provides some important insights into working with big data in AR environments.

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Immersive analytics for the suggestion of opinions in the analysis of a medical report from a collaborative social network

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Abstract. Doctors are mostly in need of several opinions in order to make a good decision. Indeed, medical social networks have become at place of exchange of experiences between doctors. In addition, supervised learning of medical record will help physicians quickly find the right concise explanation of their medical images. To do this, we present in this article a model of opinion suggestion based on a collaborative social radiological network. Indeed, the opinions shared on a medical image in a medico-social network are represented in the form of a textual description which in most cases requires a cleaning using a medical dictionary. In addition, we describe the textual description of medical image with TF-IDF weight vector using a " bag of words" approach. We use latent semantic analysis to establish relationships between textual terms and visual terms in shared opinions about the medical image. Multimodal modeling looks for medical information through multimodal queries. Our model is evaluated against the ImageCLEFmed baseline, which is the basic truth for our experiments. We have conducted many experiments with different descriptors and many combinations of modalities. The analysis of the results shows that the model based on two methods makes it possible to increase the performance of a search system based on a single modality, visual or textual.

Keywords: Multimodal modeling of medical information, Radiological social network, Multimodal information retrieval, Immersive analytics, Bag-of-words, Big data.

1 Introduction

Social networks on the theme of health seem to flourish on the Web in recent years. These social networks bring together the health professionals or only doctors and open to industry (pharmaceutical, ..) or to patients. However, these networks their mission is to revolutionize medicine in the real world by accomplishing a connection between doctors, exchange ideas safely without wasting time. Patients can have real-time notifications of doctors and thus have different opinions.

adfa, p. 1, 2011.

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Content-based medical image retrieval is relative to the context of his capture and interpretation by a radiologist. Current techniques do not allow us to extract images, visual characteristics of low level (color, texture or interest point). The question frequently asked: how best to use the visual characteristics of low level to link automatically to concepts? This problem is known by the name of "semantic gap" [1]. When both textual and visual modalities are reunited, it will be essential to exploit the two assemblies. Any time, we must take into account that it is easier to automatically associate meaning to a text than to an image.

Many image retrieval systems by the text are realized such as (Google Images, Yahoo!, Flickr…) which are based on information from image annotations. For example, Google indexes web images according the surrounding text (file name, description, link, ...) and Flickr indexes the database images according the keywords that the users assign themselves to images. However, the indexing of text associated with the image is the simplest solution to implement what gives the idea to associate with new images annotations existing in a database [2].

To automatically annotate new images, there are two approaches: the first which is based on a supervised learning and training images are manually classified. Another approach is to automatically discover hidden links between visual and textual elements using unsupervised learning methods [3]. This technique introduces a set of latent variables meant to represent the co-distribution of visual and textual elements.

To annotate a new image, we must first extract the visual description and a function of probabilistic similarity, will return the state that maximizes the probability density of the text annotation and the visual element. Finally, the annotations are sorted by probability values.

Medical information in collaborative medical social networks do not cease to grow, from which comes the necessity to develop medical image retrieval and annotation systems appropriate self while using both modalities. A natural approach is to use the representation based on "bag of words" for modeling the image. This approach has already proven effective, especially for image medical annotation applications [4][5]. Indeed, standard collections as TREC, or ImagEVAL ImageCLEFmed for the evaluation of these systems. We propose a model that combines both visual and textual information in collaborative social networks of health. The relevance of our model is evaluated on a search for medical information. This makes comparing the results obtained with our model to those obtained with a single modality, textual or visual.

The information seekers whether it be a patient, a physician, health personnel etc. can search useful information in medical social network and that is the reason which we propose in this article our model of representation of information in a social network Medical. Next, we present a model based of multimodal research by applying a fusion by latent analysis. Finally, we show the results of the application on the ImageCLEFMed dataset.

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2 Literature Review

Social networks have not only revolutionized the way people communicate and interact with each other [6][7]. But also play an important role in health [8]. In the next two sections we will present immersive analysis and work similar to our work.

2.1 Immersive Analysis

In the last decade, the "Immersive Analytics" [9] is an emerging research field. It is an axis that explores how new interaction, display and analysis technologies can be used to support analytical reasoning and emphasize decision-making. This new area of research aims to provide panoply of multi-sensory interfaces that allow collaboration between imagination, scene and intuition. In other words, allowing a user to deeply extend the data and to go very far in his analysis. In fact the immersive analysis [10] is about presenting us an immersive environment that relies on new display technologies such as large touch surfaces, sensors and many other features that make it easy to display data in complete clarity using 2D or 3D techniques which in turn facilitates their deep analysis that will later serve decision makers. Visual analysis [11] is the result of a combination of analytical reasoning of projected data on interactive user interfaces. It's actually the key to exploring and understanding a mass of data. According to several researches [12], there is a big difference between simply presented data, and data represented in a more visual way. The representation of data is the key to good reasoning. We are in a world of big data, certainly there is always hidden information, it is here that appear the importance of data analysis. And this is actually the goal of a visual analysis that allows you to discover the hidden data and display it effectively and in a more pleasant way. What to say if we add intuition and human perception! So, immersive analysis is the combination of visual analysis and geographical representation. That's why in fact we thought to take advantage of this science to allow the user to live the situation by making comparisons, experimenting once he is connected to his immersive environment in order to support the analysis of the situation and therefore guide him in his decision-making process. In the next section, a presentation of our approach that results from a combination studies already presented in the state of the art section.

2.2 Related Work

The co-occurrence model proposed by Mori et al. represents the first approach for associations between text and image [13]. First, images of the training set are divided into regions that inherit all the keywords of original images from which they depend. Visual descriptors are then extracted from each region. All descriptors are clustered into a number of groups, each of which is represented by its center of gravity. Last, the probability of each keyword for each of the region groups can be measured.

[14] proposed a translation model to represent the relationships between text and content. According to their view, visual features and text are two languages that can be translated from one to the other. Thanks to a translation table having estimations of

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probability of the translation between image's regions and keywords, an image is annotated by choosing the most probable keyword for each of regions.

[15] have extended the translation model of [14] to a hierarchical model. It combines the "aspect" model [16] which builds a joint distribution of documents and features, with a soft clustering model [15] which maps documents into clusters. Images and text are generated by nodes arranged in a tree structure. The nodes generate image regions using a Gaussian distribution, and keywords using a multinomial distribution.

[17] suggested improvements to the results of [14] by introducing a language generation model, called Cross-Media Relevance Model (CMRM). First, they use the same process as Duygulu et al. for calculating the representation of images (represented by blobs). Then [14] made the assumption that there is a one-to-one correspondence between regions and words, while Jeon et al. assume that a set of blobs is related only to a set of words. Thus, instead of seeking a probabilistic translation table, CMRM simply calculates the probability of observing a set of blobs and keywords in a given image.

[18] proved that the process of features quantifying using a Continuous-space Relevance Model (CRM) can avoid losing information related to the production of the dictionary in the CMRM model. [17] Using continuous features of probability density to estimate the probability of observing a particular region in an image, they showed that the model performance on the same dataset is much more efficient than the models proposed by [14] [17].

Some studies have attempted to use the LSA technique for combining visual and textual features, including [16, 19] who applied the Probabilistic Latent Semantic Analysis for automatic image annotation. With this approach, text and visual features are considered as "terms". It assumes that each term may come from a number of latent subjects, and each image can contain multiple subjects.

In the transformation model, [20] the text query is automatically converted into visual representations for image retrieval. First, the relationship between text and images are taken from a set of images annotated with text descriptions. A transmedia dictionary which is similar to a bilingual dictionary is set up in the training set.

[21] propose to do the opposite, which is to translate an image query into a text query. Based on both textual and visual queries, the authors transform visual queries into textual queries, and acquire new textual queries. After that, they apply text retrieval techniques to deal with initial textual queries and new textual queries constructed from the visual query for image retrieval. Finally, they merge the results.

Recently, nearest neighbor methods which treat image annotation as image retrieval problem, have received more attention. [22] introduce a baseline technique that transfers keywords to images using its nearest neighbors. A combination called Joint Equal Contribution (JEC) of basic distances to find nearest neighbors is used on low-level image features; the keywords are then assigned using a greedy label transfer mechanism. A more complex nearest-neighbor-type model called TagProp is proposed by [23]. The model combines a weighted nearest-neighbor approach with metric learning capabilities in a discriminative framework which allows the integration of metric learning by directly maximizing the log-likelihood of the tag predictions in the training set.

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2.3 Our proposed model

As part of this work, we aim at giving answers to issues raised in the previous section. First, in order to avoid the dependence on the quality of the segmentation phase, we are working in a context without segmentation. In order to support image retrieval by textual queries independently of any manual annotation, we propose to add the bidirectional transformation between text and image. Finally, we place ourselves in a system with incremental knowledge learning, which requires no special knowledge at the beginning of the life of the system. This constraint seems essential, but also realistic, because most applications do not have specialized knowledge in their early life.

In our model, text/image associations are learnt by an incremental learning method via relevance feedback without any knowledge at first. Unlike other models where prior knowledge is available, in our system, knowledge comes from user interactions. Therefore, our system knowledge is progressively improved over time through interactions, without requiring any off-line learning stage.

3 Representation of information

Content-based image retrieval is difficult to automate, since it depends on the representation of the information. Several methods have been proposed in recent years to build a content-based image retrieval systems. However, the lack of explicit information on user request, and the real difficulties for a computer to effectively interpret the content of an image, make this problem of indexing and image retrieval is especially hard. In fact, the content-based image retrieval is performed on the signified image, ie on its interpretation by a human reader, as well as to the context of his capture. This context should be considered as a meta information. This is, to retrieve image with the name of the place visited, the name of the animal photographed, the name of the person close-up etc... However, current technical computer vision only allow us to extract images, visual characteristics of low level (color, texture or point of interest). The distance involved to automatically interpret the content of an image is still very important. The recurrent question is increased in these terms: how best to use the visual characteristics of low level to connect automatically to concepts ? This problem is known as the semantic gap. When the textual and visual modalities are combined into one document, it seems better to simultaneously operate these two types of content. You should know, firstly it is easier to automatically associate meaning to a text than an image, and secondly, it is easier to compare similar images, it is hoped that complementarity between the image and the text is conducive to better indexing, relative to the two media separately. However, several studies have been published using bag of word model to image retrieve.

3.1 Representation of information in a medical social network

In a medical social network, several physicians' can share their opinion on a medical image. However, the shared opinions require automatic processing to extract relevant keywords. We present our model of representation of medical social network, which is

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to describe the text and images with textual terms and visual terms. The two modalities are first processed separately using the approach BoW to the visual and textual description. Indeed, they are represented as TF-IDF weight vector characterizing the frequency of each visual or textual words. The vector describing the textual content is cleaned using the UMLS thesaurus. To use the same mode of representation for the two modalities can be combined with a fusion method by Latent Semantic Analysis (LSA), after making multimodal queries to retrieve information.

Representation of textual modality

To represent a text report in the form of a weight vector, it is first necessary to define an index of textual or vocabulary terms. For that, we will apply initially a stemming algorithm with Snowball and we delete the black words from all reports. The indexing will be performed by the Lemur software[1]. However, the terms selected are then filtered using the thesaurus UMLS. Each report is then represented following the model of Salton [24], is as a weight vector $r_i^T = (w_{i,1}, \dots, w_{i,j}, \dots w_{i,|T|})$, where $w_{i,j}$ represents the weight of the term t_j in a report r_i. This weight is calculated as the product of two factors $tf_{i,j}$ and idf_j. The factor tf_{ij} is the frequency of occurrence of the term t_j in the report r_i and the factor idf_j measures the inverse of the frequency of the word in the corpus. Thus, the weight $w_{i,j}$ is even higher than the term t_j, and frequent in the report r_i and rare in the corpus. For the calculation of tf et idf, we are using the formulations defined by Robertson [25].

where $|R|$ is the size of the corpus and $\left|\{r_i | t_j \in r_i\}\right|$ is the number of documents in corpus, which the term t_j appears at least once. A textual query q_k can be considered a very short text report, it can also be represented by a weight vector. This vector is noted q_k^T, will be calculated with formulas of Roberson but with b = 0. To calculate the relevance score of a report r_i opposite an query q_k, we apply the formula given by Zhai in [26] and defined as:

$$score_T(q_k, r_i) = \sum_{j=1}^{|T|} r_{i,j}^T q_{k,j}^T \quad (1)$$

Representation of medical image.

The representation of the visual modality is carried out in two steps: the creation of a visual vocabulary and the representation of the medical image using thereof. The vocabulary V of the visual modality is obtained using the approach BoW [27]. The process consists of three steps: the choice of regions or interest points, the description by calculating a descriptor of points or regions and grouping of descriptors into classes constituting the visual words. We use two different approaches for the first two steps. The first approach uses a regular cutting of the image into n^2 thumbnails. Then a color descriptor with 6 dimension, denoted Meanstd, is obtained for each thumbnail, by calculating the mean and standard deviation of normalized components $\frac{R}{R+G+B}$, $\frac{G}{R+G+B}$ et

[1] http://www.lemurproject.org/

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$\frac{R+G+B}{3\times255}$ where R, G and B are the colors components. The second approach uses the characterization of images with regions of interest detected by the MSER [28] and presented by their bounding ellipses (according to the method proposed by [29]). These regions are then described by the descriptor SIFT [30]. For the third step, the grouping of classes is performed by applying the k-means algorithm on the set of descriptors to obtain k clusters descriptors. Each cluster center then represents a visual word. The representation of an image using the vocabulary defined previously for calculating a weight vector r_i^V exactly as for the text modality. To obtain a visual words from the medical image, we first calculate the descriptors on the points or regions of the image, and then is associated, at each descriptor, the word vocabulary, the nearest in the sense of the Euclidean distance.

Fusion Model.

In this section, we show the fusion of both textual and visual descriptors using latent semantic technology. However Latent Semantic Indexing (LSI) was first introduced in the field of research information and has proven its effectiveness in recent years [29]. This technique involves reducing the indexation matrix in a new space sensible to express more "semantic" dimensions. This reduction is intended to make it appear the "hidden semantics" in the co-occurrence links. This is called latent semantic. This latent semantic allows for example to reduce the effects of synonymy and polysemy. It is also used to index without translation, no dictionary, parallel corpus, that is to say composed of documents in different languages, but supposed to be translations of each other. Technically, LSA method is a matrix transformation operation M of co-occurrence between terms and documents. This is in fact a singular value decomposition[2] it of the matrix : $M_{i,j}$ describes the occurrences of term i in document j.

Suggestion opinions through research similar medical images.

Each modality of reports (text and image) is processed independently. We obtain a textual matrix report-term $M_{r,t}$ and the visual matrix report-term matrice $M_{r,v}$. The fusion of these two methods is first obtained simply by concatenating the columns of the two matrices $M_{r,t}$ and $M_{r,v}$ in a matrix $M_{r,vt}$ because it is of different coordinates on the same set of documents. This merged matrix is then projected in a latent space to obtain the latent matrix $M_{r,k}$, with k the new reduced size. Therefore, each document is represented by a line latent matrix $M_{r,k}$. For a query containing text and images, we apply the same process with the reports. Then, this vector is projected into the reduced space for a pseudo-vector $q_k = q * \sum_k V_k^t$. Finally, the calculation of the value of relevance of a document to the query (Relevance Status Value or RSV) is calculated according the similarity of the query vector q_k with the lines of the latent matrix by using the function *cosinus*.

[2] Singular Value Decomposition (SVD)

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We present below our algorithm that shows the search steps in a medical social network :

Algorithm SuggestionOpinions
Input :
R_q: Query of a medical report (Text or Medical Image or Text with Medical Image)
Output :
TImages : The list of similar images
Var
$M_{rq,vt}$, $M_{r,vt}$: Result from the concatenation of two matrices
$M_{rq,k}$, $M_{r,k}$: Latent Matrix
q_k : Query projected in a small space
0. **Begin**
1. $M_{rq,vt}$ ← Extract_Matrix_Terms(R_q) U Extract_Matrix_Visual_Terms(R_q)
2. $M_{rq,k}$ ← Extract_Lalent_Matrix ($M_{rq,vt}$)
3. $q_k \leftarrow q * \sum_k V_k^t$
4. **ForEach** R **In** the social network DataBase **Do**
5. $M_{r,vt}$ ← Extract_Matrix_Terms(R) U Extract_Matrix_Report_Visual_Terms(R)
6. $M_{r,k}$ ← Extract_Lalent_Matrix ($M_{r,vt}$)
7. TImages ← Extraction_of_the_nearest_Medical_Images (Cosinus (q_k, $M_{rq,k}$))
8. **End ForEach**
9. **End**.

In the following, we present in figure 1 our search engine based on immersive analysis to suggest opinions about similar clinical cases.

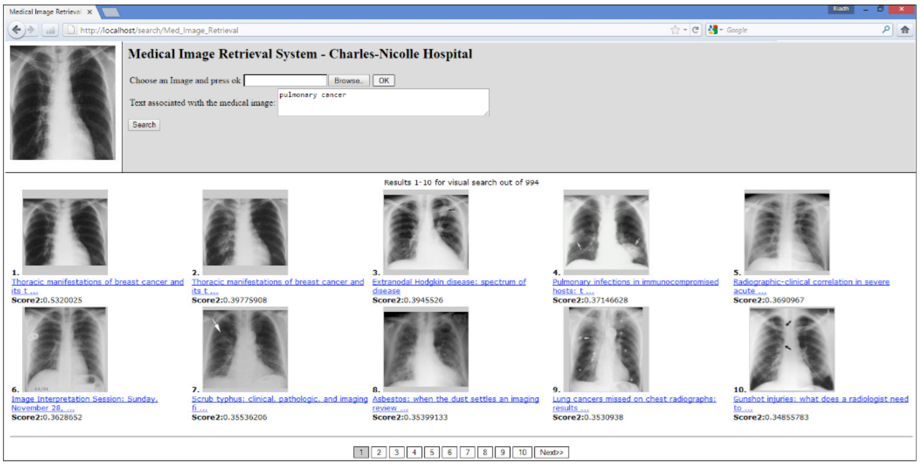

Fig. 1. Our medical image retrieval system on a text + image query.

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4 Experimental evaluation

4.1 Test data and evaluation criteria

The pertinence of our model is evaluated on the collection provided for the competition ImageCLEFMed [30]. This collection is composed over 45,000 biomedical research articles of the PubMed Central (R). Each document is composed of an image and a text part. The images are very heterogeneous in size and content. The text part is relatively short with an average of 33 words per document. The goal of the information search task is to return to the 75 queries supplied by ImageCLEFMed a list of pertinent documents. All queries have a textual part, but many do not have a query image. Order to have a visual part for each query, we use the first two pertinent medical images returned by our system when we use only the textual part. This corresponds to a relevance feedback fact by the system user. The criteria of average accuracy (*Mean Average Precision - MAP*), which is a classic criteria in information retrieval, is then used to evaluate the pertinence of the results.

4.2 Results and Discussion

To demonstrate the contribution of the use of our model compared to only textual or visual model, we realized experiments using a single modality, textual or visual, then experiments combining two modalities, modality text with visual descriptor, this visual features for both Meanstd and SIFT previously presented. The text vocabulary is consists of approximately 200000 words whereas the two visual vocabularies are constituted of 10000. Table summarizes the MAP values obtained for each experiment. On the one hand, it can be stated that the use of the single visual modality irrespective of the descriptor used leads to poorer results that the use of the only modality text. On the other hand, combine a visual descriptor with the text improves search performance with the only textual descriptor. These overall observations are confirmed by the precision/recall curves presented in Figure 2. A detailed analysis per query show that, for some, the first results returned by the visual modality is best for text modality. We can add, about the performance obtained with a visual modality, that the regular division of the associated image at Meanstd color descriptor is more robust than MSER + SIFT. We explain this behavior by clustering problems. With the color descriptor, we work with 6 characteristic parameters and 4 million thumbnails to consolidate vocabulary words. With SIFT descriptor, we have 128 features and settings 54 million thumbnails. In the second case, the thumbnails are divided very irregularly in the space of descriptors, because of the use of MSER, the large size and the large amount of data. This situation is very unfavorable for clustering algorithms such as K-means [31]. Also, it has been shown in [32] [33] that the descriptors of the most densely spaces of the parameter space are not necessarily the most informative.

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Table 1. Result of average precision obtained for different modalities

Modality type	MAP
SIFT	0.1287
Meanstd	0.0962
Text	0.2346
Fusion : Text + SIFT	0.3667
Fusion : Text + Meanstd	0.2734

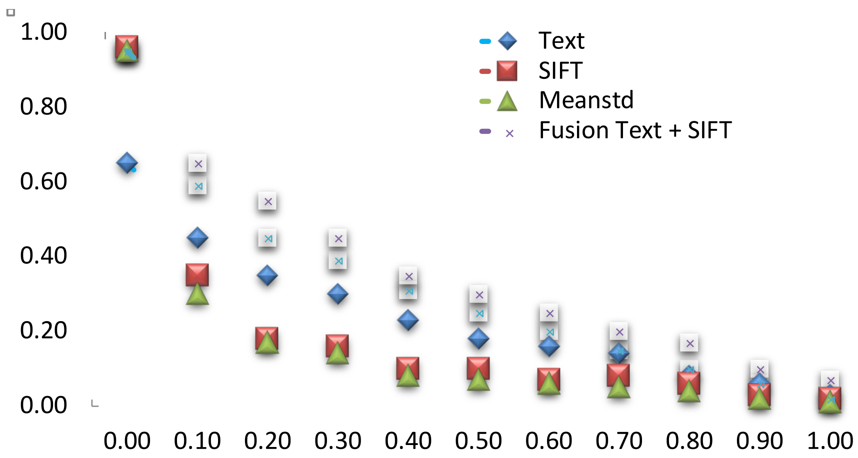

Fig. 2. Precision / Recall curve of modalities (text only, visual only and fusion text/visual)

5 Conclusion

We have presented in this paper a representing model of multimedia data extracted from radiological social networks where they are used for annotating medical images. This model is based on a fusion with LSA of the textual and visual information using the "bag-of-words" approach.

The performance of the indexing and search system has been evaluated based on real dataset of ImageCLEFMed and the obtained results were very promising to use a media model specialized radiology, like the one proposed to retrieve information from a collection of radiological media. Indeed, the fusion of both textual and visual methods allows each time to increase the performance of the system. In this context, Larlus [31] proposes a clustering method that allows uniform quantifications of spaces contrary to K-means which focuses on dense spaces. This method could be used to improve our system when creating the visual vocabulary.

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Real Time Hand Tracking Method for an Immersive Application

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Abstract. This paper presents a real time fingertip tracking method used for immersive application. The first step of the method consists of segmenting the input image captured by a video camera and detects the area representing the human hand. The latter one is identified by means of skin color detection method. The output of the first step is a black and white image where the hand area is coloured in black while the background is in white. In the second step, the hand shape is analysed and the fingertips are detected using convex-hull method. The barycentre of the fingertips is then calculated and to estimate the position of the hand. Using the estimated position in each frame, many applications belonging to human computer interaction and immersive domains could be proposed. In this paper, we propose an immersive application which consists of moving virtual objects according to the estimated hand position.

Key words: Augmented Reality · Image Processing

1 Introduction

Immersion into a virtual world could be defined as the feeling of being present physically in a non real world. To reach that perception, different parameters could be taken into account such as images, sounds, sensors and stimuli. Hardware devices and softwares are involved into the process of creating the virtual world. For the hardware part, different devices could be used such as video-cameras(2D or 3D), head mounted display, data gloves,etc. The software part corresponds to the program allowing the interaction between the human being and the virtual world and so produces the perception of immersion. An important domain allowing the immersion in a virtual world is called human-computer interaction (HCI). This domain is becoming more and more present in our daily life. Using video-cameras, researchers in computer vision brought on a wave of applications for human-computer interaction and specially for video games and 3D animation. Many of the applications are based on human body tracking. In this paper we present a hand tracking method to create an immersive application. In the next part, we present a related work on hand motion tracking. The section number 3 explains how the segmentation is achieved to detect the hand observed in the images. The section number 4 presents the method to detect

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the fingertips. Finally we present our application and the experimental results obtained using a 2D video camera.

2 Related work

Several methods on hand motion tracking using video-cameras were proposed during the last two decades [1][2][3][4]. Both 2D videos cameras and 3D cameras were used[5][6]. The advantage of using 2D cameras is the affordability comparing with the 3D ones but less data can be exploited using the first type of cameras. In fact, all vision based methods for hand tracking start by extracting features from the images. Only 2D features are used in the case of simple video-cameras while a third dimension is used for the 3D videos cameras.

The methods could then be divided in different categories. The first one deals with a 3D parametric model and the tracking is defined as a minimization problem where a cost function is minimised to obtained the best parameter values that make the model pose match with the hand one[7]. The cost function is also called a dissimilarity function where extracted features from hand images and model ones are used to compare the poses from real hand and 3D model. The dissimilarity function is minimized by means of minimsation algorithm such as the simplex approach proposed by Nelder and Mead [8] or using statistic methods such as particle filter [9]. The second category is mostly called data-driven method and uses a database of gestures calculated before the tracking process. It consists of matching the real hand pose with ones stored in the database through regression or classification techniques[10]. The author used coloured glove to improve the matching between input images and the ones stored in a database of images. The most important problem with this kind of methods is the huge number of hand gestures which makes impossible to create a database with all hand poses. In general a limited number of gestures is used to create a real time application.

Another category of methods simplifies the hand tracking problem to fingertips tracking. The method, then consists of detecting the fingertips for each input image and track them in a sequence of video. The advantage in this category is the fast tracking process which allows to create real time application easily.

Kumar and Shubham [11] proposed a segmentation algorithm which estimates hand position be calculating the centroid of orientation of the observed hand shape in a video sequence. Chen and al. [12] proposed a similar method which the identifies the finger areas for segmentation and recognition of the hand gestures. Finger detection algorithm was proposed by Zhou and al. to detect the finger using a 3D model represented by cylindrical surfaces and parallel features are then used to localize the hand fingers. Lee and al.[4] analyzed the hand shape using the curvature of the calculated contour in order to detect the fingertips. In a previous work, we proposed a fingertip tracking method using convex hull [1]. In this paper we propose a fast tracking method to apply for immersive application. Our method estimates the hand centroid position by calculating the

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barycentre of the fingertips. Convex hull is used to detect the fingertips. Our method is tested on real video sequence to move virtual object.

3 Segmentation

The first step of our method is called segmentation and it's considered as a fundamental part of the tracking process because it can greatly affect the final results. The segmentation consists of dividing the image into two areas : foreground and background. The foreground represents the hand in black colour while the rest of the image will be in white and represents the background. At the end of this step, a black and white image is obtained. In order to clarify this process, the following subsections will describe how images and colours are stored in the computer and then the process to achieve the segmentation.

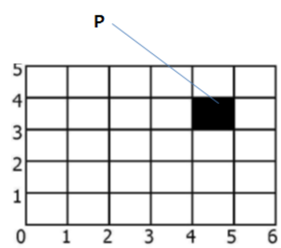

Fig. 1. Representation of an image as a matrix of pixels

In the computer, an image could be represented as a matrix of pixels as shown in figure 1 where each pixel will correspond to a color. Especially the pixel is a value encoding the color. We can differentiate three type of images: black and white images, grey scale images and colored ones. According to the type of the image, the pixels will take different values.

- Black and white image is also called digital, bi-level or two-level image. It means each pixel is stored as a single bit i.e a 0 or 1.
- Grey scale image is a matrix where a pixel represents the intensity of the grey color. In the computer the grey intensity is a value between 0 and 255.
- Colored image is also a matrix of pixels but each pixel will correspond to a vector of three values, each one between 0 and 255. The three values will represent one color.

There are many other types of images like the 3D ones or multispectral images but in this work, only the three kind of images presented before are considered. The next subsection gives an overview of some important color spaces that can be used to detect the skin color and explains the chosen(HLS) one in this work.

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3.1 Color spaces

It's important to notice there are many color spaces that can be used to represent the color. The following subsections present two of them.

RGB colour space This color space is the most used one and very easy to understand. It's based on using 3 values between 0 and 255 which encode the blue, green and red colors(Figure 2). Even if it's the easier one to understand, it doesn't deal with the main problem in computer vision which is the light variation. In fact, two images representing the same scene but taken in different conditions of lighting will be considered as completely dissimilar by the computer. In fact, the R,G,B values of the pixels will be completely different.

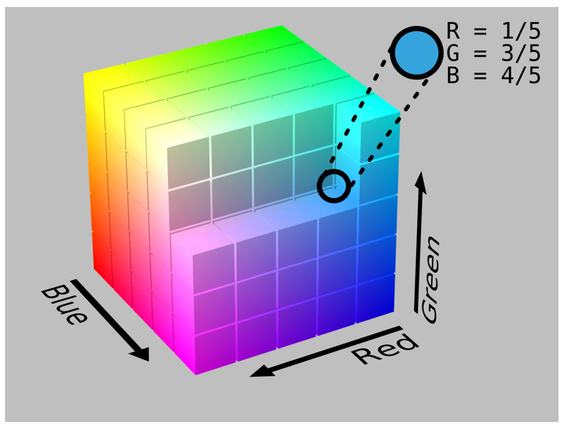

Fig. 2. RGB colour space [13]

HSL color space HSL stands for hue, saturation, and lightness is also often called HLS(Figure 3). This space colour deals better with the lighting variation because the colour is divided in pure colour information (with the H and S values) and the light one with the L value. For more clarifications : the pixels of two images representing the same scene but with different lighting will have the hue and saturation values very close. This colour space was used in this work and gave better results that the RGB one.

3.2 Skin Color detection

To achieve the segmentation it's important to distinguish the colours and select only the ones representing the hand. To detect the colour representing the hand, the proposed system starts by covering a square with the hand as shown in the figure 4.

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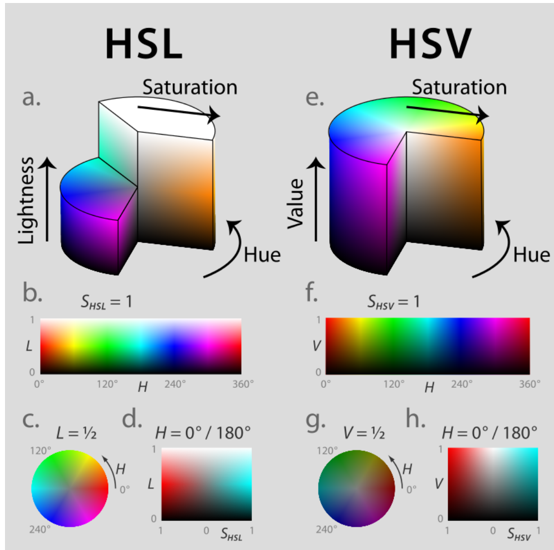

Fig. 3. HSL colour space [13]

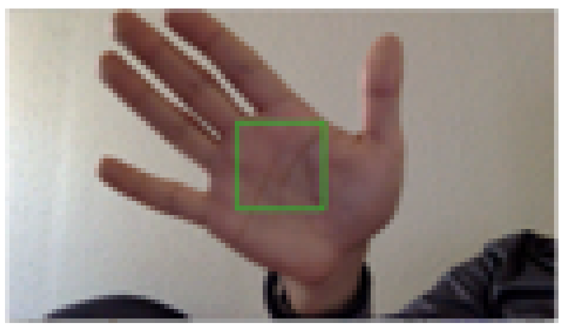

Fig. 4. initialisation of the process : covering a square with the hand and save the color hand

The median value of the pixels contained in the square is computed. According to the median value, two thresholds maxValue and minValue are defined using an empirical method and all the values between them are considered as the skin color. During the segmentation process, for each input image all the pixels encoding the hand will be colored with black color while the background will be colored with the white one.

4 Fingertips detection process

The first step of the fingertips detection process is to computer the hand contour from the black and white hand image. For that purpose, a method proposed by

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canny[14] is used. The second step. which is one of the most important part in that work. is to compute convex hull of the contour. The convex hull of a set of N points could be defined as the smallest perimeter fence enclosing the points. In our case the set of points consists of the contour points obtained by canny method. It could also be defined as the smallest convex polygon enclosing the points. The convex hull and convexity defects of the hand(Figure 5) are computed using the Sklansky's algorithm [15]. The points of the convex represent the points where the contour of the hand is convex, in other words the fingertips. The convexity defects represents the points where the hand contour is concave, in other words the points between the fingers (Figure 5).

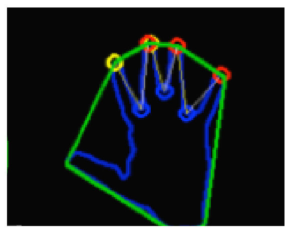

Fig. 5. hand contour (in blue colour) with detection of fingertips and the convexity defects (points between fingers)

5 Application and experimental results

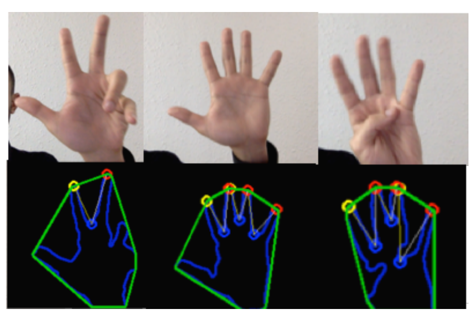

Fig. 6. Results : three poses of the hands with the results of the tracking. The first line represents the input images and the second one shows how the fingertips are detected

Once the fingertips detected, the barycentre is calculated. This latter represents the hand position in the image. The 2D coordinates of the barycentre will

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be used as the centre of a 3D virtual cube generated using the OpenGL library[1]. Our application is implemented using a machine with an Intel i5 processor 2,7 GHz and Intel Iris Graphics 6100 1536 MB. A video camera providing 2D images with a size of 480x620. The figure 6 shows the results of tracking the fingertips. The last figure (Fig7)shows how our application allows to move the 3D object according the position of the hand. In fact the first line represents the input images taken by a video camera and the second line shows the 3D object (Cube) following the hand position.

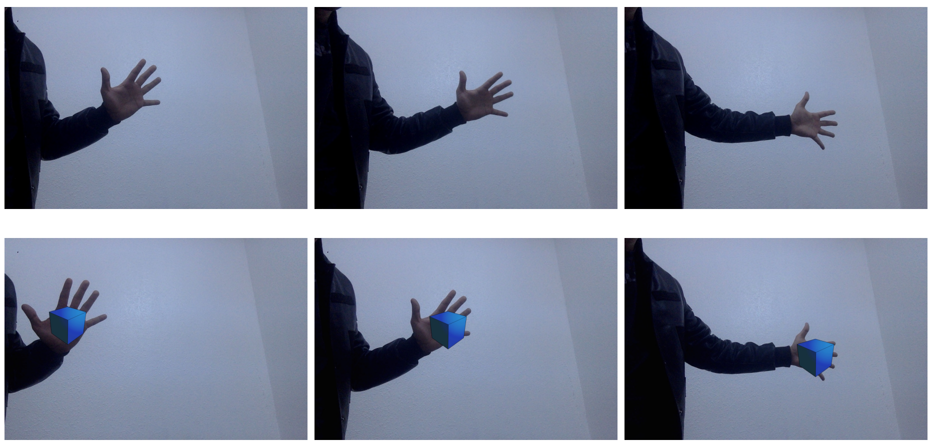

Fig. 7. Moving 3D cube according the hand position. First line : the input images. Second line: results.

6 Conclusion

In this paper, a real time fingertips tracking method was proposed and used to create an immersive application for moving virtual objects. The fingertips tracking method is based on HSL colour space segmentation algorithm and allows to detect the skin colour. The hand contour, convex-hull and convexity defect are then calculated in order to detect the fingertips. The barycentre of the latter represents the 2D position of the hand. Matching a virtual object position with the hand one allows to move the 3D object and create an interaction with a virtual world. Our proposed application uses only one hand. In future work, both hands can be involved in an immersive application to move, scale and rotate virtual objects which can provide a more complete human computer interaction system.

[1] www.opengl.org

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Special Track

Immersed in Cultural Heritage

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Digital Heritage: Digital Drawing and new Research Tools for Investigation in History of Architecture

Hypothesis of virtual reconstruction of Monchique Convent (Porto, Portugal)

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Abstract. This work aims to address the Digital Heritage topic in the light of the new investigation opportunities within History of Architecture, which have been brought by technological development. The protagonism assumed by digital drawing will also be addressed as a research, analysis, preservation and promotion tool of the cities' built heritage.

Our object of study - the conventual complex of Monchique (Porto, Portugal), which has suffered several transformations over time (both in form and function), serves as an example to show how digital tools contribute to the spreading of historical knowledge as a living memory, mostly to a wider audience and not only to experts in the field. The three-dimensional models, such as the one we propose to build, take on shapes capable of (non-destructively) reconstitute previous stages or the constructive evolution of the building, enabling its better understanding, within a both humanist and enlightened perspective.

Given that the digital cannot replace physical and phenomenological experiences of built heritage, it does however allow innovation in its holistic and multidisciplinary reading, providing new opportunities for its knowledge and fruition, as it is the specific case of the virtual tours and the augmented reality.

In conclusion, we fit in a wider vision which perceives that the combining of science, culture and education, together with the potential of digital and immersive technologies, can actively contribute to an improvement in learning and development of multiple perspectives on the built heritage and, consequently, on the shift of learnings between experiences, in a shared construction of knowledge.

Keywords: Digital Heritage, Digital Reconstruction, Monchique Convent.

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1 INTRODUCTION[1]

Today, cultural heritage faces a new reality due to the development of digital technologies and the Internet. If, on one hand, citizens are presented with the unprecedented opportunity of access to cultural materials, on the other, authorities within this domain are able to reach increasingly wider audiences, involving new users and developing creative content which will be accessible for both leisure and education. Thus, the usage of means such as augmented reality (AR)[2], virtual reality (VR)[3] and mixed reality (MR)[4] becomes more common regarding the access and promotion of cultural heritage. This combination with technological development also adds to a better understanding of our common past, increasing its appreciation, conservation and protection.

We based ourselves in these premises, gathering different methodological and analytical approaches, in a collaborative and multidisciplinary perspective, which allows the testing of new technologies within the History of Art and Architecture field. In the specific domain of Digital Heritage[5], the creation of three-dimensional models, combined with its visualisation in different channels, enables the verification of the information obtained from documental, iconographic and archaeological sources, in a virtual dimension which allows the recreation of issues such as: urban settlement, scale, layout and interior and exterior design of constructions, as well as its environmental, spatial and landscape realities [6]. By extension, this methodology contributes to a greater awareness regarding the landscape and both the landscape and environmental framework of the built heritage. “To perceive the landscape is (…) to carry out an act of remembrance, and remembering is not so much a matter of calling up an internal image, stored in the mind, as of engaging perceptually with an environment that is itself pregnant with the past” [7].

One of the biggest obstacles in a state of nature as the one we suggest is in the conciliation of various sources, from several entities and that sometimes do not allow a

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1 This paper is part of an ongoing PhD. research project in Heritage Studies, with a specialisation in History of Art, at the Faculty of Arts of the University of Porto. The aforementioned paper is being developed under the supervision of Maria Leonor Botelho (FLUP - DCTP/CITCEM) and is co-supervised by Teresa Cunha Ferreira (FAUP – CEAU). The project is currently being financially supported by FCT and has the following reference: SFRH/BD/132302/2017. The journey to the USA is funded by "papers@USA grants" awarded by Luso-American Development foundation and has the following reference: VR/MV/2018-126.

2 For more about AR application on cultural heritage appreciation, see: [1]; about the interaction between devices capable of AR and paper maps for exploring cultural heritage, see: [2]; about the virtual reconstruction of buildings, see: [3].

3 Example of virtual reality application in the reconstitution of Song's dynasty Chinese temple: [4].

4 Often referred to as hybrid reality, results from the combination of augmented reality with virtual reality in creating new visualisation environments.

5 “Digital heritage is made up of computer-based materials of enduring value that should be kept for future generations. Digital heritage emanates from different communities, industries, sectors and regions” [5].

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unified vision of the architectonic object: archive documentation, field archaeology, typological and artistic analysis and material culture study.

1.1 Object of study

Our object of study is Monchique Convent, already addressed by us in scientific meetings [8]. Taking into consideration the deep changes this conventual complex suffered throughout the times and the current state of ruin of part of the building, we find imperative the promotion of its awareness, seeking to reinscribe it in the memory and collective legacy of the city, of its inhabitants and of everyone who visits it. "The task of the historian is to rectify again, with all means he can reach, the gaps that nature's strikes have inflicted from the time of its original creation" (as for Monchique's specific case modifications are explained by other factors such as the change of function and ownership, among others) [9]. Given this, we resume Aloïs Riegl's challenge, which encourages the restitution of historical value of the built heritage. That being said, "(…) this cannot occur on the monument itself, but only in a copy or in sheer thoughts and words"[10]. Far from 1905, when these words were first published, and using the opportunities provided by technological development, we embark on this replacement by formulating a hypothesis of digital reconstruction of the built heritage.

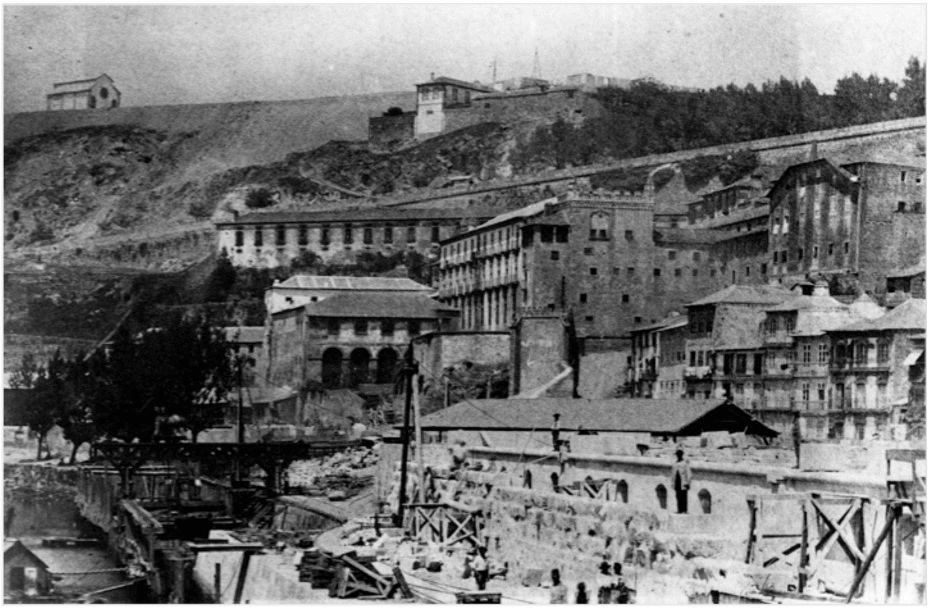

Fig. 1. General view of the Convent of Monchique (1862). In the foreground the Customhouse of Porto, under construction. Cliché from the collection of Vitorino Ribeiro. Historical Archive. Porto City Hall.

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1.2 Objectives

The main purpose of this study is the digital translation of a lost historic and artistic environment: Monchique Convent in mid-16th century, emphasising the role of the new digital tools in this process.

It is intended, on one hand, to maximise opportunities brought by the digital platforms where it is possible to suggest a reconstitution, discuss it and update it in a timely manner and at a low cost. On the other hand, focusing on the narrative question is essential to understand digital heritage and its communication to a wider audience. As Maurizio Forte outlines “the new challenge in virtual environments is to develop advanced narrative mechanisms. The experience is the very new way of storytelling” [11]. The produced material will take into account this perspective.

It is intended that the final product, resulting from a collaborative and interdisciplinary research, can be (re) used in multiple platforms, being broadcasted in different channels, aimed at different audiences in different contexts, and may assume a more recreational or educational character.

Our proposal will focus on contributing to the expansion of knowledge, its preservation and promotion, at the same time that we digitally reconstruct the conventual complex. We hope that this investigation can add on – in a perspective of knowledge sustainability – to the emergence of new points of view or of renewed justifications regarding the architecture built during the "manueline age"[6] both in this city and in the northern region of Portugal.

Fig. 2. Convent of Monchique (1983). Historical Archive. Porto City Hall.

[6] The architecture known as "manueline" - safeguarding the older expressions - was developed and consolidated during the reign of D. Manuel I (1494-1521), still prevailing at the beginning of D. João III'reign (1521-1557). Seen as an unprecedent construction surge it was one of the richest times in History of Art in Portugal. Corresponds to the final phase of goth and, like other european art forms at the time (e.g.: "Tudor" and "Elizabethan"), it is commonly associated with the current monarch or dynasty.

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1.3 Methodology

As a general procedure, this study, developed within the cultural heritage field, pursues and deepens a positioning framed in the principles established by the international doctrine (ICOMOS, Council of Europe, UNESCO). Namely, "Council of Europe Framework Convention on the Value of Cultural Heritage for Society" (Faro, 2005) [12][7], as well as, within the specific domain of digital heritage, the "Guidelines for the Preservation of Digital Heritage"[13], the "Charter on the Preservation of the Digital Heritage"[14] and the "Recommendation concerning the preservation of, and access to, documentary heritage including in digital form"[15], with the inherent recognition of the importance of the digital knowledge as a legacy for the future generations.

In turn, the success of the present investigation implies an effective understanding of values and meanings conveyed by architectural heritage and of its polysemic significances, achieved through historical knowledge, reading and interpreting material expressions of human action in the land. Seeking the accomplishment of a reconstitution hypothesis, we based ourselves in the application of the Crypto-History of Art method, assuming "an absolutely new concept to widen an old historiographic practice (…), to incorporate the study of lost heritage in the current methodology of this subject [of History of Art]" [16]. Specifically, "the analysis of a fragment of an artistic set almost inexistent these days, in order to unravel its possible initial structure", enables us – through a visual, documental, stylistic and iconographic analysis – the widening of the historiographical practice [17], which is one of the goals proposed for this study.

The investigation process has started with archival research, including pictures and maps, monastic funds and notarial documents, looking for the intersection between different sources, as for example: functional (fig. 3) and chronological (fig. 4). When analysing the sources, the reports of important city columnists, from different historical periods since the 16th century, were studied, in particular: João de Barros (1496-1570), Manuel Pereira Novaes (17th century), Agostinho Rebelo da Costa (18th century), Henrique de Sousa Reis (1810-1876) and Damião Peres (1889-1976). Regarding the digital reconstruction proposal, we focused on the London Charter (2009) [18], on the International Principles of Virtual Archaeology [19] and on the Berlin Charter (2015) [20]. These documents are perceived in its whole and seen as resulting from the need of a theoretical debate which offered heritage related organisations a better use of technology potential and the search for minimising the chances of more controversial usages.

7 This one stands out for the establishment of the founding concept of common cultural heritage and of the construction of the concept of shared responsibility: by gathering built tangible heritage, intangible heritage and contemporary creation.

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2 DIGITAL HERITAGE: MONCHIQUE CONVENT

2.1 Monchique Convent's crypto-history

The place of Monchique has been subjected to a continuous "cultural-devotional occupation"[21]. We know that before the Christians appropriation of the convent, it might have been a Jewish quarter and a synagogue, and that it was on these very fields that nobles Dom Pêro da Cunha Coutinho and his wife Dona Beatriz de Vilhena have subsequently ordered the construction of the feminine convent of Monchique.

On 18 July 1533 papal approval was asked to found the convent, and a contract was signed (even before papal approval) with the architect Diogo de Castillho (1490-1574) for the church construction. Meanwhile, the transformation of Coutinho de Monchique family's noble house into conventual residence was initiated[8]. In 1534, the papal Bull “Debitum Pastoralis Officii”, by Paulo III [(1468- 1549) – (pap. 1534-1549)], gives permission to the foundation of this convent of the Saint Francis Order, in Monchique, at the time located outside the city walls of Porto [22].

According to several sources, the construction of the convent covered many building periods. It results from an irregular layout along the hill, adapting to the field's topography, in different plans, which communicate by stairs. It spread from the top of Monchique to the river, like a waterfall, in a sequence of phased volume bodies that completed each other.

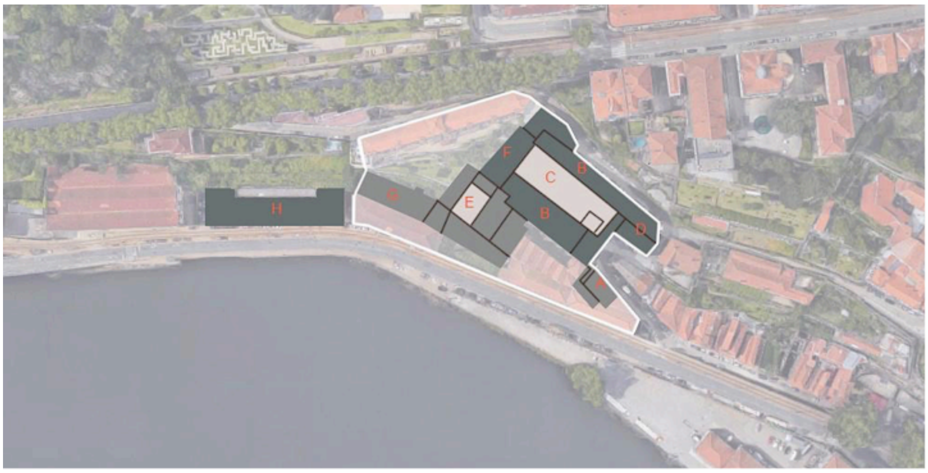

Fig. 3. Scheme of the functional distribution of the Monchique Convent (A – Old Chapel, B – Convent, C – Cloister, D – Chaplain’s House, E – Demolished Cloister, F – Church, G – Demolished Structure, H – Wines Warehouse). Elaboration by the author.

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[8] Before, Diogo would have taken part in his brother João de Castilho's next constructions: Viseu Cathedral's vault (1513) and Jerónimos Monastery (1517-1518).

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It had two cloisters, each with its own fountain, watersheds, gardens andhome gardens. The convent's church, with a longitudinal floor plan, single nave and rectangular main chapel, displayed the gallery and the choir, which are connected with the nave through two overlaid arches; it owned a sacristy and the bell tower was located between the church and the conventual building. It had a rectangular floor plan, with three floors crossed with a stone arch. The two upper floors accommodated the dormitory and the lower flor contained the refectory- This was about forty metres long, with three naves formed by two column rows, with eight on each row. These columns support the stonework arches which in turn support the vault of the building, limited by another tower, whose function was to serve as a recreational viewpoint for the nuns. These two towers, of rectangular layout and hip roof, were topped by battlements.

The main cloister was located behind the church choirs, at the kitchen's arcade level. The second cloister, of smaller size, also with arches and columns, was made of brick, with a stone fountain at the centre. The chapel of Senhor dos Passos was situated next to this cloister. Over the dormitory, facing North – South, it is believed there might have been an extension, widthwise, on the river facing side (possibly in the 18th century), "from which has resulted the construction of a gallery as well as the reduction of both turrets built at the time of the foundation of the convent" [23]. By the river there was the chaplains' house and a lodge to host the families when visiting the nuns.

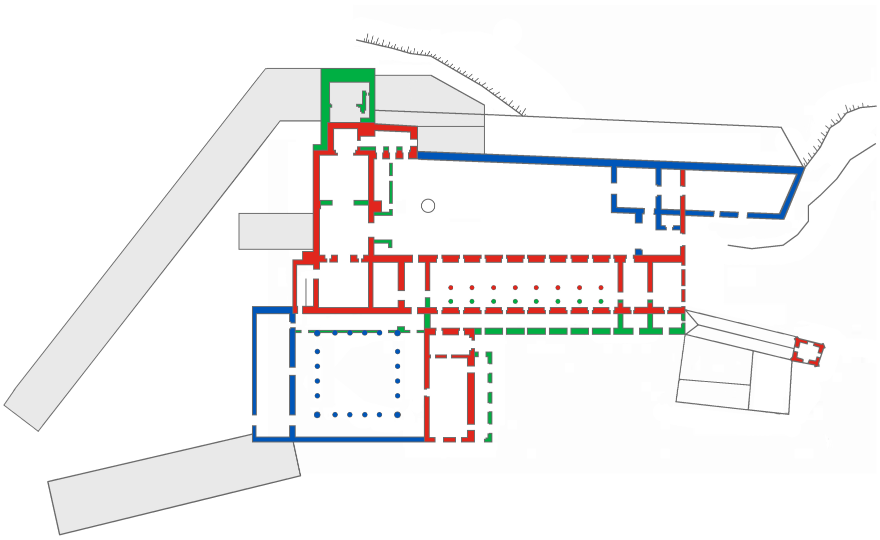

Fig. 4. Phases of construction of Monchique Convent (Phase 1 - Red, Phase 2 - Blue, Phase 3 – Green). Elaboration by the author from the owner's Plants [25].

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The convent would have had a manueline portico [24]. Currently, this can be found at the National Museum of Soares dos Reis in Porto. The first construction stage, finished in the 16th century under the supervision of Diogo de Castilho, displays features associated with manueline constructions. In the 17th and 18th centuries, the whole building was extended with the aforementioned cloisters with gardens and other dependencies.

Fig. 5. Manueline portico (1983). Historical Archive. Porto City Hall.

In 1681 a new dormitory was added and in 1699 a new main chapel. The chaplains' house was built between 1761-67 in order to increase the convent's income. Its conclusion meant to turn it into a wine warehouse. In 1958, after DGEMN intervened, the building receives the Commands and the Fiscal Guard. The frontispiece shows the coat of arms of Saint Francis Order. The warehouse of the new dock is incorrectly acknowledged as part of the convent. It was built by the same General Company to serve as a deposit and thus to extend its headquarters in Miragaia. The current Ignez Neighbourhood corresponds to the third stage of the convent construction, in the back of the fence, and might have been erected to accommodate the servants. Later it became property of the counts of Burnay, a sawmill, woodwork and nail factory, a working-class neighbourhood with affordable houses and also a student residence. Following the extinction of religious orders in 1834, as part of the church general Reform, the convent fell into decline and its goods were assigned to several landlords [26]. Subsequent occupation always had an industrial nature. Today, part of the com-

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plex, divided by different owners, is in ruins, and some of the buildings, such as the church and the main building, are coverless.

2.2 Hypothesis of Digital Reconstruction

For the last 20 years computer-generated imagery (CGI) production in archaeology and in the visualisation of historical contents for the public has greatly increased, in such a way that computer visualisation assumes itself, gradually, as an integral part of archaeological and cultural heritage representations. Mastering digital tools enables progress in the knowledge of objects of study and its scientific update to directly feed the didactic, recreational and promotion dimension of investigation projects linked to the heritage field. "In a technologically literate society, tool-using is assimilated to the operation of artificial systems, much as speaking is assimilated to writing" [27].

Digital reconstruction processes are shown as a viable solution, non-intrusive, versatile and totally reversible within the processes of knowledge of built heritage, in its diachrony and synchrony. Likewise, this reading brings innovation in the translation of a precise and framed description of knowledge, seeking to dilute the barrier between scientific research and its interpretation and presentation to civil society.

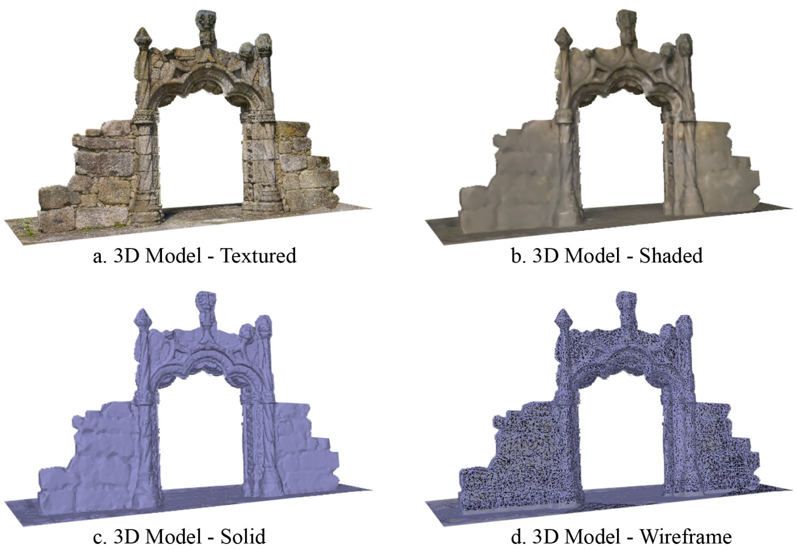

Fig. 6. Three-dimensional representation of the Manueline portico. Experimental development made by the author with the permission of the National Museum of Soares dos Reis in Porto.

Through an accurate bibliographic and historical research and through a systematisation and analysis of existing archival, cartographical and iconographical documental material, it is possible to reach identification, recognition and documentation of past identities associated with buildings and urban environments (changed over time).

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Despite the likely character of the sources we collected, the reconstruction work we propose is developed within the hypothetical field. As mentioned before, this complex has been object of many additions, usage modifications and functional reconversions seeking the adaption to new activities that have been continuously taking place in the different buildings. These modifications involved deep changes in its volumetric configuration and in its interaction with the environment.

3 Final Considerations

The complex debate between the concrete date and the materials provided by the Histories of Art and Architecture and by Archaeology (based on evidence and empirical observation), and by virtual reality/cyber-archaeology, have led to the development of new models, based essentially in the human interaction rather than pure observation. Thus, individual participation in this increasingly complex process of knowledge and acknowledgment of built heritage is progressively requested.

Augmented reality, where synthetic images, text or voice overlap real images, and virtual reality, together with the creation of new alternative worlds - framed in a vast set of unprecedent opportunities for the cultural material access -, demand the strengthening of the discussion regarding the quality, quantity and diversity of information generated by these processes. In turn, the most recent investigation methods, such as high-resolution ground-penetrating radars and digital photogrammetry also create new perspectives in the interpretation of the existing reality. Scanning an object implies giving it a new meaning. It is, therefore, necessary to promote the development of a set of tools that allow thinking of this technological development and these changes, evaluating and discussing them, while contributions are made in the development and sedimentation of a critic and constructive thinking, topped with a spirit of competency, discipline, orientation and method.

In what concerns the dissemination of the knowledge and the understanding of digital heritage, in its need for transversal communication to a wider audience, it is essential to take into consideration the user experience and storytelling. As Maurizio Forte states “the new challenge in virtual environments is to develop advanced narrative mechanisms. The experience is the very new way of storytelling” [28]. The promotion of cultural heritage is also the telling of a story, making it appealing and attractive, never forgetting the higher levels of historical rigor.

In short, the implementation of investigation projects in the Digital Heritage field – based in the Histories of Art and Architecture – lead us to explore approaches aiming to recover, analyse and interpret the lost or invisible/transformed heritage within the urban landscape. This implies and assumes what was already addressed here regarding a shared interdisciplinary development with the local population, who desirably should have an active role in the whole process.

The final product, resulting from a multidisciplinary research, should be able to be (re) utilised in multiple platforms, anticipating the possibility of spreading it in several channels aimed at different publics and in different contexts.

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Exploring the Use of Virtual Identities for Broadening Participation in Computer Science Learning

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Abstract. This paper reports on a design-based research study investigating the impacts of virtual identities on public secondary school students in a computer science learning workshop targeting groups currently underrepresented in STEM disciplines in the United States. Using grounded theory methods, results from three workshops were analyzed to address (1) how to characterize the relationships between learners' virtual- and physical-world identities and (2) the impacts of avatar use on students' performance and engagement in computer-based learning environments. The central results are characterizations of four types of relationships between students and their virtual identities that we term (1) *Strategic Investment*, (2) *Avatar as Tool Investment*, (3) *Avatar as Self Esteem Measure*, and (4) *Judging Context Appropriateness*, each with implications for establishing design principles for STEM learning environments utilizing virtual identities.

Keywords: Computer science education · K-12 · Virtual identities · Immersive learning · Videogames · STEM identity · Avatars · Education · Self-efficacy · Computer ethics · Career · Programming · Human-computer interaction

1 Introduction

Educational technologies such as adaptive learning systems, educational games, and Massive Open Online Courses (MOOCs) have proliferated. Nearly everyone who uses a computer also uses a virtual identity, e.g., social media profiles, online shopping accounts, videogame characters, avatars, and more. Given the widespread use of such virtual identity technologies in educational technologies, it is important to better understand their impacts on, and interrelationships with, physical-world identity and behavior and to establish innovative and best practice in their design and deployment. We seek to discover best practices for using virtual identities to enhance performance, engagement, and STEM identity development for public secondary school students from

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demographic groups currently underrepresented in STEM disciplines in the United States (focusing on African American, Caribbean American, Latinx, and female students). Towards this goal, this paper reports on results from a series of computer science learning workshops deployed to address how to characterize (1) the relationships between learners' virtual and physical-world identities and (2) the impacts of avatar use on students' performance and engagement in computer-based learning environments.

2 Theoretical Framework

2.1 Learning Sciences

The key approaches from the learning sciences that were drawn upon in the design, implementation, and analysis of this intervention were (1) critical pedagogy theory, (2) constructionism, (3) approaches to computational literacy, and (4) grounded theory.

Well-known work in critical pedagogy theory [1] emphasizes a notion of dialogue as a pedagogical practice in which co-construction of meaning occurs when educators and students identify and engage hopeful vocabulary with the possibility of social empowerment. In this approach educators and students share ideas horizontally with mutual trust. Building on Piaget's venerable constructivist theories of cognitive development, his protégé Seymour Papert applied this lens on pedagogy to develop the approach termed constructionism. Constructionism is now commonly applied both as a pedagogical philosophy and technique in which building objects is central to the process of learning, and [2] furthermore, the public sharing of these built objects with others is seen as crucial to learning as it provides a sense of increased accountability [3].

Computational literacy is an emergent form of literacy that will "have penetration and depth of influence comparable to what we have already experienced in coming to achieve a mass, text-based literacy" [4]. It involves both using and, crucially, producing computational technologies. This project focuses not only on the learning of the building blocks of "literate programming" but also on "computational literacy" [4], and more generally, "procedural literacy," defined as facility with activities that "encourage active experimentation with basic building blocks in new combinations" [5][6].

Finally, Glaser & Strauss' grounded theory methods [7] provided an inductive approach to systematically generating conceptual categories from the data that is synergistic with a critical pedagogy approach to supporting student empowerment and agency. This process of seeking to meaningfully describe student-avatar relationships without imposing prior theoretical assumptions entailed a hermeneutic approach to the study of human conduct [8]. This approach involves preparation through minimizing preconceptions, data collection, coding, memoing, and the conceptual sorting of memos.

With regards to content development, the intervention in this project is aligned with the influential Exploring Computer Science (ECS) Curriculum [9]. This intervention adopts elements of Units 1-4 of the ECS curriculum: (1) Human-Computer Interaction (especially connections among social, economic, and cultural contexts), (2) Problem Solving, (3) Web Design (including social responsibility), and (4) Programming.

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2.2 Physical-World, Virtual, and Blended Identities

Prior research on player-avatar relationships (PAR) describes the human and non-human, physical and digital, material and immaterial parts that are “broken down and rebuilt” [10] during avatar creation, customization, and use. Harrell and Veeragoudar’s prior study of the relationships between underrepresented students in STEM and their avatars in learning games [11] characterized students’ perceptions of the construction and use of their avatars across three dimensions: (1) avatar appearance, with preferences ranging from everyday to extraordinary categories, (2) avatar ontological status, with perceptions ranging from first-person mirror representations to third-person external representations, and (3) avatar use, with uses ranging from deployment as instrumental tools to a means for imaginative identity play. In related work, other studies are useful for reinforcing and broadening these three main dimensions more generally to PAR as a player’s (1) identification with their avatar, (2) attachment to their avatar, and (3) perception towards the avatar’s instrumentality [12][13], describing the degrees of self-similarity, affinity due to likeness, physical control, responsibility, and suspension of disbelief [14], and usefulness that players perceive their avatars to have [15].

Given the broad range of possibilities afforded by avatar creation and customization systems, extensive research has also been performed to better understand the motivations and behaviors of players in their selection of character traits for their avatar across artistic, psychological, and technological factors. In seeking to better understand the ways in which players’ physical and virtual world identities are blended through the personalization process, Harrell’s notion of blended identity [16] provides a mapping between aligned aspects of a player’s physical identity (e.g., actions, characteristics, capabilities), the virtual identity (e.g., technical system affordances and properties), and blended identity (i.e., the playable character which is under the scope of user control).

3 Methods

3.1 Participants

Participants included Cambridge and Boston, MA public school students recruited through partnerships with the schools and via a collaboration with a non-profit organization called Innovators for Purpose. The majority of participants were enrolled in introductory computer science courses. The first workshop included twelve middle and high school participants. All twelve self-identified as “Black or African American;” four self-identified as female and eight as male. The second workshop included seven high school participants, four self-identified as “Hispanic or Latino” and three as “Black or African American;” four participants self-identified as female and three as male. The third workshop included seventeen high school participants, thirteen self-identified as “Black, Caribbean, West African, or African American,” and four as “Hispanic or Latino;” fourteen self-identified as male and three as female.

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3.2 Materials and Procedure

The workshops used both paper-based and digital materials to facilitate student learning of fundamental computer science principles as well as ECS topics such as human-computer interaction, privacy, and security. This included books with design examples, sticky notes for ideation, grid paper and markers for paper prototyping, index cards and pens for documentation, feedback, and game testing, and computer equipment with a high-speed internet connection. A key component of the study is a computer science learning platform developed in the MIT Imagination, Computation, and Expression Laboratory (ICE Lab) called *MazeStar*, the features of which include tools enabling learners to create customized games [17]. A key component of *MazeStar* is *Mazzy*, a game in which players solve mazes by creating short computer programs. In our workshops we use *MazeStar* as a platform enabling students to address issues of their own concern within their communities through design. *MazeStar* and *Mazzy* provide an experimental setting in which the authors have conducted evidence-based research to better understand the impacts of avatar use in students' learning.

3.3 Data Collected

Activities were videotaped and audiotaped and all computer monitors were screen-captured. Avatar customization actions were logged by the AIRvatar system, a custom telemetry system to capture data about user avatar customization [18]. All paper-based student materials were collected and photographed. In-game performance data and student survey data (regarding topics such as students' demographics and dispositions toward computer science) were collected. Individual semi-structured clinical interviews were conducted roughly one month after the workshop.

3.4 Data Analysis

The following procedure describes the qualitative research strategies from grounded theory methodology which were employed to analyze student discourse data. In preparation for the analysis process, we created a matrix of student data. Individual researchers performed open conceptual memoing of student transcript data. This enabled broad ideation and evaluation of emerging theories throughout the analysis process, ensuring all student discourse artifacts (e.g.: workshop transcript, interview notes, screen capture images) were openly coded prior to applying external theoretical models. Next, individual researchers applied an existing coding scheme to interpret the analysis matrix populated with the data provided by the students during the workshop and follow-up interviews. The coding scheme which was applied is a subcomponent of a validated instrument called the Advanced Identity Representation (AIR) Inventory. The AIR Inventory was developed to systematically annotate empirical study data of identity creation in video games to support the emergence of coherent theories from voluminous collections of verbal, textual, survey, and video data. The MIT ICE Lab developed the initial instrument in 2011. Iterative, accretive development of the advanced instrument was achieved through several rounds of user studies, validating its usefulness as a rubric

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for recognizing and characterizing moments of conceptual flux in subjects' spoken references to their avatars, particularly regarding to subject/object status.

An additional round of analysis was performed by applying a finer-grained coding scheme from the AIR Inventory. Utilizing grounded theory techniques, aggregates of discourse-based evidence resulted in concepts and theories articulating characterizations of four types of relationships and emotional connections between students and their virtual identities, described below in the results section. Finally, group discussions facilitated the synthesis of individually-constructed memos and codes, allowing the most significant themes to emerge. The integration of both individually- and group-constructed codes, themes, and analyses was systematically performed until core categories were identified upon reaching "theoretical saturation" [20]. The core strategies identified through this extensive analysis process are described below.

3.5 Results

Analysis of over 40 hours of transcribed interview data yielded four characterizations of the relationships between students and their virtual identities were elicited from the study data, which are (1) *Strategic Investment,* (2) *Avatar as Tool Investment*, (3) *Avatar as Self Esteem Measure*, and (4) *Judging Context Appropriateness*, each with implications for both future studies and for establishing design principles for STEM learning environments utilizing virtual identities. Consistent evidence of three phenomena emerged from the study results: (1) Likeness Bias (a significant bias towards the "authentic" self, and a stigmatization of identity play/tourism), (2) Avatar as Object (a subset of students use avatars strictly instrumentally), and (3) Importance of Context (students strongly preferred avatars that they deemed suited to the game genre/fictional virtual world at hand). These results are elaborated in Table 1.

Table 1. Results Summary: Characterizations of four types of relationships and emotional connections between students and their virtual identities. Note that the example narratives excerpts have been selected from a larger body of evidence transcribed from student interviews.

	Phenomenon description and relevant avatar user types	***Projection between physical-world and blended identities***	***Example student narrative excerpt from student transcript data***
Strategic Investment	Students invested in effort to ensure that their avatars resembled them and described emotional attachments to their avatars, but also claimed to be emotionally disinvested in avatar features	<u>Projected from physical identity to blended identity:</u> Physical-world attributes: skin color, hair, nose, color preference, religion, and so on. <u>Projected from blended identity to physical world identity:</u> Sense of investment; limitation acceptance; disinvestment	"I made mine, like myself…the problem would be like, I don't know, the nose, I guess. But everything else was fine…the hairstyles, or the skin color, and it kind of disappoints me a little bit, but I know it's hard to get the exact details of every single thing. . . I kinda, I don't worry about it too much, so I just try to make it look like me as much as possible...I would like to have, I kind of get a little mad, but

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	that they were unable to customize adequately due to limitations of the avatar creator; Mirror; Identity-Player.	in avatar mirroring; reason for degree of (dis)investment.	I don't, I don't get worried about it that much."
Avatar as Tool Investment	Students who use avatars strictly instrumentally (and not for identity play) still see the type of avatar as likenesses of their physical-world identities in terms of the types of tools or playthings they appropriate to their social category; Mirror; Instrumental-User.	<u>Projected from physical identity to blended identity:</u> Instrumental control, in addition to items mentions for *Strategic Investment*. <u>Projected from blended identity to physical world identity:</u> Sense of appropriateness of the tool to social identity; relationship to avatar as object.	"I would have easily found something I was happy with, whether or not he looked similar to me or was a polar opposite. Because as long as I think he looks cool, he or she looks cool, probably he, as long as I'm okay with it, I don't feel a need to make him to look like me so I don't really feel like it would have impacted my experience in building the map at all...in the workshop…I didn't really feel like the character had a significant effect on one making the game or two playing it...So he kind of just became an object that I was moving around."
Avatar as Self Esteem Measure	Students consistently suggested that a desire to create a non-likeness avatar reflected a lack of self-esteem; Mirror; Identity-Player/Instrumental-User.	<u>Projected from physical identity to blended identity:</u> Personal history/attachment (e.g., nostalgia, repeated creation of same character), in addition to items mentions for *Strategic Investment*. <u>Projected from blended identity to physical world identity:</u> Self-esteem.	"I feel that they [players who create characters that do not look like themselves] don't care about themselves in the real world, and they want to express their new life in the game and be someone completely different than in reality...They don't really like who they are."
Judging Context Appropriateness	Students strongly preferred avatars that they deemed suited to the game genre/fictional virtual world at hand -- they also associated preferences for genres/fictional world types with their physical world identities; Mirror;	<u>Projected from physical identity to blended identity:</u> Range from no customization at all (only control) to context-specific adaptations in addition to items mentions for *Strategic Investment*. <u>Projected from blended identity to physical world identity:</u> Sense of genre	"Um, for sports it's probably different 'cause I try to make it, like, I guess as the best athlete as possible. So you know...height and strength, and whatever. That's what I try to do for sports...when I do the sports one I try to make the avatar as, like, make it look like an athlete with the muscles and height...When it's like, uh, like a game that has, like an adventure or something like that, I would usually, I would make it like me. Like, me, you know."

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Everyday/Extraordinary Appearance/Context.	preferences, sense of realism/illustration preferences (e.g., anime style).

4 Conclusion

This study has resulted in more nuanced ways to characterize the relationships between learners' virtual and physical-world identities and revealed characterizations of four types of relationships and emotional connections between students and their virtual identities. Our findings suggest that developers must take seriously students' potential social and emotional investment in avatars that represent students' physical-world identities. Although many students initially stated that "it doesn't really matter how the avatar looks," in practice these students invested a significant amount of effort to customize their avatars to look like themselves. Furthermore, use of likeness avatars has been shown to impact students' performance [21]. In fact, across a number of conditions in prior work, participants using *successful likeness* avatars (showing a likeness avatar when is successful and shape otherwise) were the highest performing out of all conditions, while (like here) self-reporting did not reveal a difference in engagement [22]. We found that participants take up a strategic form of engagement when their customization aspirations are thwarted by the avatar creation systems' affordances.

In conclusion, we recommend that developers be intentional in the design of virtual identity creation systems in order to build empowering computer-based learning platforms and environments for young learners. Considering *Strategic Investment* means affording learners ways to more meaningfully map traits from physical- to virtua-world identities. Per *Avatar as Tool Investment*, designers must acknowledge the identity-laden effects of color, shape, and other properties on the perception of even the most generic and abstract avatars. Acknowledging *Avatar as Self Esteem Measure* means ensuring platforms support designing diverse likeness avatar representations. Finally, addressing *Judging Context Appropriateness* suggests providing graphical embellishments that fit both the game domain theme *and* student interests. Taking such design implications into account supports not only creating systems more equitable to diverse learners, but systems that better enable learners' sociocultural identities to be powerful resources for their STEM identities.

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Special Track

Personalisation in Immersive and Game-Based Learning Environments

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The Effect of Learning Styles and Scaffolding Strategy on Students' Achievement in a VR Learning Environment

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Abstract. It is commonly accepted that non-native speakers immerse themselves in English-speaking countries, currently thought to be the most effective way for second language acquisition. Nevertheless, the majority of elementary school students in China cannot cover the cost of traveling to a country where the citizens generally speak English. Meanwhile, each individual has its own preferred way to acquire knowledge and retain information, which has been considered as a vital factor for personal performance. Thus, in this paper, a virtual reality game based on children's stories for Chinese elementary students to learn English has been built. Moreover, an experiment has been conducted among fourth grade students by situating the experimental group in the virtual reality game under the guidance of specific learning goals, while the control group learned without any guidance using only the virtual reality game only. The experimental results show that: (1) the post-test score for all students was significantly higher than pre-test scores. (2) The post-test score for the experimental group was higher than the control group. (3) Compared with intuitive learners, the sensory learners tend to spend less time to finish the same task.

Key words: Virtual reality (VR), Educational Game, English Learning, Learning Styles, Scaffolding Strategy Elementary Education.

1. INTRODUCTION

English, a universal language, is a vital factor for professional success as it is deemed to be one of the significant capabilities for competition in many countries around the world [1]. It is commonly accepted that non-native speakers immersed in English-speaking countries is effective for second language acquisition [2]. Nevertheless, the students in China lack the environment to learn English through using English in their daily lives. The question arises as how to construct an Interactive Language Learning environment in China for speeding up the formation of students' English skills.

Game-based learning, especially the environment-based learning method, is a rapidly emerging field, with VR technology becoming widely available. Educators already recognize that virtual reality is quite useful for language learning by offering an immersive space [3] Compared with teacher-centered, grammar-driven instruction, simulating a real-world environment for EFL students to communicate with native speakers is much more meaningful [2]. Besides that, the VR game weaves children' stories into its development with the goal of creating a firsthand experience, not only for learning, but also for entertainment.

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Few English-related games with VR technology already exist to target EFL learners. To our knowledge, our virtual reality game with children's stories is the first VR game for EFL students in a wide release specifically geared toward the learners of the English language without the help of a teacher or an English immersive environment.

1.1 Learning English Using Virtual Reality

Many studies indicate that a 3D game is an innovative alternative to traditional language learning for EFL learners, as it is able to build up the motivation and engagement for learners [4]. Yu-Li Chen revealed that a virtual reality environment with immersion positively affected student language cognition [3]. Susan Jang etc. described direct manipulation of the virtual environment as being more useful for learning than passive viewing [5]. In this experiment, interestingly, the learners with different learning styles could communicate with game characters in English very well in the virtual-reality-based, game-like learning environment (VRGLE).

1.2 Children's Stories for EFL Learners

A previous study found that digital storytelling projects could help student understand their curriculum content efficiently[6]. Interactive CD-ROM storybooks enhance the skill of reading comprehension for pupils as well[7]. Furthermore, ESL preschoolers can acquire new vocabulary significantly through reading storybooks [8]. Abu Rashid concluded that Vocabulary-learning with children's native stories is effective for ESL secondary students [9]. Whereas we want is to help students to make out the plot in all English VR environments using familiar children's stories and learn best by doing so.

1.3 Scaffolding Strategy

Scaffolding could guide students and make sure they can be navigated properly. With the support of scaffolding, students are able to achieve higher levels of achievement and study effectively [10].Applying scaffolds to support students' learning could make positive influence as follows: first, with the supportive interventions, students tend to achieve goals that are usually higher than those without scaffolds [11].Besides, an effective scaffold should not restrict the students' learning process but should be able to enhance their performance [12].In this research, the guidance of learning goals helped students focus on the material which is most relevant to the learning objectives by providing them with the learning goals, key points and difficult points before immersing themselves in the VR game.

1.4 Learning Styles

We all have preference for absorbing information, analyzing information and making decisions from different environments. Educators have showed interest towards various learning styles for many years. Honey and Mumford stated that a learning style could be defined as an individual's preferred way of learning [13]. Besides learning styles were considered as an useful educational tool, each individual has different abilities to capture different types of information, for example some students may be good at

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acquiring aural information, while others may learn well with pictures and tables[14]. Therefore, unique learning environments may help students with their studies.

Felder and Soloman have divided students' learning styles into four dimensions: active style – reflective style, sensing style – intuitive style, visual style – verbal style, and sequential style – global style [15].Gary Cheng indicate that active learner mostly valued the ease of use and usefulness of VR game, and verbal students were mostly satisfied with the communication and identity features in VR game [16]. Additionally, the visual-auditory-kinesthetic model focuses on students' strengths in absorbing information as well [17]. VAK learning style concludes three sensory modes of learning: Visual, Auditory and Kinesthetic. Visual learners learn best by seeing. Auditory learners learn best by hearing, and kinesthetic leaners learn best by doing. Based on research done on what extent virtual reality environments affect the process of exercising spatial abilities for different modal and personality type learning styles, Hauptman and Cohen assumed that the achievement of the visual students were greater, but not significantly [14].

Philip suggested that educational research and resources should be directed toward those educational interventions which demonstrate improvement of student learning. However, there is a lack of evidence to support the efficacy of the Learning Styles hypothesis[18]. Practical classroom implication educators should find a cross-over point where both visual learner and auditory learner can learn best [19]. It is difficult to meet all students' preference in a classroom. And the efforts to study learning style in a classroom are less meaningful. With the advent of technology, educators can put their efforts of learning style onto the individual level. For example, Gwo-Jen Hwang et al. developed two versions of the computer games (a global and a sequential version) to meet the individual's learning style based on the cognitive features of the global and sequential learning styles. And they found that the personalized educational computer game not only promotes learning motivation, but also improves the learning achievements of the students[20].

In this study, the sensing style and intuitive style dimension of Felder-Silverman learning style has been adopted to measure each individual's performance based on an English immersive environment, as it matched with our experiment. And the students' preference can be minimized to an individual level through adaptive technology in the English VR environments rather than measuring the whole group of students' preferences in a classroom. Students with the sensing style are more likely to learn something which is relative to the real circumstance, while students with the intuitive style prefer to have abstract conception.

1.5 The Aim

This experimental study aims to demonstrate that game-based language education with VR technology can help primary grade students with different learning styles learn English. Moreover, the aim of the study is also to find out if the game applied with a scaffolding strategy can develop the skill of English usage.

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2. METHOD

2.1 The Setting and Developed VR Educational Game

In order to explore the achievements and efficiency of students' English learning in a VR environment, we constructed this game-based VR educational game and chose the contents from an English textbook for fourth grade students in China. The game engine was controlled by the HTC Vive Tracker enabling high levels of presence. Figure 1 shows a model of the VR English educational system based on children' stories, which contain a virtual reality environment, a learning materials database, and students' action database. This system was built based on task-oriented learning model, so students were not free to choose where they should begin with. They would follow the task sequence which we arranged and study all the content step by step. If they did not finish a task, they could not go on to the next one. For the learning of English as second language students, the most difficult part is the pronunciation. Therefore, this game demands students to try again if the pronunciation is not correct through speech recognition. However, we offer students hints to help them when they feel it is difficult to pronounce the sentences or finish certain tasks, which can ensure that all the students finish the tasks although with different speeds. Actually, there is no need to provide tasks rigidly, and we prefer to offer hints for learners by cloud computing, as too much anxiety can lead to learners' negative behaviors [21].

One of the important features of this VR game is formative assessment, including immediate feedback and minimized interaction for learners. Besides that, students in this VR game play a role along with completing the tasks, which brings entertainment. In addition, the task for a theme was designed with certain parts, including learning part, practice part and applying parts.

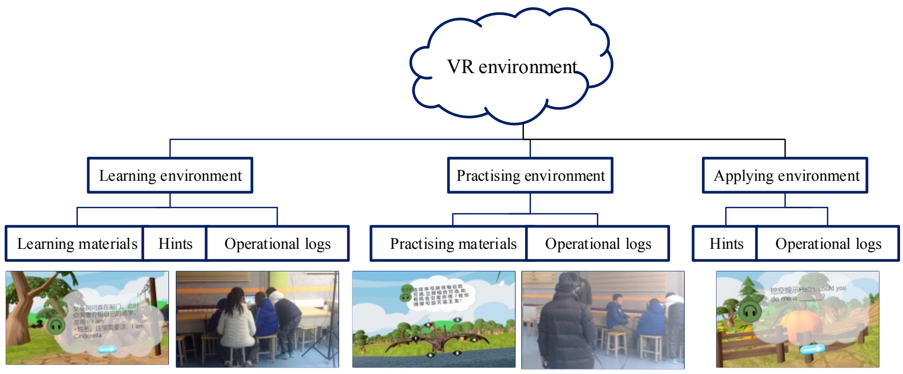

Fig.1 The model of VR English educational system based on children' stories

The game's background story was presented after the students logged into the virtual reality game. The storyline is based on a well-known fairy tale named Cinderella. In this story, Cinderella wants to go to the Prince's ball, but she has no carriage. Cinderella finds a witch who tells her about a magic pumpkin which can be turned into a carriage. The pumpkin can be found at a farm across a bridge. After receiving help from a farmer, Cinderella finds the magic pumpkin.

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The students play the role of Cinderella who requests help from the witch. While speaking to the witch, the students can learn a few sentences, such as, “Could you do me a favor?”, “I want to go to the prince's party, but I have no carriage.”, “It is very kind of you.” and so on. At this point, the system gives the students a study card for each sentence needed to speak to the witch. There is also an opportunity to receive feedback and to allow the students to retry, re-listen and skip each sentence. Students could hear the sentence being read out by clicking the button on both the study card and feedback card. After the students finish this stage, the system would give feedback for the whole conversation in the witch’s house. This feedback card displayed their ranks of achievements and frequency of practice. Before the students cross the bridge, they were asked to defeat the Tyrannosaurus by imitating some English mantras triggering a cannonball. This stage is for practicing the sentences which they have received the lower scores in witch’s house.

When the students arrive at the farm and ask for the farmer’s help, they are provided the opportunity to use the sentences which they have learned in the witch’s house, with the help of hint cards and feedback cards. When they finished the conversation, the system gives them additional feedback. When they find the magic pumpkin, they need to talk to the magic pumpkin as well. This conversation and functions are like those on the farm. After they finish all the tasks, the system provides feedback based on their scores, ranks and coins representing the frequency of practice, their weakness and the top 5 ranks in their class. The framework of the system is shown in Figure 2.

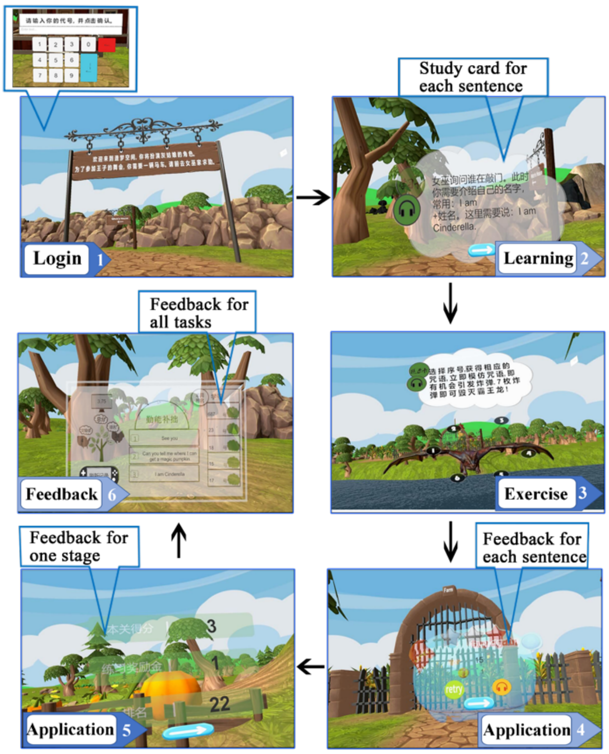

Fig.2 Six screenshots illustrating the VR English educational game

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2.2 Participants

There were 38 fourth grade students who took part in this experiment. All of them were 9 to 10 years old and were studying in the same class at an elementary school in Xi'an, China. 20 students, 13 boys and 7 girls, were in the experimental group while 18 students, 11 boys and 7 girls, were in the control group. All students had at least 3 years of experience of learning English. Most of them learned English using digital game on computers, iPads or mobile phones every week. However, only two of them had previous experience of playing virtual reality game. Usually there are 30 individuals selected in each group. However, a small sample size of 10 to 20 is tightly controlled [1]. A small sample size could help with the individual level. In this study, a sample size of 38 was selected.

2.3 Measuring Tools

The instruments used in this study were the pre-test, the post-test and the questionnaires of learning style for discovering their preferred ways of information acquisition. All the questions in the pre-test were the same as the post-test, and they were used at the beginning and end of the experiment respectively to measure their English performance. Two English teachers in their school have checked and agreed upon all the questions as well.

Students' learning style can be broken into Visual, Auditory and Kinesthetic (V-A-K). Some people possess a preferred or dominant one mode, while some like two modes, and it is also possible that some have three modes. They were classified into the uni-modal(V,A,K), bi-modal(VA,VK,AK) and tri-modal(VAK)[22].The following is the internet link for the VAK questionnaire: http://www.staffs.ac.uk/sgc1/faculty/personal-skills.

For better understanding of the students' learning preferences, we also classified students' personality type by using the Felder–Silverman model, which has four dimensions, including active/ reflective, sensing/ intuitive, visual/ verbal and sequential/global. In this study, the sensing/ intuitive dimension of Felder-Silverman learning style was adopted to figure out how long does each student with certain learning preference finish the same task. And this is the link of the questionnaire: https://www.webtools.ncsu.edu/learningstyles/.

2.4 Data Analysis

In this study, two independent variables of different learning styles were collected, including the VAK learning style and the Felder-Silverman learning style, while the dependent variables were the result of the post-test and the time taken for finishing the task in the VR environment. And all the data was analyzed with IBM SPSS Statistics. Once the data was collected, the method of “one-way ANOVA” was adopted to compare the achievement and efficiency between the two groups and the different learning styles.

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3. Experimental Results

For exploring that the VR English environment is valid, we first collected students' results for the pre-test, and one-way analysis of covariance (ANCOVA) was applied to evaluate students' performances between the experimental group and control group. The assumption of homogeneity of regression was reviewed and no violation was found ($F=1.14$, $P>0.05$). Therefore, the assumption stands and the students' prior knowledge were equal across groups. Figure 3 shows the design of the experiment.

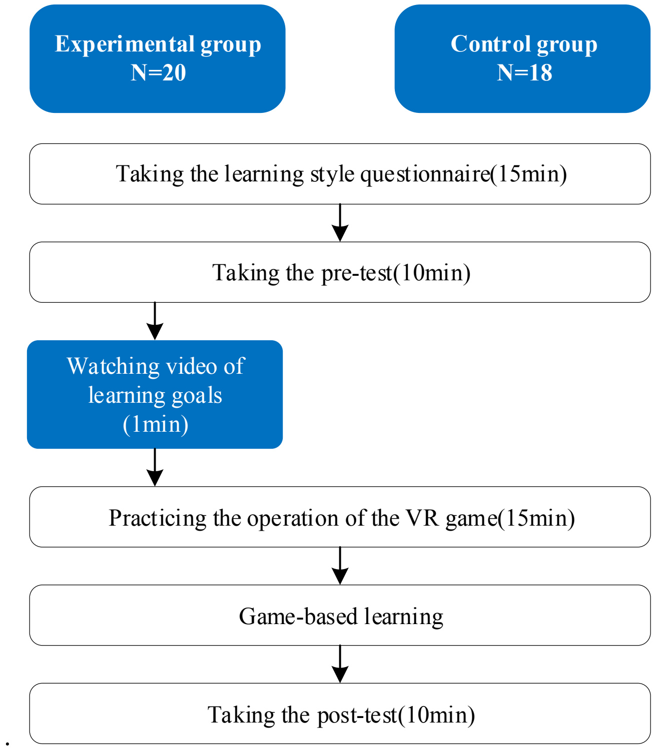

Fig. 3 Diagram of the experiment design

3.1 Analysis Achievement between Two Groups

For better understanding of whether the VR game with children's stories could promote students' achievement of higher levels, two paired-samples T tests were performed, and a significant difference was found for achievement between pre-test and post-test in both experimental group ($t=-5.88$, $P=0.000<0.001$) and control group ($t=-2.61$, $P=0.018<0.05$). The means and standard deviations between two groups were shown in Table1, and there was significant difference between pre-test and post-test scores. That implies the students benefited from the VR English game.

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Table 1. Grade of groups: means and standard deviations

	Pre-test		Post-test	
	M	SD	M	SD
Experimental group	63.60	18.30	77.40	16.28
Control group	56.67	21.70	66.00	15.54

Scaffolding Strategy, telling students the learning goals, can help students to understand the task better and improve their ability. Specifically, it can help them to finish the task by themselves. To better understand whether the Scaffolding Strategy could promote students to perform better, in this study, a one-way ANCOVA was used on the post-test between the two groups. The result is presented in Table 2, showing that students in the experimental group achieved significantly higher than that in the control group ($F=4.85$, $P=0.034<0.05$). This means that students given clear goals performed better in the VR game.

Table 2. The one-way ANCOVA result of the English learning achievement of the two group

	N	Mean	SD	Adjusted Mean	F	η 2
Experimental group	20	77.40	16.28	3.64	4.85	0.119
Control group	18	66.00	15.54	3.66		

*p <.05.

The time that students spent to finish the same task in a VR environment between the two groups was also analyzed. The time taken by the students in the experimental group (Mean=21.69, SD=3.80) was about the same as that in the control group (Mean=23.24, SD=5.20).

3.2 Analysis of Learning Efficiency among Their Learning Styles

Currently, lots of educators pay much attention to student's learning style in a Virtual reality environment, and they agree that students learning style plays an important role in their studies in the VREs. Therefore, in this research the students' learning efficiency was investigated according to their learning style. A total of 38 students took part in the experiment. However, due to a technical glitch, one students' time record went missing. The students were divided into two groups: some students preferred sensing (17 individuals) and students preferred intuition (20 individuals), according to the Felder–Silverman model. To further verify the efficiency between students preferring sending and the students preferring intuition, the one-way ANCOVA was conducted. The results are displayed in Table 3, and there is a significant difference in the test between the two groups ($F=4.55$, $P=0.04<0.05$), implying that compared with the students who preferred sensing, the students who preferred intuition spent more time to finish the same task. So students who preferred sensing learn faster than those who preferred intuition in the VR learning environment.

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Table 3. The one-way ANCOVA result of time spent by students to finish the task in VR game

	N	Mean	SD	Adjusted Mean	F	η 2
Sensory learners	17	21.18	3.54	0.86	4.55	0.115
Intuitive learners	20	24.10	4.61	1.03		

$*p < .05$.

We also investigated the efficiency of 37 students, including 12 students with uni-modal (V, A, K), 12 students with bi-modal (VA, VK, AK) and 13 students with tri-modal (VAK), by using the VAK questionnaire. All the students have been asked to finish same task in the VR environment. The results revealed that there is no significant difference between the three groups (F=0.46, P>0.05). As for performance, there is no significant difference among different learning styles. In other words, learning English in VR games is beneficial to serial learning styles students.

4 Discussion and Conclusions

Previous studies have confirmed that a VR environment could improve student's motivation and enhance their problem-solving ability[23]. And proper Scaffolding Strategies would help with students' achievement and efficiency. Therefore, in this study, a game based virtual reality game was constructed and 38 students were asked to finish the same task in the virtual reality game. In addition, students finished the learning style questionnaire before involving themselves in the VR game.

With the result of the pre-test and post-test, it was concluded that all students would benefit by learning English in a game-based VR environment. Meanwhile the students under the guidance of learning goal had higher performance than those without instructions. While the instruction of learning goal did not maximize students' effectiveness, this may be restricted by the small sample size.

Furthermore, as for the sensory-intuitive domain, the VR game offered a tangible representation of abstract concepts. For example, students can experience the stories and talk in the VR environment, which can help student achieve better understanding towards the abstract conceptions[14]. In this study, students who preferred Sensing were able to finish the task faster than those who preferred intuition, while both groups tend to achieve the same level. That is to say, students with particular learning preference tend to have higher learning efficiency, and for some students they may study more slowly, but they would still achieve the same level. As students with a sensing preference can work more effectively under actual learning circumstances, it is reasonable that they can finish the task faster in the VR environment.

On the other hand, according to the results, it took the same time to finish the task among the students with uni-modal, bi-modal and tri-modal. There is no significant difference of achievement among the three groups as well. That is to say, the students with uni-modal (V, A, K), bi-modal (VA, VK, AK) and tri-modal (VAK) performed similar in the VR English game. This result is reasonable, as previous studies have mentioned that the feature of virtual reality environments are as follows: highly immersive, interactive, visually oriented, highly sensory, and colorful [24, 25, 14].

It should be noticeable however that this study has some limitations. The sample size was relatively small in this study, and the numbers of boys are more than girls, so we

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did not compare the performance between genders. Besides, for most of the participants in this research it was their first time to learn English through a VR game, which could help the VR game to draw their attention easily. So this might help them perform better. We should also notice that no teacher was involved in this research, however teachers play important roles in education. In the future, it would be worthwhile to explore how teachers can use these VR materials to properly help students learn better.

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Student Primary School Teachers' Attitude towards Virtual Reality in Primary School Education

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Abstract. As the general interest in several fields of application for virtual reality (VR) technologies rises, we see efforts to establish VR as a medium for teaching in our early education system. In order to investigate the current attitudes of becoming primary school teachers towards the integration of VR in different primary school education topics, we conducted a survey among 277 student primary school teachers with different specializations. We assumed that the students' interest would be connected to the experiences they made with VR. In addition, we hypothesized that the students' interest would be positively correlated to the overall perceived benefit of the different subjects through the use of VR due to motivational reasons. We also assumed a connection between the previous experiences and the perceived benefit so that a participant who made previous experiences knows more about the applications and possibilities of VR. Furthermore, we hypothesized that the studied main subject influences the perceived benefit of particular primary school subjects so that a student with a certain main subject was more likely to see the possibilities of the application of a new medium in the corresponding primary school subject. This paper depicts the findings from the study, together with a discussion of possible effects on teacher training for primary school education. Furthermore, we discuss the given qualitative answers in terms of possible factors that influence learning processes and indicators that determine learning outcomes using the medium VR.

Keywords: Virtual Reality · Primary School · Learning Environment · Media Learning · Teachers' Attitudes

1 Introduction

Right from the start of serious development progress in terms of virtual reality (VR) in the early 90s, many researchers thought of the educational possibilities of immersive virtual environments. Bricken named VR as "the next step in the evolutionary path" [1] right after the computer revolution. Thinking of VR as a paradigm shift, reality generation as a replacement for symbol processing, participants replacing observers and the interface being replaced by an overall inclusion of the user are just some of the changes brought by VR [1]. Considering programmable participation, natural semantics, constructivism, cognitive

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presence and multiple participants as some of the main issues posed by VR in educational terms, Bricken states: "Just substitute the virtual for the actual, then get rid of the constraints of the actual" [1].

Furthermore, the possibilities of accurate, schematized, substantiated and metaphorical representations in VRs expand the world of possible applications in educational use, especially through the two principles of visualization: spatialization and multi-sensory input [2]. Following Milgram et al., we see VR as a digital environment that is completely synthetic with the purpose to immerse the participant-observer with enabled interaction [3]. The application of a VR in the educational domain is called an educational virtual environment (EVE) [4]. Until now, there are many research fields in terms of EVEs [5–7]. In a ten year review of empirical research on the educational applications of VR, which is based on 53 research studies, Mikropoulos stated in 2009 that VR seems to be a mature technology appropriate for pedagogical use [8].

But empirical research and technological developments may not be sufficient to bring VR into our educational system: Without a pedagogical and didactical fundamentum and the teachers' support of the use of this immersive teaching and learning medium, VR cannot go far in the educational context. In order to investigate the attitude of becoming teachers towards the application of VR in early education, we conducted a survey among 277 student primary school teachers, asking them, in addition to general question about gender, studied subjects and their main subject, about their attitude towards their experiences with VR, interest in experimenting with VR and their perceived benefit of the use of VR technologies in primary school education.

2 Do we need VR in Primary School Education?

2.1 Application of VR in Primary School Education

Virtual and augmented realities (ARs) have already been used in pilot projects in primary schools [9]. Different studies show potential benefits in teaching and learning with VR and AR. In a project from Kerawalla et al. 133 children aged 9-10 years participated in an AR for understanding how the earth and sun interact in 3D space to give rise to day and night [10]. Other formal learning aspects like improving imaginative writing [11], the construction of three-dimensional shapes [12] and the comprehension of planetary phenomena [13] have been investigated recently. Roussou, Oliver and Slater developed a virtual playground for primary school students between the ages of 8 and 12 in order to investigate how learning improves through interacting in an immersive virtual environment [7]. In addition, research in encountering social issues like school phobia [14] and bullying [15] is on its way to enhance pedagogical action in primary schools.

2.2 Proposed research model and research hypotheses

We assumed that the students' interest (INT, consisting of I1, I2, and I3) would be connected to the experiences (EXP) they made so that a student who is

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generally more interested in working and experimenting with VR would be more likely to have already experienced VR in one way or another (H1).

Furthermore, we hypothesized that the students' interest would be positively correlated to the overall perceived benefit of the different subjects (PEBE, consisting of S1, ..., S9) through the use of VR due to motivational reasons (H2).

At this, we also assumed a connection between the previous experiences and the perceived benefit so that a participant who made previous experiences knows more about the applications and possibilities of VR (H3).

We hypothesized that the studied main subject influences the perceived benefit of particular primary school subjects so that a student with a certain main subject was more likely to see the possibilities of the application of a new medium in the corresponding primary school subject (H4). To check H4, we were making up pairs among the different studied main subjects and the subjects of the primary school curriculum (table 1subject pairstable.1.1) and hypothesized their connection (H4.1- H4.9). In summary, we examined the hypotheses presented below.

- **H1** There will be a positive relationship between overall interest and previous experiences.
- **H2** There will be a positive relationship between overall interest and overall perceived benefit.
- **H3** There will be a positive relationship between previous experiences and overall perceived benefit.
- **H4.x** There will be a positive relationship between the studied main subject and the perceived benefit of the corresponding primary school subject.

Table 1. subject pairs

hypothesis	studied main subject	primary school subject
H4.1	Geography	Local History and Geography
H4.2	Mathematics	Mathematics
H4.3	German	German
H4.4	English	English
H4.5	Religion	Religion
H4.6	History	Local History and Geography
H4.7	Physical Education	Physical Education
H4.8	Arts	Arts
H4.9	Arts	Handicrafts

3 Research Method

3.1 Sample

All 277 participants of the survey were student primary school teachers from the University of — in Germany, of which 237 were female, 42 were male. The rep-

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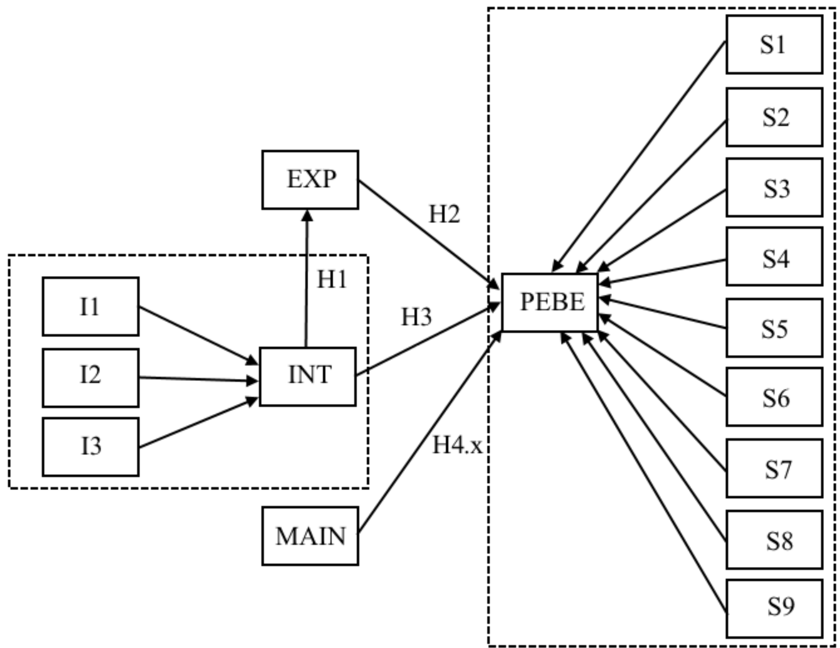

Fig. 1. research model

resented main subjects were Social Studies (17), Geography (50), Mathematics (21), German (71), English (40), Religion (46), History (20), Physical Education (7) and Arts (4).

3.2 Questionnaire

To investigate the attitude of student primary school teachers towards the application of VR in primary school education, we first asked them general questions about their gender, their envisaged school type in their teaching studies (in order to sort out students with a different background than primary school education), their main subject and their minor subjects.

The next part containing questions about experiences and attitudes towards VR started with a brief description of VR (translated from German): *Virtual Realities (VRs) are completely synthetic digital worlds which are fully generated by a computer. Usually VRs are experienced through head mounted displays - these are displays which are attached to the head of the user and trace the users head motions in order to change the picture on the display according to the head orientation and head tilt.* We know that this definition does not cover all aspects of a technologically independent description of VRs. The decision to focus on

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the technical aspect of the currently dominant technology of the head-mounted display (HMD) was made on the basis of simplicity.

The first subsection asked about the previous experiences of the participants with the medium VR using a VR headset with an adaptable smartphone or with a professional HMD.

The next subsection contained three questions about the students interest in working and experimenting with VR in general, covering the interest fields *personal interest in experimenting with VR*, *exploring the didactical possibilities of VR in primary school education in the course of their studies* and *application of VR in their later professional life as a primary school teacher*.

The third subsection asked for nine school subjects about whether the use of VR as a teaching and learning medium would bring a benefit for pupils or not. The items of the third subsection (German, Mathematics, Local History and Geography, Arts, Music, Physical Education, Religion, English, and Handicrafts) were orientated on the german primary school curriculum.

A fourth section gave the participants the possibility for a brief description of a specific application for the VR technology in one or more particular subjects in primary school education.

3.3 Procedure

Before the participants filled out the questionnaire, they were shown a promotional video from the HTC Vive [16]. The medium of the promotional video was chosen because it is intended to show the wide range of possibilities of the advertised product. The choice in favor of the particular video from HTC was made through a pretest where five students were shown four promotional videos from HTC and Oculus and were later asked what video would show best the operating principle and the possibilities of the VR technology.

Afterward, the participants were given 10 minutes to complete the questionnaire. The students were encouraged to fill out the survey on their own and thinking about their individual experiences, interests, and attitudes.

3.4 Findings

Experiences Of all participants, 275 answered the single choice question *What have been your previous experiences in terms of virtual reality systems or applications?* with the five possible items *I have already used a VR headset with an adaptable smartphone (Google Cardboard, Daydream View, Gear VR, ...) before.*, *I have already used a professional VR head-mounted display (HTC Vive, Oculus Rift, ...) before.*, *I own a VR headset with an adaptable smartphone (Google Cardboard, Daydream View, Gear VR, ...) and use it sometimes.*, *I own a professional VR head-mounted display (HTC Vive, Oculus Rift, Microsoft HoloLens, ...) and use it sometimes.* and *I do not have any experience with VR.*. The findings show that 1.1 % of the participants own a VR headset with an adaptable smartphone or a professional HMD, 19.7% have already used a VR headset with

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Table 2. interest in VR

interest area	personal experimenting	in the course of their studies	in later professional life	overall interest
personal experimenting	1.000	**.243****	**.245****	**.677****
in the course of their studies	-	1.000	**.593****	**.768****
in their later professional life	-	-	1.000	**.795****
overall interest	-	-	-	1.000

**. The coefficient is statistically significant at the 1% level (both sides).

adaptable smartphone or HMD once and 79.2% do not have any experience with VR by the time of the survey.

Interest To survey the students interest in VR, we asked three questions about different fields (personal experimenting with VR, exploring the didactical possibilities of VR in primary school education in the course of their studies, application of VR in their later professional life as a primary school teacher) of application of VR which were to be answered on a 4 point Likert scale (*not interested*, *rather not interested*, *slightly interested*, *very interested*). Summarizing the items *not interested* and *rather not interested* to *rather not interested* and the items *slightly interested* and *very interested* to *rather interested*, the following results were found: 36.4% of the students are rather not interested in personal experimenting with VR, while 63.6% are rather interested. 22.7% of the students are rather not interested in exploring the didactical possibilities of VR in primary school education in the course of their studies while 77.3% are interested. 37.2% of the students are rather not interested in the application of VR in their later professional life as a primary school teacher, while 62.8% are interested. The items were highly significantly correlated (Spearman-Rho correlation) among each other (table 2interest in VRtable.1.2). We then summarized them to an *overall interest* as the average value of the three interest items.

Fields of Application We then asked the participants *In what subjects in primary school can you, from the perspective of a becoming primary school teacher, think of a possible benefit from the use of VR as a teaching and learning medium for pupils? Note that it is not important what software is currently available, but rather think of the general possibilities of VR with the right software.*. The

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Table 3. VR applications in different subjects in primary school

subject	no benefit	rather no benefit	recognizable benefit	great benefit	**sum**
German	93	148	29	5	**275**
Mathematics	63	82	97	33	**275**
Local History and Geography	4	28	110	133	**275**
Arts	31	58	122	65	**276**
Music	51	127	80	15	**273**
Physical Education	98	59	78	40	**275**
Religion	94	126	45	7	**272**
English	59	129	70	15	**273**
Handicrafts	63	82	97	33	**276**

four-point Likert scale consists of the items *no benefit*, *rather no benefit*, *recognizable benefit* and *great benefit*. Table 3VR applications in different subjects in primary schooltable.1.3 shows the results of the study. The most prominent answer which shows recognizable or great benefit through the use of VR was the subject *Local History and Geography* with 88.36 % in favor for VR, followed by Arts (68%), Handicrafts (47%) and Mathematics (47%). The answers with the strongest rejection of a possible benefit through VR are German (87.63%), Religion (80%), English (68.36%) and Music (64.72%).

Table 4correlations between perceived benefit between subjectstable.1.4 shows that most of the perceived benefits of the use of VR in different subjects are significantly correlated (Spearman-Rho) with each other. The answers of the subjects were summarized and the *overall perception* was calculated as the average value.

Influence of Experiences on Interest There was no statistical significant connection (Chi-Square) neither between the previous experiences (Yes or No) of the students and their interest shown in the study nor between the experiences and the calculated overall interest.

Influence of Interest on Perceived Benefit We found a highly significant correlation (.000) between the calculated overall interest and the calculated overall perception (r=.454) using the Spearman-Rho correlation.

Influence of Experiences on Perceived Benefit There was no statistically significant connection found between the previous experiences of the partici-

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Table 4. correlations between perceived benefit between subjects

subject	German	Mathematics	Local History and Geography	Arts	Music	Physical Education	Religion	English	Handicrafts	Overall Perception
German	1.000	.344**	.180**	.225**	.280**	.147*	.372**	.467**	.136*	.571**
Mathematics	-	1.000	.172**	.212**	.005	.090	.117	.189**	.209**	.469**
Local History and Geography	-	-	1.000	.303**	.269**	.153*	.271**	.411**	.188**	.529**
Arts	-	-	-	1.000	.350**	.224**	.254**	.303**	.406**	.618**
Music	-	-	-	-	1.000	.302**	.235**	.312**	.211**	.545**
Physical Education	-	-	-	-	-	1.000	.129*	.107	.274**	.523**
Religion	-	-	-	-	-	-	1.000	.454**	.083	.514**
English	-	-	-	-	-	-	-	1.000	.211**	.629**
Handicrafts	-	-	-	-	-	-	-	-	1.000	.561**
Overall Perception	-	-	-	-	-	-	-	-	-	1.000

*. The coefficient is statistically significant at the 5% level (both sides).
**. The coefficient is statistically significant at the 1% level (both sides).

pants and their overall perception about the benefits of the application of VR in primary school subjects.

Influence of Studied Main Subject on Perceived Benefit of Particular Subjects In addition to possible influences from the variables interest and experience, we investigated how the studied main subject influences the perception of the possible benefit in a specific subject in the primary school curriculum. Therefore we summarized the items for the perceived benefit from the use of VR in particular school subjects in primary school to *Yes* (recognizable benefit and great benefit) and *No* (no benefit and rather no benefit) and took a look at the different main subjects from the students.

Here, as shown in the table 5correlations between perceived benefit and studied main subjecttable.1.5, we found significant correlations between the studied main subject *Social Studies* and the primary school subject *Physical Education*.

The studied main subject *German* was highly significantly correlated to the primary school subject *Local History and Geography* and significantly correlated to *Physical Education*.

The studied main subject *English* was significantly correlated to the primary school subject *English*.

Furthermore, we found significant correlations between the studied main subject *Religion* and the primary school subject *Religion*, between the studied main subject *History* and the primary school subject *Handicrafts* as well as between

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Table 5. correlations between perceived benefit and studied main subject

main subject	German	Mathematics	Local History and Geography	Arts	Music	Physical Education	Religion	English	Handicrafts
Social Studies	.703	.970	.583	1.767	.002	**4.631***	.228	.321	1.645
Geography	2.144	.070	1.763	1.162	.099	.897	1.482	1.230	.776
Mathematics	1.213	1.772	2.840	.741	.109	1.908	.344	.514	.512
German	1.819	.001	**8.384****	.837	.471	**5.554***	1.423	.1.290	.234
English	.383	1.964	.034	1.124	1.922	2.070	.079	**4.202***	.538
Religion	.114	.058	.106	1.197	.464	1.936	**5.016***	.502	1.812
History	.138	1.303	.924	.518	3.728	.443	.011	.013	**5.236***
Physical Education	**6.164***	.056	.049	.044	1.581	.594	2.619	2.266	.132
Arts	.573	.012	.535	1.932	.413	1.706	.091	.071	.000

*. The coefficient is statistically significant at the 5% level (both sides).
**. The coefficient is statistically significant at the 1% level (both sides).

the studied main subject *Physical Education* and the primary school subject *German*.

4 Discussion

The results show that the attitudes towards the application of VR as a teaching and learning medium in primary school education vary significantly among student primary school teachers. The most prominent answers for a recognizable or great benefit through the use of VR, Local History and Geography, Arts, Handicrafts and Mathematics may have been chosen due to their spatial or constructive orientation. The assumption that the primary school subjects German, Religion, English, and Music would have no or rather no benefit may have been made due to the apparent lack of possible visualization or spatialization.

In our first hypothesis, we assumed that there would be a positive relationship between overall interest and previous experiences. This hypothesis could not be verified. In fact, only a fifth of all participants did ever experience a VR so by now, the general visibility of this new technology is very low so many users that may be interested in VR technology simply do not have access to VR systems.

The second hypothesis assumed that there would be a positive relationship between the students' overall interest and their overall perceived benefit. This

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hypothesis could be verified, we found a highly significant positive correlation between the two variables which was moderate in strength. This implies that general interest in VR is connected to the perceived benefit of the application of VR in learning and teaching settings in general. In addition to that, we found out that almost all of the perceived benefits from different subjects were connected to each other what may also result from a risen interest or confidence in the VR technology in general.

The third hypothesis predicted a positive relationship between the previous experiences and the overall perceived benefit. We could not verify this hypothesis what may have the same reasons as the rejection of H1, in particular, the lack of visibility of VR technology in public. In addition, just because one uses a specific software in VR, may not ensure that the user understands the full range of possibilities of the VR technology.

The fourth hypothesis claimed a positive relationship between the studied main subject and the perceived benefit of the corresponding primary school subject. For the verification of this hypothesis, we generated nine separate hypothesis concerning the different corresponding subjects (studied main subject and primary school subject). In this study, we could only verify the hypotheses H4.4 and H4.5, representing the corresponding subjects English/English and Religion/Religion. We found out that student primary school teachers with these main subjects were more likely to rate the possible benefit through the application of VR in their English/Religion classes in primary school higher than students with other main subjects. Considering these results, we had to drop the assumption of a general validity of H4 so that this hypothesis was only true for the subjects English and Religion.

We assume that the participants of the survey may not have had enough experience in their main subjects because the chosen courses to carry out the survey were undergraduate classes with students who had less experience than student primary school teachers right before their final exams or professional primary school teachers. Besides that, the choice of the main subjects English and Religion may come with a high personal interest of the participants in the topic already before commencing their studies. This could explain the found connection between the main subject and the corresponding subject in primary school, English and Religion.

It is quite interesting that we found the unexpected connections between the main subject Social Studies and the primary school subject Physical Education, the main subject German and the primary school subjects Local History and Geography and Physical Education, the main subject History and the primary school subject Handicrafts as well as between the main subject Physical Education and the primary school subject German. An investigation about these would be interesting for further research. By now, we assume a connection between the major and minor subjects, where for example Geography, Social Studies, and Physical Education are often paired with German.

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5 Conclusions

In this study, we found some interesting connections between different variables. As the main result, we can say that there is a moderately strong relationship between the personal interest in VR technology (in different areas) and the perception of a possible benefit from teaching and learning with VR technology in primary school. Following these perceptions and attitudes of future primary school teachers it would be interesting to investigate, how interest and perceived possible benefit actually influence the learning outcomes of the pupils.

Even though there is existing research in terms of factors influencing learning processes and outcomes in VRs [5, 17], it would be interesting to investigate the factors mentioned by student teachers that cause the perceived benefit. In the free text answer in the fourth section of the questionnaire, many students described topics, where either visualization and spatialization would help to enhance the childrens' understanding of particular (sometimes abstract) concepts. Other answers described topics which already have spatial or visual representations in the real world (for example plants, animals, countries, cultures) but are not easily accessible for teachers and their classes. Another aspect was the motivational factor: Just by using and experimenting with the new medium, children can easily be motivated for the topics represented through the VR technology, for example in Physical Education (virtual parcours). The exploration of the impact of these factors on learning outcomes may be a further research desideratum.

In terms of cognitive benefits over for example television or normal displays, the participants named the possibility to learn through activities, experimenting and making experiences in the VR. That can be related to the concept of presence. Even though there has been researching about if and how presence in VR influences learning processes and learning outcomes [18–21], there is still a lack of a substantiated investigation of how presence influences the learning processes on different age groups, cognitive levels and in particular topics.

We are convinced that VR enables new possibilities in teaching and learning. But to bring VR into schools, we do not only have to prove the effectiveness of VR settings in terms of teaching and learning. We rather have to convince professional teachers and becoming teachers of the utility of VR in their classrooms and develop VR software for teaching and learning together, combining technical know-how with didactical and pedagogical demands. Therefore, high-quality supply of immersive education has to be designed, implemented and tested jointly by teachers, immersive education, and virtual technology experts. We see immersive education as a highly interdisciplinary research area which has to combine know-how from pedagogical, technological and content viewpoints.

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Experiential Critical Thinking: Prototyping a Humanities Learning Module in VR

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Abstract. This work-in-progress paper discusses the potential role of virtual reality (VR) in humanities instruction. We describe the design rationale and first three prototypes of our proposed Experiential Critical Thinking platform (ECT). ECT is designed to exist in a hybrid learning environment, where digital, virtual, and traditional modalities of instruction coexist and reinforce each other. As a starting point for ECT, we have created two iterations of a VR experience connected to historical material about Che Guevara and the Cuban Revolution (CHE), with a third in development. CHE 3.0 emphasizes abstract and critical thinking about source material and argument construction.

Keywords: immersive learning, virtual reality, humanities, constructivist theory, virtual reality learning environments, kinesthetic learning, critical thinking, experiential critical thinking

1 Introduction

Effective and engaging learning is immersive. Decades of research on games has demonstrated the value of immersion into playscapes, and much of the literature on serious games and games for learning hinge on the same principle: if we can hold a student's attention, they will learn [5, 6]. VR presents an environment in which students are immersed, engaged and can be provided opportunities to exercise critical thinking skills, all of which contribute to better learning experiences. VR also allows for dynamic visuals, which lead to better cognitive process quality when compared with static text, further articulating a use case for VR as an educational methodology [8]. In this paper we describe the design rationale and first three prototypes of our proposed Experiential Critical Thinking platform (ECT). The goal of the ECT is to build an extensible, reusable platform for deploying humanities-oriented VR modules to support traditional instruction. As technology increasingly intersects with instruction, and as digital technologies become the primary technologies students and instructors will use, ECT

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explores the use of VR as a viable future platform for abstract thinking and higher education, making experiential research experiences possible even in large lecture classrooms.

2 Designing a Platform for Experiential Critical Thinking

Our vision for the ECT platform is that it will exist in a hybrid learning environment, where digital, virtual, and traditional modalities of instruction coexist and reinforce each other. Our working hypothesis is that students who experience part of their learning in VR will become better thinkers outside of it. Learning in VR may offer one of the rare instances where we can help students learn-by-doing at scale. Experiential learning ties the kinetic to the intellectual, connects familiar embodied actions to more abstract concepts, and we are particularly interested in seeing how VR can support students in having a physical experience of an abstract exercise, such as argument construction or idea generation.

VR is increasingly being used in teaching environments where practical, applied skills are part of the curriculum. This is why we see so much VR in medical schools and engineering schools. Teaching students anatomy on a virtual body is resource-saving, but it also allows students to operate on (virtually) live patients and observe immediate responses to their actions. The humanities are no less applied, but humanities instruction has become complicated by the fact that in the traditional large university classroom faculty have lost the ability to provide students with the iterative practice of research. Students are expected to perform research, but they do not get a lot of supervised practice. We are looking toward VR to provide us a space in which students and faculty can explore abstract ideas and practice them to do research and analysis. The context and infrastructure of VR may allow students to do this individually and provide faculty with data on their performance during the research phase – not just at its conclusion when the student submits their final paper. We are as motivated by the potential of VR as an experiential learning modality as we are by its potential to make personal attention and individualized teaching opportunities possible for every student, no matter what size of classroom they are in.

ECT is not a game, but it finds much of its intellectual rationale in constructivist theories of learning that have largely been applied in games [12-14]. Constructivism finds a natural ally in VR. If learning is a function of how the individual constructs meaning from their own experience, then VR has the potential to capture the complexity of reality through complete tasks, interaction, and instructional sequences [1]. This is how the VR experience has the potential to return the student to a traditional space of learning, where they are actively involved in the process of meaning and knowledge construction. We posit VR as a transformational education modality, not because we want to change how people learn, but because we want to return learners to a place of engagement and experience. Instructors and students today face a constant bombardment of media and digital content. There is strong evidence that this has led to shorter attention spans and lower engagement and critical ability in students [11]. To counter this, there is evidence that suggests that Virtual Reality Learning Environments

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(VRLEs) initiate interaction, immersion and trigger the imagination of the learner. When compared with non-immersive teaching, “immersive learners showed better retention of symbolic information and revealed more interest in a VR class” [8]. VR has also been proven to aid in the comprehension and assimilation of concepts [10]. A constructivist method of learning allows students think critically, making VR an appropriate vehicle for critical analysis and instruction [7]. Ultimately, just as “games allow players to be producers and not just consumers” the VR environment makes students active participants in the narrative and solvers of the problems we confront them with – VR, like games, subverts the passive environment of large classroom, and provides students with a space in which to fail safely, experiment, and learn. [5]

We are well aware that broad adoption of and investment in VR in the Humanities (or in higher education in general) won’t happen until we can demonstrate that it can work in more than one context and for more than one class. It also must be shown to support the needs of a broad curriculum and the process of humanities inquiry. Educational VR for critical thinking and the humanities is not an obvious project for industry venture capital to invest in (unlike medical training in VR). These realities inform our design process, which is aimed at a VR system that is affordable and reusable. For these reasons, the ECT platform has the following design constraints: 1) Reusability: the platform has to be capable of being reused across a large landscape of humanities projects; 2) Plug & play functionality: the platform needs to be hardware and software agnostic, and needs to be architected in such a way that an instructor without coding experience can provide the data to the platform to create an original VR experience. From a user perspective, the design is immersive and uses known interaction modalities. Within ECT, students will be focused on exercising their cognitive capabilities, not on learning new content or figuring out the environment. From a developer/creator perspective, ECT is architected in such a way that content is easily organized in sections, allowing for the inclusion and creation of new content as well as the deployment of cognitive assessment and qualitative assessment mechanisms.

3 CHE Prototypes

As a starting point for developing the ECT platform, we have created two iterations of a VR experience connected to historical material about Che Guevara and the Cuban Revolution (CHE), with a third actively in development. The first two iterations of CHE were prototypes of educational VR that tested the usability of the concept itself. The current prototype emphasizes critical thinking about source material and is designed to invite students to assess and sort different types of historical information against a variety of hypotheses. The context for the experience is a speech by Che Guevara in which he presents the case for land reform in the aftermath of the revolution, and a return to prosperity for the island without US involvement. The VR experience is designed to fit into the classroom teaching of Professor Levy’s introductory Latin American History classes. In the class environment, students will have read the speech and will have had lectures on the context of the Cuban revolution, the Cold War and the politics and economics of the late 1950’s and early 1960’s. The goal of the VR module is not

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necessarily to increase content knowledge of the historical moment, but to generate and model a critical thinking practice in the context of evaluating historical sources and their contribution to an argument.

3.1 CHE 1.0 & CHE 2.0

The previous builds were immersive and allowed the users to explore 360 degrees of the surrounding environment from a seated position. The content related to the Cuban revolution but included limited kinetic opportunities. We tested these builds for usability and user experience and these early prototypes showed indications of success. The first build was tested with 80+ users in an HTC Vive VR headset in early February 2017. The second prototype was tested with a similar number of users in early June 2017. The exit questionnaires show that users were able to draw conclusions based on the data and cite their reasoning after only a few minutes of exposure to the material in VR. We estimated users would spend 5 -15 minutes in the experience, and the average time in Che 1.0 was 7.4 minutes, in Che 2.0 it was 8.2 minutes. Many users expressed great satisfaction with the experience, and some referred specifically to the non-linearity of exploration that the experience allowed ("it has inspired me to think of the linearity of learning and the need for multiple forms of context), as well as how different it felt to experience the material in VR ("I felt like I was in a different realm").

Users in the first trial mentioned the discomfort of reading in VR, so we addressed legibility in Che 2.0. The feedback from Che 2.0 focused more immediately in the experience itself. The responses continued to be overwhelmingly positive, and feedback encouraged us to start increasing the levels of interactivity in Che 3.0. One clear result of the early tests that the experience generated a period of undivided focus for the user. The VR environment is rich in detail and is not connected to the web or to a smartphone, allowing users a rare moment of distraction free immersion that is very hard to replicate outside of VR. Part of what we will measure in the third build is how the interactivity and focus permitted in the VR experience contributes to the cognitive value of the VR experience, and whether that increased focus results in educational gains outside of the experience.

3.2 CHE 3.0

The latest prototype, CHE 3.0, is developed in Unity for the Windows Mixed Reality headset, which provides an immersive viewing experience and handheld motion controllers allowing navigation and interaction. Users enter a low-poly natural environment modeled after the Cuban jungle. The space is expansive, and they can walk around within the virtual space as much as their physical space permits. Greater distances can be covered via teleportation using the motion controllers. Historical data related to Che Guevara and the revolution is represented in this immersive world as a physical object, a "data block" that can be picked up and examined. Each data block maps to a quotation from an historical source related to the topic of the Cuban revolution. This exercise is designed to model agency within the information science structure. The traditional lecture class makes it difficult for students to practice what they are learning. We can

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lecture on the act of doing research, but it is difficult to explain to someone how to do it practically. The VR experience asks students to physically turn a piece of evidence around to analyze how it sheds light on a particular issue [Figure 1]. As students actively manipulate the data blocks, they internalize the cognitive message, namely what instructors mean by "research."

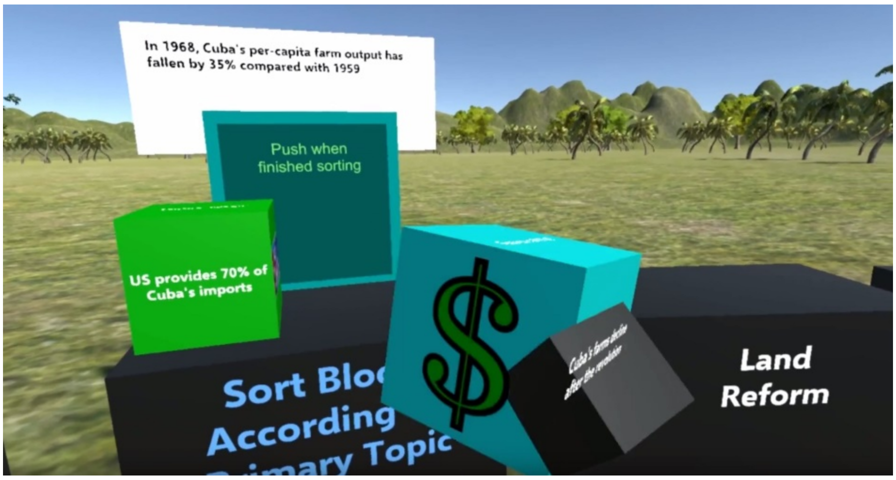

Fig. 1. CHE 3.0 screenshot: Data block held by user while sorting onto topic platforms

Users are led through a series of exercises in the experience where they are asked to sort the different data blocks in terms of topic, source, bias and role in constructing an argument for a specific hypothesis [Figure 2]. Each exercise builds on the previous one, exposing relevant information along the way. For example, at the start of the first exercise, the data blocks contain only the quote of historical source and the user is asked to sort them according to primary topic (US-Cuba relations, land reform, peasant life, economy). Following the completion of this exercise, the blocks are annotated with icons indicating their topics, and subsequent blocks added to the environment arrive with icons already in place. In this manner, the user gradually builds an understanding of the data and is then able to use it to form high quality arguments. The learning objectives for the experience are as follows:

- A good argument is constructed of relevant points of data.
- A good argument draws on data from a variety of data sources.
- A good argument is aware of the bias of the data sources.
- An argument is constructed to support a hypothesis, not a fact.
- A good argument martials relevant, varied & unbiased data to support a hypothesis.
- The hypothesis has to be a point of contention to support an argument (it should be feasible to argue the opposite of the hypothesis)

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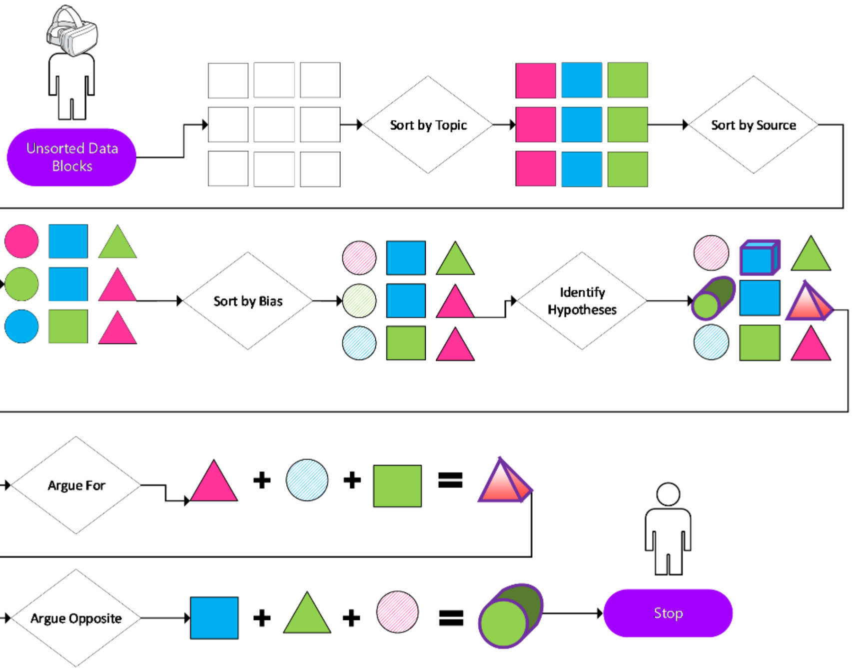

Fig. 2 Interaction flow for CHE 3.0

By putting students in an environment in which they physically build an argument through the act of assessing and evaluating multiple sources, we are modeling the research process. This process is similar to the explorations that can happen face to face in a small seminar classroom but is impossible to manage in a large lecture classroom. It is as difficult to teach someone to drive by lecturing them about it, as it is to teach students how to do research by lecturing about it. This VR experience aims to be an example of kinetic, immersive, experiential learning at scale.

3.3 Evaluating Learning Outcomes

A key objective of our prototyping is to contribute to a better understanding of the relationship between immersive VR and higher level cognitive processes. We are developing a testing strategy that includes measuring user feedback, physical data from users, and retention and activation of core concepts outside of VR. Through the first two iterations we tested our hypothesis with over 150 students and began to gather data about student interactions and the impact on classroom performance. An open question in VR is how to assess the extent to which participants are interacting with and attending to the content and how this contributes to learning outcomes. Assessing the relationship between what the user looks at and does and connecting that to other qualitative outcomes outside of VR gives us insight not only about how VR can help educate in the humanities, but how we want to design a humanities-oriented VR experience for maximum effectiveness.

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Our next testing stage focuses on collecting and analyzing physical information about participants in the VR module. There is strong evidence that we can "measure" cognitive engagement through eye movement and the parasympathetic nervous system, and we intend to collect and analyze this data in partnership with our colleagues in neuroscience [5, 6]. As our system, and VR more generally, develops greater capabilities for dynamic adaptation, we believe we can create a learning environment that optimizes the cognitive benefit for each individual student. Collecting eye-tracking data informs us of how participants attend to the material. This allows us to measure whether elements are seen and the extent to which interaction with material is aimless or guided. Coupled with system logs of which objects were manipulated and moved, we can get a quantitative sense of the user's interaction with the system. This data will also be connected to pre- and post-experience surveys of the users as well as classroom outcomes. Comparing learning outcomes provides critical information on how different strategies relate to different learning outcomes and the extent to which attention to each piece of material contributes to learning. Because this is designed as a hybrid learning experience, we will also compare results to non-VR conditions. We will have a group of students/users in the class who will not be exposed to the VR experience. That group will also be split in two, with one group having exposure to additional reading material and time to read it, while the other group will not be offered anything additional. This framework allows us to plan for testing that controls for exposure time to (any) material.

4 Conclusion

VR augmentation of traditional learning approaches in the humanities shows tremendous promise with regards to our ability to engage students, improve their long term cognitive capabilities, and measure our success in meaningful and repeatable ways. In the short term, VR enables new mechanisms for engaging students, increasing knowledge retention, and testing skills. Survey results from the first two CHE iterations have been promising on this front. They demonstrate strong student interest in VR, promising knowledge transfer immediately after VR, and indications of extended improvement in student performance following VR (in exams). Even more importantly, we regard VR as a new communication platform, one that prioritizes kinesthetic and visual learning over more traditional forms. We believe we need proven, easily scalable environments that enable many teachers and many researchers to test the possibilities in VR. While our development work at the moment is focused on the specific CHE experience, our goal is to use the lessons learned from iterating there to inform the broader design of the ECT platform. Ultimately, ECT has the potential expand the speed and the breadth of research into VR and the humanities, and help us make students, in the words of Joseph Aoun "robot proof". For this we will need a curriculum that teaches them "literacies and skills" [2] rather than content. The ECT platform is designed to do this at scale.

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