eShadow+: Mixed Reality Storytelling Inspired by Traditional Shadow Theatre

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Abstract. eShadow is a digital storytelling platform inspired by traditional Shadow Theatre. It enables the creation of digital stories within a project-based approach that may start from scenario development and include the creation of digital puppets and sceneries, the set-up and recording of story scenes and the final assembly of a digital story. This paper presents details about eShadow architecture, features and how its use has been enhanced, employing the PerFECt framework, to combine it with immersive technologies such as projection mapping, to create mixed reality installations that offer rich learning experiences to participants in informal learning settings. Two installations are described and compared. The evaluation results demonstrate the effectiveness of the approach towards engaging learning experiences that combine mixed reality approaches with arts such as black light theatre.

Keywords: Onlife Communities, Digital Storytelling, Shadow Theater.

1 Introduction

Shadow theatre is a storytelling tradition in many countries in Far and Middle East using flat articulated puppets which are held between a light source and a trans-lucent screen usually in the form of a white sheet. It is a medium with significant educational value within the wider context of drama and performance arts (Hatzigianni, Miller, & Quiñones, 2016) (Moumoutzis, Christoulakis, Christodoulakis, & Paneva-Marinova, 2018). This is due to its ability to engage people and promote their creativity. In particular, children and adults find their own ways to act and imitate, create dialogues, get inspired and convey their own messages, direct, become stage designers, sing,

strengthen their self-confidence giving life to the puppets, improvise and create their own stories. Thereby they cultivate their oral speech skills and develop in multiple modes their intelligence (multiple intelligences) in an entertaining manner.

eShadow (http://www.eshadow.gr) is the digital version of shadow theatre (Moumoutzis, Christoulakis, Christodoulakis, & Paneva-Marinova, 2018). It enriches traditional features with digital technology elements to offer a new way of dramatized and personalized digital storytelling. It enables the production of rich multimedia content interactively using innovative input devices and supports online collaboration. It offers an intuitive way of setting up scenes and enacting them: The user can select the desired scenery objects and digital puppets and then move them with mouse drag operations. All movements can be easily recorded along with the voice of the user. These recordings can be exported in appropriate file formats to be further edited with external video processing tools.

eShadow gives emphasis to the realistic motion simulation of shadow theatre's puppets that is based on a physics engine. Realistic movement provides an explanation for the popularity of eShadow among Greek teachers and students as revealed during several field trials as well as during testing with actual professional performers (Moumoutzis, et al., 2017). Furthermore, realistic movement of digital puppets creates an atmosphere of playful interaction where the users are engaged in theatrical improvisations that can be very important to develop communication skills related to oral expression and interpretation of body language.

eShadow is used in many schools to promote project-based learning combining arts, within a wide range of school topics ranging from language learning, history and humanities to mathematics, physical sciences and computer science (Moumoutzis, Christoulakis, Christodoulakis, & Paneva-Marinova, 2018; Moumoutzis, et al., 2017; Moraiti, et al., 2016; Moumoutzis, et al., 2021; Hatzigianni, Gregoriadis, Moumoutzis, Christoulakis, & Alexiou, 2021). The creation of such artworks with eShadow is based on a project-based process with three distinct stages, which is generic and refers to any media artwork such as movies, digital games, interactive animations etc. In particular, the stages of this process are the following: Preparatory actions (pre-production), subsequent development (production) of the main materials of the artwork, and final assembly (post-production) of a digital story. During the pre-production phase, users of eShadow are able to create their own digital puppets using either a suitable external image processing tool or specialized software tools that accompany eShadow (Moraiti, et al., 2016; Moumoutzis, et al., 2021; Hatzigianni, Gregoriadis, Moumoutzis, Christoulakis, & Alexiou, 2021).

After successfully implementing a significant number of project-based learning interventions in primary and secondary schools following the above-mentioned digital storytelling approach, a new approach employing (Moumoutzis, et al., 2021) mixed reality technologies was adopted to offer immersive informal learning experience targeting not only children but adults as well. This paper describes in detail this new usage of eShadow, i.e., eShadow+, showcasing two specific installations and the evaluation results drawn using a standard tool, namely the User Experience Questionnaire (UEQ) (Laugwitz, Held, & Schrepp, 2008) to evaluate the overall experience of the participants.

The rest of the paper is organized as follows: Section 2 presents the theoretical framework employed to study how eShadow could be used in new, mixed reality, scenarios. Section 3 presents implementation details of eShadow and its accompanying tools along with the process flow for the production of eShadow stories. Section 4 presents how eShadow has been used in mixed reality informal learning experiences. Section 5 presents the evaluation results. Section 6 concludes and presents plans for future work.

2 Concept and Rationale of Onlife Learning Communities and the PerFECt Framework

People learn and create within certain social contexts, in environments, physical or virtual, within which other people are engaged as well possibly with different roles but common goals and expectations to create or learn. People are connected to each other in this process of creating or learning. They even connect to other people that are not present such as creators of artifacts used, creators of the knowledge they use or even with people that will exist in the future and will use the products being created. In this respect, the central concept of community is employed to signify the social context within which human creativity is exercised or learning happens.

The goal is to provide a comprehensive approach for supporting Onlife Learning Communities by employing digital technologies within an overarching framework that is informed by current trends in re-conceptualizing and re-thinking about our societies facing the so called "hyperconnected era". This is reflected in the term "onlife", which has been employed in The Onlife Manifesto (Floridi, 2015). This term stresses the fact that the deployment of information and communication technologies and their uptake by society radically affect the human condition, modifying human relationships as well as relationships of humans to the world. The term onlife is a neologism introduced by Prof. Luciano Floridi claiming that "we are neither onlife nor offline, but onlife". Its use in the Onlife Manifesto is related to the fact that the ever increasing pervasive-ness of digital technologies lead to a blurring of the distinction between reality and virtuality as well as between human, machine and nature along with a reversal from information scarcity to information abundance and a shift from the primacy of entities to the primacy of interactions.

To elaborate a framework for the establishment and support of onlife communities with the aim to empower their members to control how digital technologies support their capabilities to create and learn, there is a need to depart from established engineering practices that are based on monolithic designs done by technology experts. A new conceptual framework is needed that is based on the hypothesis that digital systems can be realized by the composition of elementary components with limited initial design and be put to work by end users, eventually facilitated by IT engineers that play the role of catalysts of change and evolution of those systems towards directions that could not be initially foreseen (Cabitza & Simone, 2015).

Elaborating on this design approach, this paper proposes a framework to establish and sustain of onlife communities, i.e., communities of creators and/or learners using

digital tools in a certain domain, emphasizing creativity and learning. This framework is presented below followed by the presentation of eShadow and a discussion on how it has been used to interpret how users understand and use eShadow in order to reframe its use in new ways that move towards augmenting the experience of learning employing projection mapping techniques combined with body shadow to provide rich interactions with digital puppets in an intuitive and engaging way.

2.1 The Components of the PerFECt Framework

Technology in general and digital technologies in specific is a catalyst for establishing and sustaining certain social structures Cabitza, Fogli, & Piccinno (2014) underline and exemplify. They emphasize the fact that end users are becoming "producers" of contents and functionalities. On the other hand, the term expert user is suggested to signify an expert in a particular domain with main goal to develop the technological capabilities available on that domain. An expert user engages in creative/authoring activities without being a professional software developer. Usually, the role of end user and that of an expert user are played by different people that may also belong to different communities. Furthermore, Cabitza, Fogli, & Piccinno (2014) suggest the role of meta-designer to describe the work done by professionals who create the socio-technical conditions for empowering end users in acting as active contributors of contents and functionalities. A meta-designer creates open systems that can be further developed by their users acting as co-designers. However, apart from the technical conditions necessary to set up such environments, there is a need to effectively create the social conditions that will allow expert users to build and adapt the artifacts to be used by end users. In respond to this need, a special user role is specified: maieuta-designers. A maieuta-designer creates the necessary preconditions for facilitating expert users appropriate the design culture and technical notions necessary for the meta-task of artifact development and involving as many end users as possible in the process of continuous refinement of the artifact, by improving participation. The user of the term "maieuta" directly references the Socratic method of getting people acquire notions, motivations and self-confidence to undertake challenging tasks.

End users, expert users, meta-designers and maieuta-designers engage in certain interactions with each other as well as with the digital artifacts and tools causing the emergence of a co-evolution phenomenon. Meta-designers focus on designing and providing the most effective tools that sustain the co-evolution between end users and expert users. Maieuta-designers facilitate the transition from end user role to expert user role. If certain end users are not interested or fail to move towards the role of expert user, maieuta-designers may facilitate the transition by systematizing the reporting opportunities or shortcomings, as identified by end users, and proposing solutions handled by expert users or suggest further technological contributions from meta-designers. As a consequence of the above, two co-evolution processes emerge:

- The first cycle addresses the interactions between end users and the system. It refers to the use of software devoted to the end users. It is shown in **Fig. 1** (left) with three homocentric cycles of arrows that represent the action-interpretation

cycle at the lower level, the task-object cycle at the middle level and community-technology cycle at the upper level.

- The second cycle is analogous and it is shown in **Fig. 1**. It addresses the use of the technological environment and the corresponding soft-ware components as building blocks of the system in continuous evolution. Three homocentric cycles (levels) are present here as well: action-interpretation, task-object, and community-technology.

There is a clear symmetry between the two co-evolution processes in terms of their constituent interaction cycles. In particular:

1. The inner interaction cycle in each co-evolution process addresses actions initiated by the corresponding user role or software that are interpreted by the other party, software or user role respectively.
2. The middle cycle refers to the co-evolution of the user task and the related digital artifact within the boundaries of the system.
3. The outer cycle captures the idea that the overall environment within which a user is working (community), co-evolves with the technology that supports the operation of the environment.

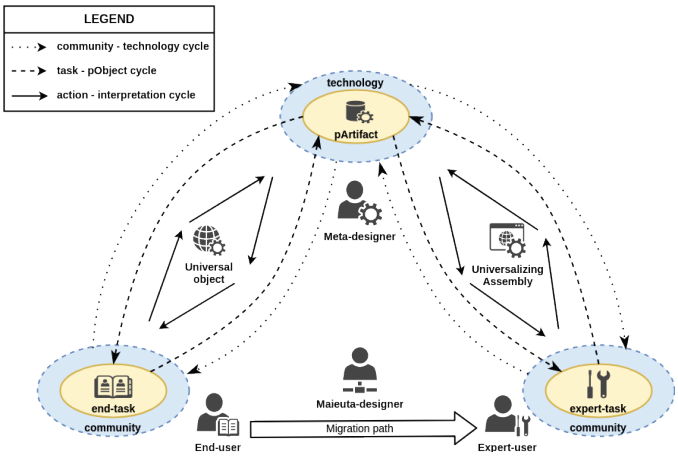

Fig. 1. The main components of PerFECt framework.

All user roles (end users, expert users, maieuta-designers and meta-designers) together with the digital artifacts, tools and even underlying physical objects used to embed the technologies used (e.g., within the so-called Internet of Things or other settings that enhance physical objects with new affordance that exploit the capabilities of digital technologies) are considered as a whole: an Onlife Community. This term is used to emphasize the fact that all user roles, via their interactions along with the two co-evolution processes, create an aggregation of humans that engage with other humans as well as with machines and natural entities in mindful interactions in a way that generalizes the notion of online communities offering new opportunities for creative expression and learning.

2.2 The Concept of Universality

Within the PerFECt framework an important notion is used to describe blends of machines and physical objects that generalize the notion of software or tool: The notion of universality. In both centers of the two co-evolution cycles in **Fig. 1** this notion is explicitly used to characterize the artifacts employed (universal objects on the left and universalizing assemblies on the right). Universality addresses the issue of causality in digital representations. A universal object is essentially an object that exhibits a behavior that can be understood by humans because it is based on causal relation-ships with other objects or processes. A universalizing assembly, on the other hand, is considered as certain assembly of digital artefacts that creates a new type of artifact that can be understood and manipulated as a universal object. The term universality is adopted from Brenda Laurel's seminal book "Computers as Theatre" where it is considered as in important aspect of all representational worlds that goes back to Aristotle's Poetics where the idea of universal actions was introduced:

> *"… an action is universal if everybody can understand it, regardless of cultural and other differences among individuals.… Aristotle posits that any action can be "universalized" simply by revealing its cause; that is, under-standing the cause is sufficient for understanding the action, even if it is something alien to one's culture, back-ground, or personal 'reality'."* (Laurel, 2013), p. 94.

Within the PerFECt framework, the meta-task of expert users is to enable the universalization of certain objects by exploiting available tools in the form of performative artifacts (pArtifacts) to account for the incorporation of the idea of performativity in digital technologies. Performativity describes the relationship between humans and the artifacts they create that is triggered by social interaction. Such interactions continuously recreate the bonds that keep the society as a whole. Niedderer (2007) emphasizes that performative objects are designed to facilitate mindful awareness of the physical and symbolic social actions and their consequences within which they are used. The term performative artifacts (pArtifacts) used here, captures the idea of intentional design for social interaction, to create and sustain social bonds and call for symbolic social actions that re-create the social contexts within which we live in. Consequently, pArtifacts offered by meta-designers are essentially the catalysts for the establishment and sustenance of onlife communities supporting the bonding of their members as well as the bonding between their members and the artifacts they create and use.

2.3 Some Notes on Performativity

The roots of the approach adopted in the set up of the PerFECt framework, i.e. the very concept of performativity and the implications it has on issues related to epistemology and digital systems design, can be attributed to the need to move beyond the pre-vailing focus on texts or symbolic representations to capture meaning. Performance is, above all, a meaning making bodily practice. Consequently, it is related to rituals and other forms of spectacles and social practices (Moumoutzis, et al., 2017). Beyond the main premises and the theoretical justification of the validity of performativity, one could

attribute the significance of this paradigm to an inherent dramatic quality of human experience.

Beeman (1993) offers a very interesting comparison and in-depth analysis of the relation between theatre and other performative genres: Revolutions, public demonstrations, campaigns, strikes, and other forms of participatory public action all have performative dimensions sharing certain features with the fundamental ritual processes. Such social dramas involve a separation with normal structures of ongoing life, the entrance of groups of individuals into state of transition, and the re-integration of the individuals into a reconstructed social reality. Beeman goes on to analyze the interrelationship of stage drama, as a generalization of theatre, and social drama, as an inclusive term to describe all performative genres that aim at changing actual reality, employing a scheme initially proposed by Turner (1990). This scheme is depicted below:

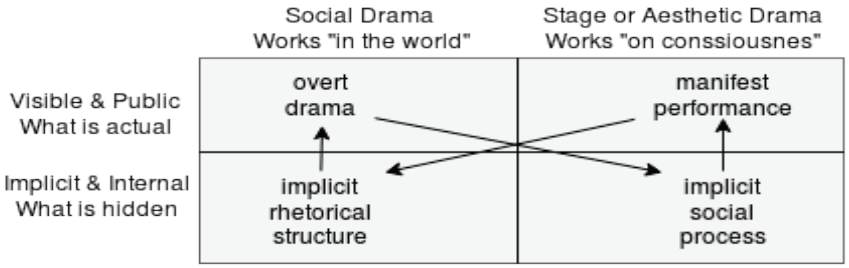

Fig. 2. The interrelationship between social drama and stage or aesthetic drama. Concepts depicted following the ideas of Turner (1990).

Above the horizontal line **Fig. 2** represents what is actual, visible and public while below the horizontal line what is hidden and virtual, i.e., implicit and internal. On the left of the vertical line social drama is represented, i.e., all performative genres related to social life while on the right any genre of cultural performance (aesthetic or stage drama). The arrows represent a circular process with a continuous feedback loop with four directions:

1. Manifest social drama (i.e., visible social and political action) feeds into the hidden space of aesthetic drama influencing both form and content of the latter.
2. The latent space of stage drama feeds into manifest performance. This way, stage drama operates as an active or "magic" mirror meant to do more than entertain being a meta-commentary on the major social dramas within the wider sociocultural context such as wars, revolutions, scandals, institutional changes etc.
3. Stage performance, within its own turn, feeds into the latent realm of social drama with its message and its rhetoric and partly account for its ritualization.
4. Finally, life itself stands as a mirror of art, of the stage drama, and the living per-form their lives in a way that the protagonists of life are equipped with salient opinions, imageries and ideological perspectives created in stage drama.

The above feedback loop continues not as a cycle but rather as a helix: At each exchange new elements are added and other elements are left behind (forgotten or dis-

carded). Beeman (1993) attributes human learning to experience and drama offers the deepest experience of all. By drama here, it is meant not only social drama, or stage drama alone, but both of them in an oscillatory process. Consequently, social dramas and aesthetic dramas in their mutual relationship and interaction produce the complex reality we all experience.

It is interesting to see how this conception of the reflective social process through which society looks at itself, learns from its experiences and continuously recon-structs or reinvents itself, resembles one of the most widely used models of learning: the learning cycle introduced by Kolb & Fry (1975) and further elaborated by Honey & Mumford (1982). This model distinguishes four phases in the learning process of an individual that proceed iteratively as depicted below:

Fig. 3. The four phases of learning according Honey & Mumford (1982).
Diagram available online at:
https://www.talentlens.co.uk/develop/peter-honey-learning-style-series

In detail, the four learning phases along with their drama counterparts proceed as follows:

1. The process starts from experiencing reality, an activity that is preferable by activist learners that try to actually do things and have concrete experiences. This is analogous to overt social drama discussed already.
2. The next learning phase is reviewing and reflecting on the concrete experience, the preferred mode of learning for reflectors that observe (their own or other peoples') actions. This is analogous to the latent realm of stage drama where social experiences are elaborated and give rise to art manifestations.
3. The third phase is concluding from the experience providing the means that will subsequently orient the individual in life. This is the preferred mode for theorists, i.e., people that build explanatory frameworks trying to find casual relationships and links to previous established norms and concepts in a way that resembles what is happening during the preparation and staging of drama manifestations.
4. Finally, the last phase is to plan the next step that will feed a new iteration. This is the preferred learning mode for pragmatists that try to exploit the knowledge ac-cumulated in order to act in real life in an informed and purposeful manner.

This is related to the latent realm of social drama where the art-refined social experience gets back into the social stage to enrich it with new concepts, plans and intentions.

2.4 Using the PerFECt Framework in eShadow+

Using the PerFECt framework, technology developers can reframe existing digital technologies and empower learning communities or communities of practice with new ways of designing and offering engaging learning experience that could combine the digital and the analogue world or, in other words, combine the most interesting aspects of the digital world into the analogue world. One such case is the repurposing of the eShadow platform to combine it with mixed reality approaches to offer an innovative intuitive way of setting up engaging learning environments. This new version of eShadow is eShadow+.

eShadow+ relies on this close connection of learning and drama presented above. In particular, it provides a creative environment where children can participate as actors or as members of an audience, in a spiral process, and have moments of experiencing historical events as participants, with moments of reflection, abstraction and, subsequently, planning for further action on the basis of a mixed reality experience that is at the center of the learning process.

When children are acting, they are essentially end users (in the terminology of the framework) that just need to follow certain rules with consistency. When children are part of the audience guided by a facilitator (this is the maieuta-designer in the PerFECt framework) exploring, analyzing and understanding the underlying historical context and events they are essentially in transition to become expert users, as the PerFECt framework suggests.

A very interesting aspect on how the eShadow+ interprets the PerFECt framework and sheds new light on its applicability in designing collaborative learning experiences, is related to the idea of de-design (Cabitza, 2014). De-design evokes the idea that omitting and leaving out features from a design is just as critical to the success of a system as it is including them positively. This is connected to the fact that any feature does both afford and constrain interactions with and through the artifact, what is left out of it has the potential to be even more important than what designers put in it on purpose. This is a disciplined inaction that is intentional and goes beyond mainstream design approaches by offering opportunities for different interpretations of the information that need to be considered in user practices, and recognize the creative power of ambiguity. The relevance of de-design to learning and creativity, is thus evident.

Following a de-design approach, eShadow+ takes the idea of universality, as used in the PerFECt framework, along with the underlying concept of causality, and uses it beyond digital technologies to account for a human body (or a constellation of human bodies) that behaves under certain rules. In summary, eShadow+ generalizes the notion of universal objects and universalizing assemblies (**Fig. 1**) to account for any kind of object that can follow well-known rules and corresponding constellations of such objects.

To better understand the above issues related to the set up and use of eShadow+, the following section presents the cultural and pedagogical basis for eShadow and its implementation and usage for several years as a digital storytelling platform.

3 The Tradition of Shadow Theatre and the Development of eShadow

One storytelling tradition that is deeply rooted mainly in Eastern cultures is shadow theater. The diversity of possibilities provided by playing with shadows (for example when children play with hand-shadows) has impressed humans throughout history. This fact is what made traditional shadow theater so popular in many countries over time (Hatzigianni, Miller, & Quiñones, 2016). Traditional shadow theater remains very popular even after the invasion of cinema, television and, lately, the Internet, in many countries around the world like Greece, China, Taiwan, France, India, Turkey, Malaysia and others. More specifically in Greece, shadow theater is a very popular form of entertainment. For older generations shadow theater was the only form of entertainment available to them. That was a time before cinema and television became available to the general public. Furthermore, traditional shadow theater is a common link across generations: Children in Greece still watch traditional shadow theater plays, learn about shadow theater in school and also play with shadow theater puppets.

Starting from these important facts, we have been exploring for the last twelve years the development of digital tools inspired by the Greek shadow theater with the aim to offer an infrastructure that will allow the set-up of engaging learning spaces for both children and adults. The result of these investigations is eShadow (http://www.eshadow.gr), a digital storytelling tool that can be used from both adults and children in order to create, record, share and watch digital shadow theater plays. It provides alternative methods for controlling the digital puppets either using a mouse or a motion sensing controller and enables real-time collaboration over the Internet (e.g., between grandparents and grandchildren living in diverse geographical locations, or between students in collaborating schools that wish to develop their digital stories). With eShadow new possibilities emerge: The enactment of intra-family communication scenarios that promote intergenerational bonding and playful learning as well as collaborative learning scenarios between students of distant schools. Such kind of new opportunities for intergeneration bonding that overcomes the physical separation of children and their grandparents is important for children's development and contributes to the well-being of the elderly as well. In a similar way, the opportunity of collaborating with children from other schools, opens up new learning opportunities and could also help in cases of remote schools with few students that wish to create links with other students in distant schools and collaborate with them (Moumoutzis, Christoulakis, Christodoulakis, & Paneva-Marinova, 2018).

The important impact shadow theater has on children justifies its use as a learning tool. Especially in primary education it is used as an alternative way of playing and learning. One basic criterion for selecting it as a learning tool is that children relate to its main character (Karagiozis) in many ways. Karagiozis has the ability to motivate

children and expand their creativity. Children find their own ways of mimicking plays, create their own improvised dialogues, express their emotions and create their own stories with unique characters. Additionally, children get familiar with the research process and with collecting and using information about different shadow theater plays. Traditional plays were written in difficult times for Greece. They all contain historical information about life and many sarcastic elements about the conquerors/authorities of those times.

Another aspect of traditional shadow theatre is music. Every play has a musical theme that is, in many cases, unique. Each shadow theater performer used local traditional musical themes for his plays. By examining the music from different plays, children can learn about musical tradition across the whole country.

When creating their own plays, children work in groups. Each group is assigned to a different task of the play creation process. The most common assets of a play are: scenario of the play, dialogues, music, characters and sceneries. Children cooperate in order to create the scenario and dialogues, find the appropriate music for each part of the play and draw the puppets or sceneries. With the active participation in the above process, children are engaged in a collaborative fun process that allows them to express their creativity.

Except from the creation of a play, watching one is another activity that offers collaborative learning experiences for both children and adults. Many traditional plays have educational characteristics. The most common topics that they address are: equality (gender and social equality), environmental protection, people with special needs, the economic crisis and many other social issues that are common to every society.

3.1 eShadow Architecture and Functionality

eShadow offers both a desktop and a web application. Several input devices are used to control the digital puppets including the computer mouse, a motion recognition controller such as Nintendo's Wii Remote or any device supporting the Open Sound Control standard. Collaborative performance online is supported to record individual scenes, store and combine them in playlists. Each remote client communicates with the eShadow server (see figure below) that handles coordination between clients so that all clients see the same scene with the movement of digital puppets synchronized.

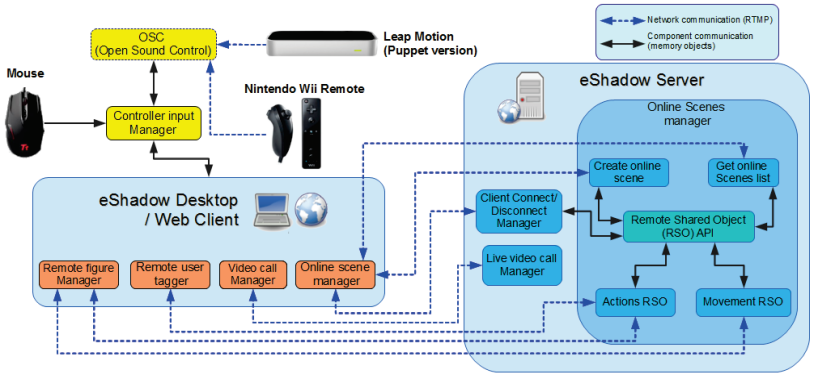

Fig. 4. eShadow client-server architecture and input devices.

eShadow offers an intuitive way of setting up scenes and enacting them. The user can select the desired scenery objects (**Fig. 4**) and digital puppets (**Fig. 5**) and then move them with mouse drag operations (**Fig. 6**). All movements can be easily recorded along with the voice of the user. These recordings can be exported in appropriate file formats to be further edited with external video processing tools.

eShadow gives emphasis in the realistic motion simulation of shadow theatre's puppets (**Fig. 6**) that is based on a physics engine. Realistic movement provides an explanation for the popularity of our platform among Greek teachers and students as revealed during the field trials as well as during testing with actual professional performers (Moumoutzis, Christoulakis, Christodoulakis, & Paneva-Marinova, 2018). Furthermore, realistic movement of digital puppets creates an atmosphere of playful interaction where the users are very easily engaged in theatrical improvisations that can be very important to develop communication skills related to oral expression and interpretation of body language.

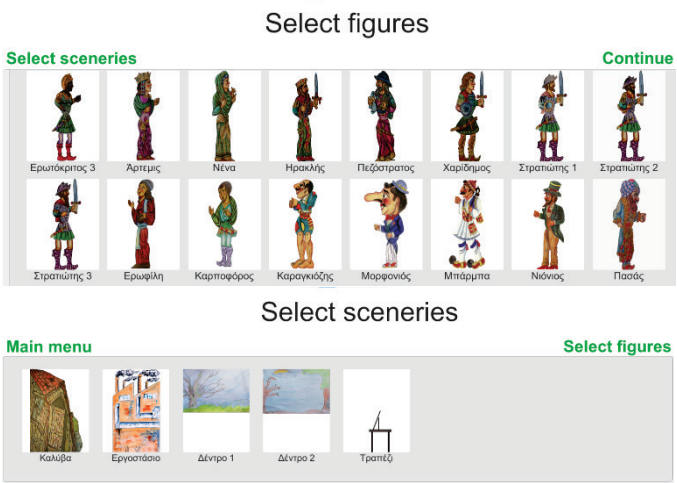

Fig. 5. Selecting scenery objects (up) and digital puppets (down) in eShadow.

Fig. 6. Enacting a scene with three puppets and two scenery objects (background picture and table) in eShadow.

Moreover, eShadow extends traditional shadow theatre by enabling collaboration not only locally but also from distance. Thus, learners from different physical locations can engage in role-playing game-like activities when preparing their stories or just for the fun of improvisation. This kind of role-playing interaction can be interesting in various communication settings including the remote collaboration between children and adults as well: Adults can impersonate favorite heroes to engage children in playful creative interactions. This resembles traditional Greek shadow theatre dialogues between Karagiozis and other characters before the main part of a shadow theatre performance.

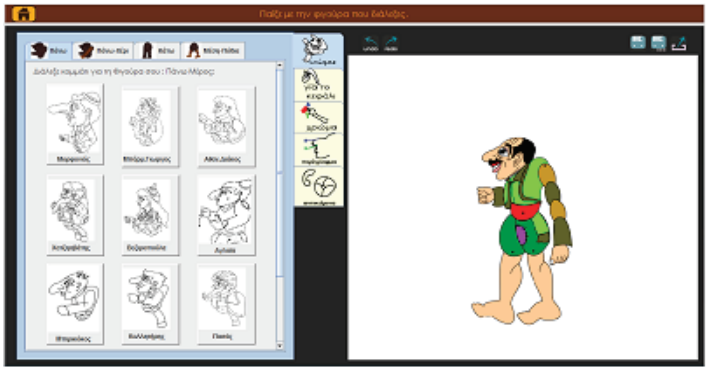

Fig. 7. Remixing a digital puppet in eShadow editor.

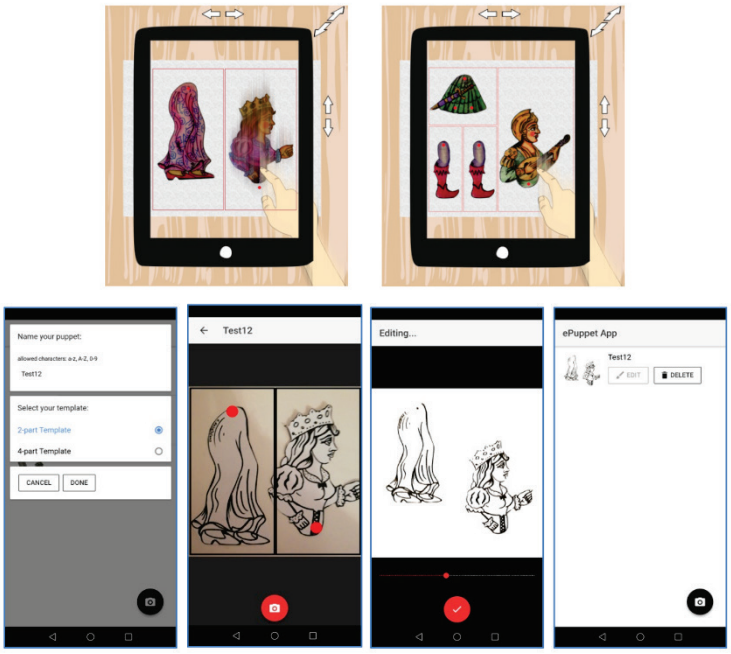

Fig. 8. Digitizing a cut-out paper puppet with ePuppet.

Significant importance has been given to eShadow's usability as it targets users ranging from young children to teenagers, parents and teachers. Throughout the system development, usability tests were conducted with real users. The results derived were then analyzed in order to extract requirements for the continuous improvement of eShadow's usability and functionality. Widely accepted methodologies were used for the evaluation of the whole system (Moumoutzis, Christoulakis, Christodoulakis, & Paneva-Marinova, 2018; Moumoutzis, et al., 2017).

A special desktop application (Moraiti, et al., 2016)tion, namely eShadow editor, enables creation of digital puppets. Significant emphasis has been given on the usability of this application as well by using similar software development methodologies (Moraiti, et al., 2016) as in the case of eShadow. eShadow editor provides a playful environment (**Fig. 7**) where children can remix digital puppets in many ways: by painting, changing the appearance of their faces, combine different body parts and use various accessories such as hats and hand-held objects. Digital puppets can be stored for further editing or exported to eShadow to be used in actual scenes and improvisations.

Yet another special application, a mobile app in particular called ePuppet, enables the digitization of a cut-out paper puppets or sketches and drawings of characters and sceneries using the camera of a mobile device (Moumoutzis, et al., 2021). The rationale behind the design and implementation of this special mobile app is to enable the creation of digital puppets following a process that bridges the analogue and the digital world offering new learning opportunities by engaging children and adults in traditional

creative activities such as sketching and drawing. **Fig. 8** below presents how this digitization process is done in the case of a cut-out paper puppet: The parts of the puppet are put in a flat surface with a constant color background in order to take a photo that is then further processed in a simple and user-friendly interface. Digital puppets created this way can be stored for further editing or exported to eShadow to be used in stories' scenes.

3.2 Digital Content Production with eShadow

eShadow embraces the most inclusive flavor of cross-curricular learning through thematic units in order to bring forward the educational innovations discussed in Section II. Within a certain theme, usually selected by the teacher, students create their own digital stories. This approach is based on research findings (Kearyney, 1989) that point to digital storytelling as a valuable, transformative tool for learners in a range of curriculum and discipline contents (i.e., cross-curricular). To this end, a learning design based on the stages of filmmaking (Filmmanking, 2022) is promoted enriched with the necessary pedagogical elements that take into account the optimum level of granularity needed before subtle variations in learning approaches can be meaningfully communicated. As Kearney (1989) notes: "representation of designs in domains such as filmmaking need to use carefully selected language and clearly communicate principles to an audience from a potentially wide range of disciplinary backgrounds. Finally, designs involving rapidly changing technologies such as digital video are essentially fluid and dynamic in nature and regular revisions are needed to explore and document future pedagogical developments". This "fluid" and "dynamic" nature of digital video is indeed the case for our approach where there is a need to use special software to simulate as realistically as possible the aesthetics and animating characteristics of shadow theatre.

Following Kearney's findings (Kearyney, 1989), the filmmaking process is adapted in a flexible game-like manner: The process begins with script writing or selection of an existing script. Playful interventions are also possible: The teacher could offer a (possibly partial) story or a set of story elements and ask students to dramatize it. This may be combined with inquiries to research actual historical events or other facts and link them to persons that will become the main characters of the story. Next is the preproduction phase that includes selection or creation of digital puppets and sceneries, articulation of story scenes and detailed design via storyboards (optional). Third is the actual production (scenes recording). The post-production phase includes audio processing (optional) and video editing to produce the final digital story. The fifth and last phase is the distribution (sharing) of the digital story.

Fig. 9 illustrates the 5-stage creativity process wrapping eShadow, eShadow editor and ePuppet, as an activity diagram that highlights tasks and additional (external) tools employed whenever necessary. It is a modular process that allows the selection of activities/tasks that will be carried out by the students of a specific class and enables alternative implementation options. For example, script writing could be skipped if an existing script is used. Existing digital puppets and sceneries can also be used instead of creating new ones. Post-production can be skipped in lower grades, where pupils

lack skills to work with the corresponding tools or when classroom time is limited. In such cases audio processing and video editing can be done by the teacher or external partners.

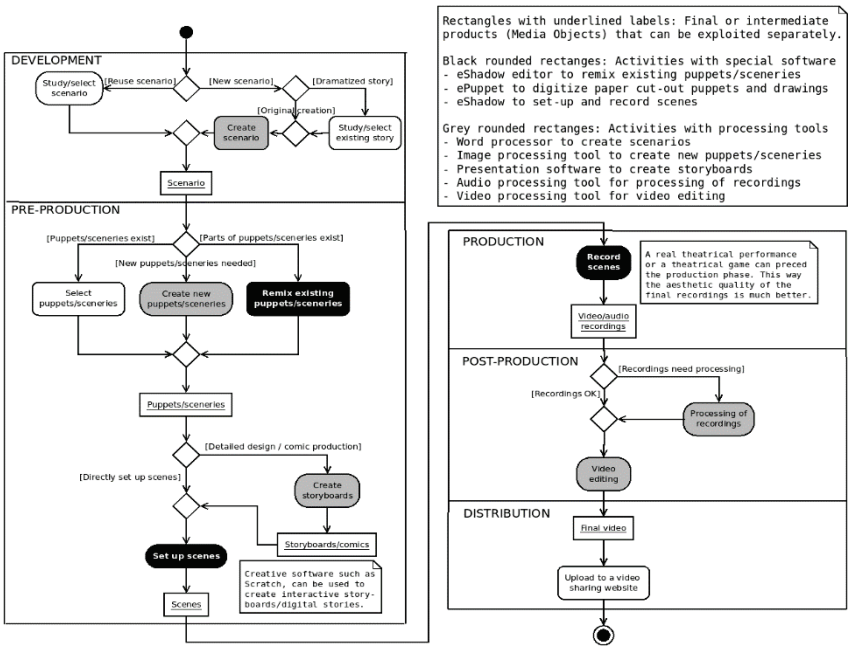

Fig. 9. The process of creating a digital story with eShadow.
The five phases are adopted from the filmmaking process.

It is worth pointing out that the whole process can be enriched with additional activities depending on teacher's goals, students' interests and time available. These additional activities could further enhance the creative, game-like and personalized nature of the approach by introducing the use of creativity platforms beyond eShadow or address issues on how stories can be adapted to students' prior knowledge, ways of learning and misconceptions to promote deep learning. Indicative enrichment activities include: (a) utilization of a creative programming platform, such as Scratch (Maloney, Resnick, Rusk, Silverman, & Eastmond, 2010) for creating interactive storyboards or an alternative form of the digital story in interactive form; and (b) preparation of a theatrical performance or theatrical games that enable students to practice the spoken word articulation and the kinesiology of the performance. See (Moumoutzis, Sifakis, Christodoulakis, Paneva-Marinova, & Pavlova, 2021) (Moumoutzis, et al., 2017) for further details regarding the use of such creative environments and combining with arts in general and theatre in particular.

4 Mixed Reality Installations

The previous section presented how eShadow and the accompany tools can be used for the development of digital stories that are essentially final products in the form of video files that can be shared and played using any appropriate video playback software or even uploaded on a video portal, such as YouTube. In this section we present a different use of eShadow that we call eShadow+. This use goes beyond the production of digital stories towards real-time performances that enable creative improvisations and interaction between participants and digital puppets using projection mapping techniques. This way it is possible to exploit eShadow and the accompany tools in new forms of learning experiences that are most suitable for specialized installations in informal learning contexts such as science fairs and exhibitions, museums etc. This section presents how this is achieved and provides two specific examples of such installations (trials) on topics related to important historical events, namely the Revolution for Greek Independence in 1821 and the Battle of Crete in 1941 during World War II.

Fig. 10. Photos from the initial use of eShadow+ during Science and Technology Day event at the Technical University of Crete.

Before organizing those two trials, a first attempt to use eShadow beyond/combined with digital story production, was done within the context of Science and Technology Day at the Technical University of Crete, an annual science outreach event organized annual for primary students and their parents with more than 4,000 participants. eShadow was used live in combination with back projection (see **Fig. 10**) to offer a mixed reality learning experience that goes beyond the passive attendance of a premade digital story towards a live performance giving the opportunity to visitors of the event to interact themselves with digital puppets in body motion improvisations that are done "behind the scenes" and projected into the audience.

After this successful first attempt, two trials were organized to document the suitability of the approach and explore new opportunities that are possible by the use of

digital technologies in live performances. The first installation (**Fig. 11**) addressed the Battle of Crete that took place on late May 1941 when German troops invaded the island within the context of the Nazi attach against Greece.

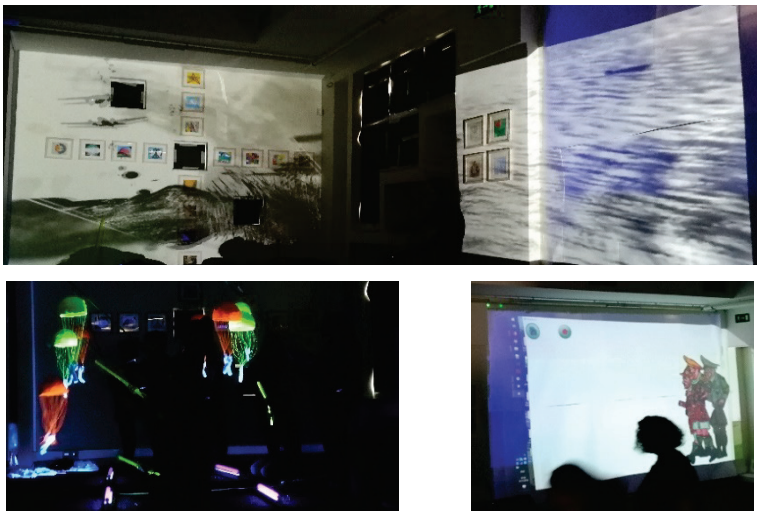

Fig. 11. Photos from the first installation related to the historical events that took place during the Battle of Crete in World War II.

Before entering the installation room, the visitors had the opportunity to get historical information about the events that took place during the Battle of Crete using a special software for the animation of spatiotemporal processes on top of Google maps. After this introductory phase, the visitors entered the installation room. The installation used project mapping to present characteristic photos and videos of the events that took place during the battle. Using black light theatre techniques, the fall of German paratroopers was represented as well as their fight with local volunteers using mostly primitive weapons. Using projection mapping as well, the eShadow was used to show German soldiers fighting with Greek volunteers. After the performance the visitors had the opportunity to experience the events using body interactions with the digital puppets. At the end, they were invited to fill the Usability Evaluation Questionnaire (UEQ) (Laugwitz, Held, & Schrepp, 2008). In total, 14 questionnaires were filled. The results are presented in the next section and compared with the results from the second installation described next.

The second installation (**Fig. 12**) was based on a local legend about the warriors of Chatzimichalis Dalianis that defended a castle of Fragkokastelo against the Ottoman army. They all died during the battle. The legend says that every year on May their shadows appear around the castle and can be seen very early in the morning, if the weather is suitable. Based on this legend that combines well with the use of shadows in representing these historical events, an installation was designed and prepared with the collaboration of local schools to prepare all the materials necessary for the final deployment. The installation included three distinct scenes:

- The first scene employed projection mapping techniques to project various visual effects around the walls of the installation room accompanied with appropriate music so that the participants were immersed and transferred to the atmosphere, time and space where the historical event took place.
- The second scene used eShadow with back projection in a big white sheet like a cinema screen where the protagonists of the historical event were shown and spoke giving details regarding the historical event.
- The third scene used black light theatre techniques with the participation of students of the collaborating schools to sum up the historical event and link to the Greek Independence Revolution of 1821 within the context of which the event took place. The emphasis was given to similar events during the revolution when many Greeks died for the freedom of Greece. One such event was the Siege of Missologhi, which inspired the poet Dionysius Solomos to write the verses of the Greek National Anthem. During the last activity in this scene, the participating students sang the national anthem.

Fig. 12. Photos from the second installation related to the historical events that took place during the Greek Revolution of Independence in the island of Crete.

After the performance the visitors were invited to interact with eShadow puppets improvising movements with the use several props. Furthermore, they were offered materials to create their own puppets on paper. Next, they were able to digitize their creations using ePuppet, one of the two accompany tools of eShadow that provides functionality to digitize hand drawing to become digital puppets (Moumoutzis, et al., 2021) (Hatzigianni, Gregoriadis, Moumoutzis, Christoulakis, & Alexiou, 2021). Following puppet digitization, the participants were able to upload them in eShadow and use them to make short improvisations.

After finishing the activity, the visitors were asked to fill the Usability Evaluation Questionnaire (UEQ) (Laugwitz, Held, & Schrepp, 2008). In total, 15 questionnaires were filled. The results are presented in the next section and compared with the results from the first installation.

5 Evaluation (Floridi, 2015)

The 26 questions of the User Experience Questionnaire (UEQ) (Laugwitz, Held, & Schrepp, 2008) are shown in **Fig. 13**. This is the evaluation questionnaire used in both the trials described in the previous section. 14 questionnaires were collected from the first trial and 15 from the second one. Respondents were both adults and children that participated in each trial Filling the questionnaire was a voluntary activity after the actual experience during each trial.

The UEQ contains 6 scales within which its 26 items are categorized:

- **Attractiveness** measures the overall impression of the product (5 items in the questionnaire).
- **Perspicuity** measures how easy is to get familiar with the product, i.e., if it is easy to learn and how to use it (4 items in the questionnaire).
- **Efficiency** refers to how easily the users can solve their tasks without unnecessary effort (4 items in the questionnaire).
- **Dependability** evaluates if the users feel in control of the interaction (4 items in the questionnaire).
- **Stimulation** measures how exciting and motivating is it to use the product (4 items in the questionnaire).
- **Novelty** addresses the innovative and creative aspects of the product and if the product catches the interest of users (4 items in the questionnaire).

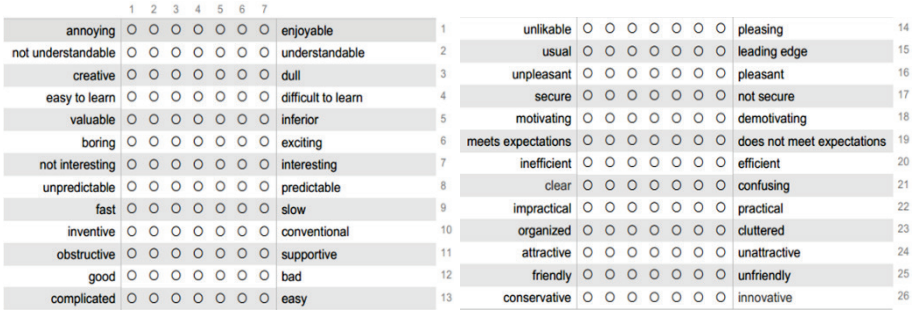

Fig. 13. The User Experience Questionnaire.

Attractiveness is a pure valence dimension. Perspicuity, Efficiency and Dependability are pragmatic quality aspects (goal-directed), while Stimulation and Novelty are hedonic quality aspects (not goal-directed). The scales and the questions corresponding to each one of them are presented in **Fig. 14**.

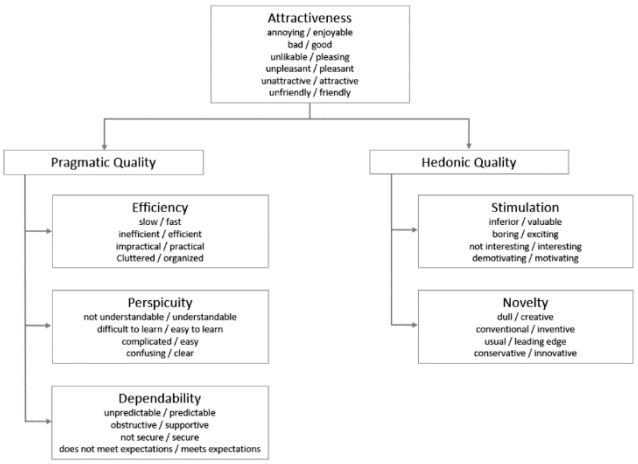

Fig. 14. User Experience Questionnaire scales and corresponding questions.

Fig. 15 shows the results from the first trial. The mean value of all six scales is positive. Comparison of the scores with standard UEQ benchmark are also shown.

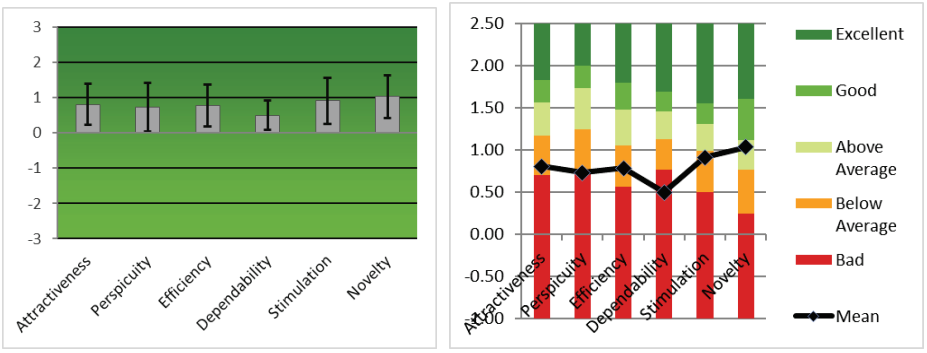

Fig. 15. Results of first trial: mean value and standard deviation for the six scales of the UEQ (left) and comparison against the benchmark of the UEQ (right).

Following the first trial and taking into account that most of the scales (5 out of the six) were "below average" in comparison with the UEQ benchmark, several enhancements were identified based also on free text feedback of the participants. The main issues for improvement addressed the overall organization of the installation and not so much about the software features per se. Furthermore, it was decided to offer more time to participants and appropriate triggers to use the software more so that they could better understand its features and innovative approach to promote creativity and learning. During the second trial 15 UEQ questionnaires were collected. The results are shown in **Fig. 16**. Comparison of scores with the standard UEQ benchmark are also show. A considerable improvement with respect to the first trial is clear: All scales' scores are above average. Attractiveness and Stimulation are within the "good" range.

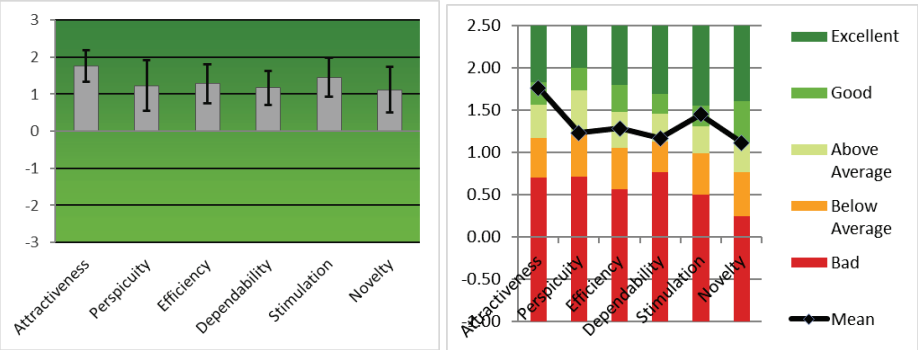

Fig. 16. Results of second trial: mean value and standard deviation for the six scales of the UEQ (left) and comparison against the benchmark of the UEQ (right).

Table 1 shows the results a simple t-test to check if the UEQ scales' means of the two trials differ in a statistically significant way in comparison with one another. As default an Alpha-Level of 0.05 has been used on the results of this t-test. A significant difference is, thus, drawn for attractiveness and dependability scales.

Table 1. Alpha values of UEQ scales comparing the results of the two trials.

UEQ Scale	***Alpha value***	
Attractiveness	0.0154	Significant Difference
Perspicuity	0.3166	No Significant Difference
Efficiency	0.2315	No Significant Difference
Dependability	0.0455	Significant Difference
Stimulation	0.2231	No Significant Difference
Novelty	0.8556	No Significant Difference

6 Conclusions

eShadow renovates shadow theatre tradition by employing Internet technologies and interactive graphics to offer a creative digital platform in tune with current trends of learner-centered pedagogies in general and cross-curricular and project-based learning in particular. The use of eShadow in schools, as it was observed, motivates students that may be hyper-active or have a negative attitude towards school. Throughout the story creation process all students exercise group work and construct valuable social knowledge and mutual understanding. Carefully selected themes encourage comprehension of concepts that are hard to understand such as abstract mathematical notations. Such stories can be further used as learning material for lower grades' students.

Beyond formal learning settings, eShadow and its accompany tools (eShadow editor and ePuppet) can be effectively combined with mixed reality technologies (project mapping) to offer experiential learning experiences in information learning settings. As it is documented from the results reported in this paper, this approach can be extremely engaging if carefully designed immersive installations are employed the enable participants to experiment by themselves with the software, developing their own creations, see them animated and use them in eShadow.

Future plans are linked to ongoing work related to the use of arts to foster creativity and deep learning in all school subjects within the context of the several ongoing projects: (a) M2-Cm (Erasmus+ code 2021-1-SE01-KA220-SCH-000032733) addressing the use of dance and music in the teaching of mathematics. Within this context, special eShadow+ installations will be developed to offer interactions with animated virtual manipulatives. (b) GAME IT (Erasmus+ code 2020-1-BG01-KA202-079103) addresses gamification in learning offering various kinds of gamified learning materials for disadvantaged students. We plan to exploit the results of this project to integrate appropriate gamification elements to eShadow+ installations. (c) MAKER SCHOOLS (Erasmus+ code 2020-1-BG01-KA201-079274) addresses the use of physical computing and 3D printing in secondary schools. Both of these topics are extremely relevant to advanced eShadow+ installations that will incorporate the design and development of specialized props that are 3D printed and possibly combined with microcontrollers such as Arduino and Raspberry Pico or single board computers such as Raspberry Pi to offer more intuitive interactions with digital puppets. This line of work in all three projects above seeks to mainstream initial results of using eShadow+ in STEAM teaching including environmental education as well.

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References

Beeman, W. (1993). The anthropology of theater and spectacle. *Annual Review of Anthropology, 22*(1), 369-393.

Cabitza, F. (2014). De-designing the IT artifact - Drafting small narratives for the coming of the Socio-Technical Artifact. *ItAIS 2014, the 11th Conference of the Italian Chapter of the Association of Information Systems.* Genoa, Italy.

Cabitza, F., & Simone, C. (2015). Building socially embedded technologies: Implications about design. In V. Wulf, K. Schmidt, & D. Randall, *Designing Socially Embedded Technologies in the Real-world,* (pp. 217-270). Springer.

Cabitza, F., Fogli, D., & Piccinno, A. (2014). Cultivating a Culture of Participation for the Co-Evolution of Users and Systems. *CoPDA@ AVI*, (pp. 1-6).

Filmmanking. (2022, 07 15). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Filmmaking

Floridi, L. (2015). *The Onlife Manifesto.* Springer-Verlag GmbH.

Hatzigianni, M., Gregoriadis, A., Moumoutzis, N., Christoulakis, M., & Alexiou, V. (2021). Integrating Design Thinking, Digital Technologies and the Arts to Explore Peace, War and Social Justice Concepts with Young Children. In C. Cohrssen, & S. Garvos, *Embedding STEAM in Early Childhood Education and Care.* Palgrave Macmillan, Cham.

Hatzigianni, M., Miller, M., & Quiñones, G. (2016). Karagiozis in Australia: Exploring principles of social justice in the arts for young children. *International Journal of Education & the Arts, 17*(25).

Honey, P., & Mumford, A. (1982). *Manual of Learning Styles.* London: P Honey.

Kearyney, M. (1989). A learning design for student-generated digital storytelling. *Learning, Media and Technology, 36*(2).

Kolb, D., & Fry, R. (1975). Toward an applied theory of experiential learning. In C. Cooper, *Theories of Group Process.* London: John Wiley.

Laugwitz, B., Held, T., & Schrepp, M. (2008). Construction and Evaluation of a User Experience Questionnaire. In A. Holzinger, *HCI and Usability for Education and Work. USAB 2008. Lecture Notes in Computer Science, vol 5298.* Springer, Berlin, Heidelberg.

Laurel, B. (2013). *Computers as theatre.* Addison-Wesley.

Maloney, J., Resnick, M., Rusk, N., Silverman, B., & Eastmond, E. (2010). The scratch programming language and environment. *ACM Transactions on Computing Education (TOCE), 10*(4).

Moraiti, A., Moumoutzis, N., Christoulakis, M., Pitsiladis, A., Stylianakis, G., Sifakis, Y., . . . Christodoulakis, S. (2016). Playful creation of digital stories with eShadow. *11th Intern. Workshop on Semantic and Social Media Adaptation and Personalization*, (pp. 139-144).

Moumoutzis, N., Christoulakis, M., Christodoulakis, S., & Paneva-Marinova, D. (2018). Renovating the Cultural Heritage of Traditional Shadow Theatre with eShadow. Design, Implementation, Evaluation and Use in Formal and Informal Learning. *Digital Presentation and Preservation of Cultural and Scientific Heritage. 8*, pp. 51-70. Sofia, Bulgaria: Institute of Mathematics and Informatics – BAS.

Moumoutzis, N., Christoulakis, M., Pitsiladis, A., Maragkoudakis, I., Christodoulakis, S., Menioudakis, M., . . . Tzoganidis, M. (2017). Using new media arts to enable project-based learning in technological education. *2017 IEEE Global Engineering Education Conference (EDUCON)*, (pp. 287-296).

Moumoutzis, N., Giodlasis, N., Anestis, G., Christoulakis, M., Stylianakis, G., & Christodoulakis, S. (2017). Employing Theatrical Interactions and Audience Engagement to Enable Creative Learning Experiences in Formal and Informal Learning. *IMCL2017 Conference on Interactive Mobile Communication, Technologies and Learning* (pp. 142-154). Springer, Cham.

Moumoutzis, N., Koukis, A., Xanthaki, C., Christoulakis, M., Maragkoudakis, I., Christodoulakis, S., . . . Pavlova, L. (2021). EPuppet: A Mobile App to Extend a Digital Storytelling Platform with New Capabilities. *IMCL2021 Interactive Conference on Mobile Communication, Technologies and Learning* (pp. 917-926). Lecture Notes in Networks and Systems, vol 411. Springer, Cham.

Moumoutzis, N., Sifakis, Y., Christodoulakis, S., Paneva-Marinova, D., & Pavlova, L. (2021). Performative framework and case study for technologyenhanced learning communities. *Informatics and Automation, 20*(4), 905-939. doi:https://doi.org/10.15622/ia.20.4.6

Niedderer, K. (2007). Designing mindful interaction: the category of performative object. *Design issues, 23*(1), 3-17.

Turner, V. (1990). Are there universals of performance in myth, ritual and drama? In R. Schechner, & W. Appel, *By Means of Performance.* Cambridge Univ. Press.

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