Institute of Mathematics and Informatics

Bulgarian Academy of Sciences

Operational Conceptual Modeling in Building and Sustaining Virtual Communities

Ph.D. Thesis

of

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for the award of educational and scientific degree "Doctor" (PhD)
in the professional field 4.6 "Informatics and Computer Science"
PhD program "Informatics"

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Sofia, 2022

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ACKNOWLEDGEMENTS

I would like to express my gratitude to my scientific advisor Prof. Radoslav Pavlov, PhD for his valuable support, supervision and guidance during my research and PhD thesis procedure. Special thanks to Prof. Desislava Paneva-Marinova, PhD for her help and support throughout the whole PhD thesis procedure including regular communication to handle important details and resolve issues. Many thanks to Prof. PhD Radoslav Yoshinov for his encouragement and valuable advice from the beginning of the PhD.

I also thank Prof. Radoslav Pavlov, PhD, Prof. Desislava Paneva-Marinova, PhD, Prof. Radoslav Yoshinov, PhD and Assoc. Prof. Danail Dochev, PhD for the fruitful collaboration in many European Research & Development projects for more than 25 years.

Also, I would like to thank Prof. Radoslav Pavlov, PhD, Prof. Desislava Paneva-Marinova, PhD, for their help in preparing all the required documents following my PhD thesis for completing the procedure. Moreover, I would like to thank all the staff of Institute of Mathematics and Informatics, Bulgarian Academy of Sciences (IMI-BAS) and Laboratory of Telematics, Bulgarian Academy of Sciences (LT-BAS) for their positive and warm attitude and support in the whole procedure.

Furthermore, I would like to express my deepest gratitude to Prof. Emeritus Stavros Christodoulakis, former director of the Laboratory of Distributed Multimedia Information Systems and Applications of the Technical University of Crete, Greece (TUC/MUSIC) as well as to my colleagues Fotis Kazasis, George Anestis, Nektarios Gioldasis, Polyxeni Arapi, Nikos Pappas and Yiannis Maragkoudakis for the excellent collaboration for many years within the context of many European Research & Development projects, where important research elements initiated and further enriched, exploited and applied in this PhD thesis. Many thanks to Prof. Katerina Mania, member of the TUC/MUSIC lab and head of the SURREAL team for contributing to parts of this work as a supervisor of diploma theses of Alexandros Koukis, and Nikolaos-Apostolos Rigas.

I would also like to express by deepest respect and gratitude to my colleagues and students in the MUSIC lab Nikos Pappas, Yiannis Sifakis, Marios Christoulakis, Andreas Pitsiladis, Alexandros Koukis, and Nikolaos-Apostolos Rigas as well as to George Boukeas and Vassilis Vassilakis who contributed to work related to parts of this thesis.

I would like to thank Nikos Blazakis for offering his traditional shadow theatre puppets and Athos Danellis for providing voice recordings that were used in special

installations that demonstrated the use of the work reported in this thesis within the context of informal learning settings combining digital technologies with traditional arts.

I would also like to thank in advance the readers and reviewers of this thesis for the time they devoted and their critical evaluation and helpful comments on my thesis. Special thanks also to the Scientific Council of the Institute of Mathematics an Informatics of the Bulgarian Academy of Sciences.

Finally, I would like to thank my wife and daughter for their love and support during the realization of this thesis.

INTRODUCTION

People learn and create within certain social contexts, i.e., environments, physical or virtual, within which other people are engaged as well possibly with different roles but common goals and expectations to satisfy their needs to create or learn. During the process of learning and creating, people connect with each other. They even connect with people that are not present (e.g., with creators of artifacts used, with those that produce the knowledge that they are trying to assimilate or even with people that will come after them to use the products of their actions). The overarching concept of community can be employed to express the social context within which human creativity is exercised or learning happens.

With the advent of digital technologies, these social contexts, the communities within which people are engaged, change radically. The first predictions that computers organized in networks will give rise to new social phenomena were made in the 1960's by Licklider & Taylor [1968] that engaged themselves in research and development efforts to design and showcase the technologies that created ARPANET, the first virtual community [Rheingold, 1987]. Today, this new landscape brought about by digital technologies is characterized by new qualities, new opportunities for action, new community affordances [Cabitza et. al., 2015]. The term onlife is adopted from the Onlife Manifesto [Floridi, 2015] and used to signify the new kind of communities brought about by the modern digital technologies, the Onlife Communities. The key research question of this thesis is to explore the design principles that can be adopted to foster such communities and support their members in creatively express themselves and learn. The central assumption is that the communities under consideration are built around digital technologies directly or indirectly. In a most simple form, a community can be formed by the people that use a certain digital tool or system to perform certain tasks. In a more complex case, the community can assign certain roles to its members with respect to their knowledge and skills and how they contribute to the development and use of certain digital technologies within the wider social context of the community. A very interesting special case are digital games, including serious games [Zhonggen, 2019; Paneva-Marinova & Pavlov, 2018; Paneva-Marinova et al., 2022; Paneva-Marinova et al., 2021; Tramonti et al., 2021].

The research reported in this thesis has been developed in order to serve a very practical objective: how existing digital systems and applications can be better understood in order to be critically evaluated to find their shortcomings and identify their strengths so that they can be enhanced by building upon the new community affordances to exploit the

dynamics brought about by modern technologies. From another perspective, this critical evaluation towards enhancements that promote community building and sustenance, offers a rational explanation of the failures or successes of existing systems so that recurring patterns can be identified and analysed. Patterns that empower users and offer guidelines for subsequently developments.

Numerous challenges arise while working on the above task: The existing situation regarding the use of certain technologies should be carefully described and analysed, issues related to the potential of new uses or the shortcomings of current uses should be identified, new developments should be designed and put in action and finally a thorough experimentation and evaluation should be done to confirm that these new developments contribute to the community needs in terms of learning and creativity while at the same time support an intuitive use of the underlying technologies. Yet another important issue is to be able to identify when and how digital technologies are used so that, if necessary, avoid the use of digital technologies in certain situations when more traditional ways of social interaction and performance are adequate. This is captured by the term de-design and this thesis demonstrates how it can be used in a fruitful way to enrich the user experience and learning opportunities.

The questions and research objectives listed above suggest a thorough study and analysis of a number of selected technological infrastructures that are used as case studies for the community building framework proposed by this thesis. In particular we analyse in detail certain platforms and applications that are targeting specific types of communities. Each platform and application has its unique characteristics and showcases aspects of the framework. The use of diverse cases studies, confirms that the presented framework is generic and effective, while the experimental results drawn for each one of the case studies confirm that the proposed approach is effective in identifying and delivering important enhancements both about the technical and the social context of the discussed interventions.

The presented dissertation is interdisciplinary in Computer Science and software engineering focusing on learning and creativity technologies. The development offers techniques, tools and methods that enable the analysis on how such technologies are actually used by their users and how they can be enhanced and even repurposed to increase their effectiveness. The aim is the creation of an inclusive design and implementation framework that can help designers and developers deliver highly usable and effective environments that establish and sustain onlife communities. This framework is titled PerFECt: a **Per**formative **F**ramework to **E**stablish and Sustain Onlife **C**ommuni**t**ies. The cases studies presented shed

light on how the framework can be used and what kind of enhancements are possible including situations when digital technologies are combined with more traditional approaches (e.g., cases of using learning technologies in combination with traditional arts).

Chapter 1 presents “Motivation, Goal, Objectives and Tasks”. The main tasks to be carried out to reach the research objectives are described.

Chapter 2 exposes the “Study of the Problem” and explains the rationale which has inspired the definition of the framework and the approach. This chapter also includes the overview of the platforms and applications that have been used in the case studies on how the thesis framework has been applied in practice.

Chapter 3 is the “Presentation of the PerFECt Framework” along with a discussion on how it was developed to address the needs that have been identified in this thesis.

Chapter 4 is the presentation of the “Research Realization and Implementation”. Details are given on how the framework has been employed to design and implement specific developments on each one of the four case studies.

Chapter 5 presents the “Presentation of Research Results – Data Analysis”. The experimental data obtained are presented in detail for each one of the case studies and the corresponding platforms and tools used are discussed. The results and thoroughly analysed and interpreted. All presented results provide evidence on the validity and the effectiveness of the approach and the significant enhancements achieved by employing the PerFECt framework. Furthermore, a number of additional enhancements identified following the interpretation of the results are presented leaving their further evaluation as part of the future work.

Finally, the results and directions for further development and deepening of the study are presented in the conclusions and contributions sections.

CHAPTER 1. MOTIVATION, GOAL, OBJECTIVES AND TASKS

1.1. Motivation

With the proliferation of modern computing technologies and the wide use of social networks to promote new personal learning opportunities, many people worldwide are engaged in technology-enhanced learning communities [Brown et al., 2018] to pursue a personalized approach to technology use and learning while at the same time collaborate with other people pursuing common goals [Linton, 2017]. Official educational systems try to take advantage of these new opportunities and transcend traditional ways of teaching towards new approaches that put the learners at the centre of the learning process and enable them to become creators of new content using appropriate tools and exploiting the plethora of materials available online. This new way of learning is ideal for addressing any kind of learning theme ranging from official school curriculum subjects to life-long learning settings, especially when it comes to the need to continuously update and extend the knowledge of professionals and teachers in related disciplines [Brown et al., 2018].

To adequately address the need of recognizing and promoting technology-enhanced learning within the above overall framework, there is a clear need to design and develop appropriate learning tools and platforms and use them within adequate learning and training frameworks offering diverse learning modes that are informed by modern pedagogical approaches that promote personalization and rich interactions to offer opportunities for knowledge construction in a personally meaningful manner [Yoshinov et al., 2016; Arapi, 2017; Yoshinov & Iliev, 2018].

The research hypothesis of this thesis is that an overarching approach that can effectively address all distinct learning settings listed above can be based on the notion of community. A community is essentially a group of people who share an interest or have a common goal. The group can evolve naturally because of the members' common interest in a particular domain or area, or it can be created specifically with the goal of gaining knowledge related to the interests of its members. This knowledge development aspect can be effectively supported by an appropriate framework that provides an effective connection between learning and certain skills that can be demonstrated via specific performed tasks of the learner.

It is through the process of sharing information and experiences with the group that the members learn from each other, and have an opportunity to develop themselves. Communities

can exist online, such as within discussion boards and newsgroups, or in real life, such as in a lunch room at work, in a learning institution, or elsewhere in any social setting.

Following the arguments above, this thesis provides a comprehensive approach to technology-enhanced learning that is based on the concept of community as a central notion for enabling learning and creativity. The approach is informed by current trends in re-conceptualizing and re-thinking about our societies facing the so called "hyperconnected era" [Ganascia, 2015].

In particular, this thesis presents PerFECt, a **Per**formative **F**ramework to **E**stablish and Sustain Onlife **C**ommuni**t**ies, i.e., communities of creators using digital tools in a certain domain, emphasizing creativity and learning. This framework is then employed to analyse and evaluate specific systems and platforms and report on their enhancements and repurposing based on the PerFECt framework as the result of elaborating and validating the research hypothesis of this thesis.

1.2. Goal, objectives and tasks of the thesis

The goal of this thesis is to provide a comprehensive approach for supporting Onlife 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" [Ganascia, 2015]. This is reflected to the term "onlife" used in the title of the framework. Onlife, is a term employed in The Onlife Manifesto [Floridi, 2015] that stresses the fact that the deployment of information and communication technologies and their uptake by society radically affect the human condition, modifying our relationships to ourselves, to others and to the world. In particular, this new reality that is brought about by digital technologies and their ever-increasing pervasiveness shakes established reference frameworks through four important transformations:

- the blurring of the distinction between reality and virtuality;
- the blurring of the distinctions between human, machine and nature;
- the reversal from information scarcity to information abundance; and
- the shift from the primacy of entities to the primacy of interactions

Our goal is put forth within a methodological approach that stems from the observation that the most effective way to understand reality is to consider change and development of "entities" and, consequently, we should always consider the primacy of "processes" rather the primacy of "entities". We build on our own experience in designing

creativity and learning systems initially conceptualized following the, so called, engineering mythology [Cabitza & Simone, 2015] that is based on a set of myths. Note here that the term myth is used to signify a certain stance, a legitimate and reasonable assumption or principle that is accepted without further analysis or justification. The myths of the engineering mythology that we identify in our previous work that this thesis is based on is that the systems we design consist of parts that interact according to certain patterns that are defined and understood at design time. As designers we seek to discover these patterns or even invent them targeting a certain harmony in the operation of the final system. On the other hand, users are expected to interact with the final system in certain ways following certain rules that are effectively imposed by the internal logic of the system.

Working this way in our projects, we have witnessed the emergence of certain patterns in end-user usage of our systems. These patterns refer to ways of end-user usage or desirable feature that go beyond our initial assumptions during design. To address these emergent patterns, we have adopted by the years elements of an alternative mythology that goes beyond the legitimacy of design as a process done by IT experts with the participation of representative of end-users in order to guide the development of digital systems. Even if we adopt user-centered or even participatory design approaches, within which end-users are assumed to have knowledge on the application domain, they are still considered as just users of the systems and their way of using these systems can be captured in advance, at design time.

The elements of an alternative mythology that we have adopted in the course of the evolution of the systems we have developed, point to the fact that such systems can be realized by the composition of elementary components without any detailed 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.

In this respect, our own experience is fully aligned with a methodology that can more effectively frame the work of software engineers as enablers or facilitators for the set-up of technological environments for Onlife Communities. To make this process more visible, we adopt a formulation of our objectives and tasks in harmony with this evolutionary process that seeks to develop innovative platforms and tools that leverage the power of digital technologies to offer new opportunities for creative expression, collaboration and learning in our hyperconnected era.

In terms of **objectives**, then, the proposed thesis has the following ones:

- Support the needs of ICT experts that seek to offer innovative technologies to establish and sustain Onlife Communities with a reflective practice approach that will allow them to critically evaluate their own way of understanding and developing digital systems and go beyond the prevailing engineering mythology towards an alternative mythology that seeks to empower users with the means that will enable them to co-create the technologies they use and evolve their practices so as to fully exploit the potential brought about by modern ICT.
- Support the needs of members of Onlife Communities with special focus on Onlife Communities of Practice and Onlife Communities of Learning taking into account the need to facilitate their gradual development from beginner to expert in parallel with the evolution of the communities themselves to co-create their own practices and tools towards continuous re-inventing of themselves.

The above goals and objectives, are realized through **the following tasks**:

Task 1 – Study of the problem, by presenting important concepts and ideas that constitute the baseline of this this thesis in general and the PerFECt framework in particular. These concepts refer first of all to performativity as an important concept that provides the ground for describing human actions and interactions going beyond usual understanding of the world based on concrete, confined objects. Performativity encapsulates bodily practices and can be linked to diverse social practices that are ultimately framed within the context of communities and can be described using a framework that links computers to theatre. This approach can be traced back to work of Brenda Laurel [2013] and links to work of philosophers and humanities scholars that also point to learning theories. Further concepts that are analysed refer to the way human fantasy works and how the use of digital technologies can provide an interpretation context for understanding causal relationships, encapsulated in the term *universal objects*. All these concepts are put under the light of the Onlife Manifesto [Floridi, 2015] and further elaborated to offer a definition of Onlife Communities starting from the idea of virtual communities.

Furthermore, task 1 of the thesis presents a number of systems classified in two broad categories: (1) platforms and (2) tools that support Communities of Practice, Learning Communities and Communities of Learning linked to creativity. The detailed presentation of the related software is achieved within the following steps:

- Present the Coursevo Multimedia Online Learning Environment and speculate on its evolution from its initial implementation as learning support system for an academic department (thus targeting blended learning support) towards a system

that enables the establishment and evolution of Communities of Practice addressing teachers and their professional development as well as other types of professionals.

- Present ViSTPro, a learning tool that enables the visualization of spatiotemporal processes, thus facilitating active learning in fields such as history, geosciences, life sciences and diverse specializations of engineering.
- Present eShadow, a digital creativity tool inspired by the tradition of Shadow Theatre and enables the creation of digital stories for self-expression or as part of creative learning interventions in formal and informal learning settings. eShadow operates as a hub that facilitates the usage of other tools to develop digital artifacts within a flexible workflow that promotes the development of digital skills

Task 2 – Presentation of the PerFECt framework elaborating on how to foster Onlife Communities by following the observations made initially regarding the logical consequences adopting the concepts analysed in Task 1 i.e., draw from the actual experience gained by developing specific tools and platforms to facilitate Onlife Communities in areas related to creativity and cultural heritage as well as in learning and professional training. Consequently, it is closely linked to task 1 that provides the concrete ground to speculate on how the hyperconnected era transforms the way in pursuing our objectives and working with our tools to produce and share our digital artifacts. This is clearly in the heart of the effort to understand how members of Onlife Communities interact among themselves and with their surrounding environments using modern digital tools and platforms and what are the new technological and community affordances that can be put into action to make Onlife Communities more effective and aligned with the dynamics of modern digital technologies. This task is realized through the following steps:

- Study the main technological affordances that bring forth new community affordances as digital technologies evolve and create new opportunities for communication and collaboration. In this respect, present and analyse the driving ideas of the Onlife Manifesto that provide a fruitful ground for a deeper understanding of our relation as humans to the digital technologies that we create.
- Analyse the concept of Onlife Communities to justify the use of the term “onlife” and present its connotations in terms of basic premises of the Onlife Manifesto and its intention to foster a rethinking of our societal concerns in the digital transition.

- Develop a conceptual framework to describe Onlife Communities employing performative models that identify and clarify the significant roles and interaction patterns between these roles. Note here that within the overall performative stance, the alternative mythology that we adopt, the ICT experts that bootstrap the technological infrastructure of Onlife Communities are in a sense also members of those communities with a special role to play in their operation. This presence in the community can be either direct (an ICT expert actually engaged in the activities of a community to facilitate the best use of its digital tools or environments) or indirect (through the tools and services that bring the onlife community into presence and reflect the underlying values and intentions of their creators).

Task 3 – Reflect on previous implementations by revisiting the specific experiences in developing tools and platforms to support Onlife Communities as a reflective practice exercise. To do so, the conceptual framework elaborated in task 2 is used as a lens to analyse the concrete observations regarding the weak and strong points of those tools and platforms as well as the specific evaluation results available from the assessment of these tools and platforms. Consequently, this task showcases, through specific examples each one pertaining to a specific tool or platform, how the conceptual framework facilitates a reflective approach to critically evaluate the work done by an engineering team towards the reframing of the experience gained to re-design, or even de-design the digital artifact available [Cabitza, 2014]. Th is the starting point towards the identification of the building blocks that, when available, will allow the members of the corresponding Onlife Communities to co-create their working landscape instead of just using monolithic digital technologies. This task is realized through the following steps:

- Reflect on the use of Coursevo platform based on the results of a large-scale teachers' training programme that combined a distant training phase with local face-to-face collaboration to establish 28 local coding clubs by 80 teachers with more than 500 students in total. This critical reflection uses the conceptual framework elaborated in task 2 to interpret the evaluation results and identify functionalities of Coursevo that were successful or possibly underused suggesting ways to overcome problems and strengthen usefulness of the platform for users' collaboration. It also analyses how face-to-face collaboration is combined with distant collaboration trying to identify the best equilibrium and provide suggestions for the design of similar future programs addressing also their

social/organizational aspects. Finally, this step identifies new ways of supporting novices in Computer Science with special emphasis on the learning of the principles of the binary system.

- Critically evaluate eShadow and its use in many schools to provide a creative learning environment linked to the traditional Shadow Theatre. eShadow is maybe the most successful of all the platforms and tools used in this thesis. Its simplicity and user friendliness are one reason for this success. The other is its openness that enables learning activities that use other software tools offering an inclusive multimedia production workflow that can be tailored to the needs of each class or group of students. Consequently, its analysis using the conceptual framework to elaborated in task 2 identifies further enhancements that guide a new version of the tool offering opportunities for actual use of the conceptual framework to address practical issues of how eShadow is further enhanced to support Onlife Communities that address creativity and arts.
- Reflect on the use of ViSTPro and the experimental results gathered. Those results showed that the tool can offer engaging learning opportunities that combine the authoring mode in combination with the playback mode of spatiotemporal processes that represent historical events. This is an interesting result that was not initially foreseen and it is put under the lens of the conceptual framework for further explanation and understanding in order to repurpose the tool as a tool supporting constructionism-based learning where the students are enabled to create a portfolio of digital artifacts and possible being evaluated on their performance to do instead of just recalling information after consuming a spatiotemporal process playback.

Task 4 – Experimentation, evaluation and improvement of the studied platforms and applications. This task is realized through the following steps:

- Experimentation of the how the PerFECt framework promotes the use of the Coursevo Platform to establish and sustain Computer Science teaching and learning communities building on previous results to effectively establish a network of Python code clubs.
- Experimentation on the applicability and effectiveness of the PerFECt framework within the field of digital cultural heritage, from two complementary points of view, the first one related a mixed reality learning approach employing the

eShadow in combination with project mapping techniques and traditional arts and the second one related to the topic of history teaching and learning using the ViSTPro tool for spatiotemporal process authoring and visualization in comparison with the use of eShadow.

CHAPTER 2. STUDY OF THE PROBLEM

The overarching term that provides an inclusive framework to address all approaches that emerge in understanding and framing how people use modern digital technologies to establish effective ways of sharing knowledge, experiences and practices, develop skills and competences, socialize and enhance traditional ways of intimacy and interaction is without doubt the term virtual communities. Following a historical overview of how this term emerged, and by speculating on its shortcomings this chapter finally offers a new term that tries to overcome these shortcomings: Onlife Communities. Then, the baseline for the work done in this thesis is the need to better analyse, extend and validate platforms and tools that are targeting communities of users with objectives related to learning and education as well as in developing digital artifacts that enhance creativity and are possibly linked to other creative activities including artistic interventions. To be able to offer a well-defined framework that enables the analysis of such platforms and tools and guide their enhancements, possibly revealing new innovative uses, the selection of a number of appropriate case studies is important because it can illuminate aspects of the framework and demonstrate its strengths and merits.

Important concepts that are related to the work of this thesis refer to performativity and how theatre can be used to describe rich interactions enabled by digital technologies as well as the concept of universality and how it is related to causal relationships that can be enhanced and better presented via the use of digital tools and technologies. In this respect, this chapter elaborates on these concepts and lays out the ground upon which the PerFECt framework is based.

All these concepts are unified and integrated within the concept of Onlife Communities and the work reported in this thesis addresses important issues on why such communities are important in learning and creativity and how they can be effectively established and sustained using digital tools such as the ones that have been used for the case studies reported in this thesis and described in the last sections of this chapter. Onlife Communities' members interact among themselves undertaking certain roles and with their surrounding environments using modern digital tools and platforms. New technological and community affordances are put into action to make Onlife Communities more effective and aligned with the dynamics of modern digital technologies. In this respect, the main ideas of the Onlife Manifesto [Floridi, 2015] provide a fruitful ground for a deeper understanding of our relation as humans to the digital technologies that we create. This chapter presents, how

these ideas can be linked to the concept of virtual communities to provide a more inclusive community building and sustenance approach under the term Onlife Communities.

This chapter also presents the selected tools and platforms that were subsequently used as a baseline for developing the framework and putting it into action and validation. In particular these platforms and tools are:

- The Coursevo platform that is a multimedia course monitoring and support system used in both blended learning and online training programmes.
- The ViSTPro platform that enables the development of rich interactive scenarios that model spatiotemporal processes and the playback of these scenarios to offer engaging learning in various domains ranging from history and cultural heritage to emergency training.
- The eShadow a tool that is inspired by traditional shadow theatre to offer an innovative and intuitive way of animating digital puppets and developing digital stories or even used for real-time improvisations and collaborative storytelling.

This chapter presents one by one the above platforms and tools addressing also issues related to their use and possible extensions that were subsequently realized using the framework elaborated in this thesis.

2.1. Analysing performativity

Performance is an important concept in the work reported in this thesis because it provides a rich conceptual ground for describing how humans interact with each other and with their environment. Performativity goes beyond the usual understanding of the world as a constellation of objects that are well-defined and confined by certain properties and exhibit certain behaviours.

Performativity 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., 2017c]. 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 social experience [Bernardi, 2009].

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 from normal structures of ongoing life, the entrance of groups of individuals into a state of transition, and the re-integration of the individuals into a reconstructed social reality. Beeman [1993] goes on to analyse 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 in Figure 1 below:

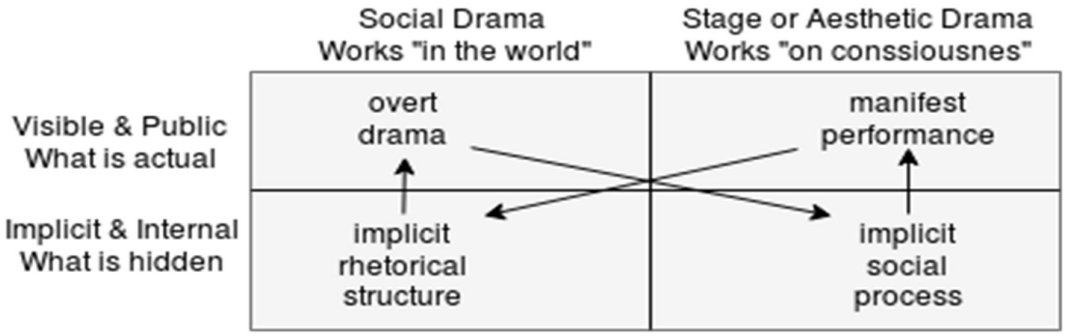

Figure 1: The interrelationship between social drama and stage or aesthetic drama.
Concepts depicted following the ideas of Turner [1990].

Above the horizontal line Figure 1 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 perform 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 discarded). 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 reconstructs or reinvents itself, resembles one of the most widely used models of learning: the learning cycle introduced by Kolb & Fry [1974] and further elaborated by Honey & Mumford [1982]. This model distinguishes four phases in the learning process of an individual that proceed iteratively as depicted in Figure 2 below:

Figure 2: The four phases of learning according Honey & Mumford [1982].
Diagram available online at [Getfeedback.net, 2021].

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 accumulated 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.

Following the above analogies to learning and the social-stage drama interrelationship, some interesting conclusions can be drawn on how hyperconnected activity can be framed as a unified space where stage and social drama, the real and the virtual, promote the emergence of a new synthesis between the chaos of raw reality (Dionysian) with human Logos (Apollonian) in a way similar to the vision presented by Nietzsche [1923] drawing inspiration from a certain conception of Ancient Tragedy.

2.2. Theatre and computers

Tracing back the appeal of theatre in Western thought as a framework to understand reality in its deepest interaction with human psyche, we reach one of Friedrich Nietzsche's first works: The Birth of Tragedy [1923]. In this book Nietzsche aims to pave a new way for meaningful life by proposing a synthesis to the dichotomy between the Dionysian and the Apollonian spirit inspired by the Ancient Greek tragedy. In Nietzsche's view, the way to achieve a new synthesis in his times was through music.

In his effort to trace the origins of tragedy, Nietzsche makes important arguments that are, in some sense, prophetic in the way that digital technologies give rise again to the dramatic notion of life especially with respect to the relation of the spectator to the spectacle not as an aesthetic relation but as an experiential one. In a comment about the origins of tragedy in general and the chorus in particular, Nietzsche [1923] brings in front an argument regarding the chorus as the "ideal spectator". Nietzsche contrasts this view with the usual belief that a real spectator is expected to "remain conscious of having before him a work of

art, and not an empiric reality" (p. 57). And he continues with the following important remarks:

> *[...] whereas the tragic chorus of the Greeks is compelled to recognise real beings in the figures of the stage. [...] We had believed in an aesthetic public, and considered the individual spectator the better qualified the more he was capable of viewing a work of art as art, that is, aesthetically; but now the Schlegelian expression has intimated to us, that the perfect ideal spectator does not at all suffer the world of the scenes to act aesthetically on him, but corporeoempirically. Oh, these Greeks! we have sighed; they will upset our aesthetics!* [Nietzsche, 1923, p. 57]

This insight of Nietzsche to consider the chorus as the impersonation of the spectator that confronts the characters on stage as real is indeed very close to the experiences promoted with virtual reality and augmented reality systems. The immersion induced in these experiences and the phenomenon of flow [Nakamura & Csikszentmihalyi, 2014] signify the entering of the interactor into the stage. The ideal spectator approaches the action on stage not aesthetically but bodily-empirically.

A few pages later, Nietzsche concludes:

> *[...] the public of the Attic tragedy rediscovered itself in the chorus of the orchestra, that there was in reality no antithesis of public and chorus: for all was but one great sublime chorus of dancing and singing satyrs, or of such as allowed themselves to be represented by the satyrs. The Schlegelian observation must here reveal itself to us in a deeper sense. The chorus is the "ideal spectator" insofar as it is the only beholder of the visionary world of the scene. A public of spectators, as known to us, was unknown to the Greeks. In their theatres the terraced structure of the spectators' space rising in concentric arcs enabled everyone, in the strictest sense, to overlook the entire world of culture around him, and in surfeited contemplation to imagine himself a chorist.* [Nietzsche, 1923, p. 65]

This is indeed an important note: The physical organization of the ancient theatre brings the spectator into the stage as part of the chorus, inside the representational worlds created by the theatrical plays. This is indeed the ideal of virtual reality within hyperconnected activities: To provide the means to surpass the "raw reality". The dramatist can do this without the use of additional facilities. Theatre, then, is in its essence a means for creating virtual realities. And there are two options here: Either the virtual reality corresponds to actual experiences that are difficult or impossible to be reproduced in another way (e.g., historical experience that cannot be reproduced due to different technology, conceptual

frameworks etc.) or it is an imagined experience. In this last case, the theatre does not mimic a reference reality but creates a new reality for the first time, a reality that corresponds to the imaginative creativity of the creator.

In this final comment Nietzsche distinguishes drama from other art forms that assume a kind of external description of the reference reality. In drama, the reference reality is experienced from the inside in a way that spreads over all participants. This magical transformation resembles what happens inside the magic circle [Salen & Zimmerman, 2004] in games where objects, behaviours and actions take unique meaning within fantasy worlds when someone goes beyond this conceptual membrane: a shield of sorts, protecting the fantasy world from the outside world.

In the ancient (and modern) theatre, the spectator is invited to transform himself during the play in order to transform the world. Within the realm of hyperconnectivity the interactor is invited to take part actively in the transformation of her/his own existence and the world in parallel. The magic transformation is the basis of the dramatic art and ICT can be considered as a global form of dramatic art that breaks the barriers of the theatrical stage and brings the theatrical interaction anywhere anytime.

Laurel [2013, pp. 44-46] provides a short summary of the function of theatre in ancient Athens and reminds us of the fact that the stories enacted in Ancient Tragedies were already known to the audience. The interesting thing about those performances, always given in pubic feasts with massive participation of the Athenian people, was that they provided the means for public discourse taking into account the current situation within the Polis (i..e. the ancient city-state). Within this context, the chorus played a very important role:

> *The Chorus in the Greek Theatre was like a mass character representing what might be cast as the citizens' responses through dance and song.*
>
> *[...] Greek drama was the way that Greek culture publicly thought and felt about the most important issues of humanity, including ethics, morality, government, and religion. To call drama merely "entertainment" in this context is to miss most of the picture.* [Laurel 2013, p. 46]

It is indeed important to note once more, as concluding remark, that tragedy (and comedy) was born in Ancient Athens within the context of a historical development that employed drama as a means for collective reflection and discourse in the Polis. Theatre provided the means (stories, characters, social gatherings) to experience, not just discuss, the public issues and, this way, educate the democratic citizens, the members of the General Assembly (Ecclesia of Demos) that was the ultimate decision-making body, in order to act as

responsible decision makers. It is interesting to note that Turkle attributes a rather similar function to computers, which she describes as *"an evocative object, an object that fascinates disturbs equanimity, and precipitates thought."* [Turkle, 2005, p. 19]

Turkle & Papert directly link computers with philosophy from a performative point of view i.e., from a perspective that addresses philosophical issues not as mere texts presenting abstract ideas but as concrete things in action, as agents interacting with other agents:

> *The computer stands betwixt and between the world of formal systems and physical things; it has the ability to make the abstract concrete. In the simplest case, an object moving on a computer screen might be defined by the most formal of rules and so be like a construct in pure mathematics; but at the same time, it is visible, almost tangible, and allows a sense of direct manipulation that only the encultured mathematician can feel in traditional formal systems [...] The computer has a theoretical vocation: to bring the philosophical down to earth.* [Turkle & Papert, 1990, p. 162]

Within this broader perspective, one could argue that digital technologies update theatre (and representational arts in general) from the "ancient" form giving new birth to the dramatic view of social life, transforming social spaces into stages and social life to social drama in a unified hyperconnected space where stage drama and social drama are fused together as onlife drama. In such settings humans, as logical/social beings, are living inside two realities: The virtual reality of our concepts, our language, our ideas etc. and the actual realities of our bodies, the material requirements of our existence. Culture is the embodiment of virtual realities into actual realities (e.g., architecture, food culture, clothing, science, language etc.) specifying the way, the mode of living in order to bring our virtual realities into existence. The problem of identity and the continuous "creation" of reality within the performative approaches of social sciences and humanities reflect exactly these facts. With hyperconnectivity a new culture is emerging, or better a meta-culture in the same way that a computer is not a medium but a meta-medium that emulates all other media [Kay, 2002]. This new culture can be better understood and engineered if we go beyond conceptions focusing on representations and the dichotomy between the virtual and the real. The challenge is to raise our awareness of the dramatic character of the hyperconnected era that promotes performative interpretations within contexts that enrich reality with universal entities that follow causal rules thus promoting mindful actions and interactions. The next section introduces the related concepts.

2.3. Human fantasy and universal objects

Within the new social context brought about by ICT, fantasy is a core concept to understand how the "blurring between the virtual and the real" is happening [Onlife Initiative, 2015]. The key observation here, made by Laurel [2013], is related to causality as a way to understand reality and interact with it in a mindful way:

> *The fact that people seek to understand causality in representational worlds provides the basis for Aristotle's definition of universality. In the colloquial view, an action is universal if everybody can understand it, regardless of cultural and other differences among individuals. This would seem to limit the set of universal actions to things that everyone on the planet does: eat, sleep, love, etc. Aristotle posits that any action can be "universalized" simply by revealing its cause; that is, understanding 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]

It is important to understand that the "blurring of the distinction between reality and virtuality" in the hyperconnected era [Onlife Initiative, 2015, p. 7] is related to the transformation of real-world objects into universal ones, following the above Aristotelian definition as described by Laurel. A real-world object or process that has been enriched with new capabilities for interaction with humans via computer hardware and software integrated into it is more understandable in terms of causal relationships, more predictable in terms of its behaviours, less chaotic in its reactions to human actions. Consider any kind of cyber-physical system such as autonomous automobile systems, medical monitoring systems, robots, or autopilots. All these systems are essentially enhancing real world objects or processes with "computer intelligence" that makes them more human friendly: easier to understand and interact with them. Due to the embedded digital technologies the capabilities of such objects or processes seem more "natural" as they provide affordances that are more intuitive for humans interacting with them. In this respect, the meaning of the word virtual is not to be used as a synonym for artificial as in terms like virtual reality or virtual world. It is rather reframed to denote potentiality as being equally real to actuality, but in a different manner. This is exactly what Deleuze describes in his treatise of Bergsonism [1966, pp. 96-98]. This potentiality that is the essence of Deleuze's virtuality is the key concept that enables the exploration of how human Logos (reason), through causality, is transforming disconnected reality into hyperconnected stages where meaningful action and interaction is possible.

At this point, it is important to add Laurel's [2013, p. 94] additional comment on how fantasy works, in relation to causality, offering the basis for make-believe environments:

> *We need only look to works of fantasy to find obvious examples of how universalization via causality works. Actions that are patently impossible in the real world (such as a person flying) can be made believable and understandable in their dramatic context if probability is established. This fact led Aristotle to observe that in dramatic action, an impossible probability is preferable to an improbable possibility. We can believe that Peter Pan flies because of the way the potential of his world is revealed, through the way his character is established in the action, and through dramatic situations that provide him with causes to use his ability to fly.* [Laurel, 2013, p. 94]

One can see here that causality is considered far more important than real possibility. In other words, reality is better understood and given meaning if it obeys causal relationships. This is indeed very much facilitated with the use of ICT, if systems are properly designed. Consequently, one can find here an important imperative for the designers of digital technologies: To effectively support the construction of causal mental models that can then be followed in order to enhance the interactions between humans and computer agents.

It is interesting to note here that although Laurel succeeds in capturing the most intrinsic characteristics of digital technologies, the characteristics that explain their success in enabling meaningful interpretations of reality through its "virtualization", she maintains a rather conservative view on the applicability of her ideas. The engagement that digital systems can offer to their users is considered from an entertainment point of view only:

> *Engagement, as I use the concept in this book, is similar in many ways to the theatrical notion of the "willing suspension of disbelief," a concept introduced by early 19th-century critic and poet Samuel Taylor Coleridge. It is the state of mind that one must attain in order to enjoy a representation of an action.* [Laurel, 2013, pp. 139]

This phenomenon of "willing suspension of disbelief" can be clearly seen in both drama and computer games where the audience and the players respectively feel for and with the characters in essentially the same way: Someone might cry when watching a film or share other feelings with the characters within a virtual setting. However, as Laurel puts it, "spreadsheets aren't pretend!" She argues that the activity within a virtual setting should be separated from its artifacts: The representation of a text, spreadsheet, database or any other artifact residing at computers, as it is being manipulated on the screen is in fact pretend, as compared to physical artifacts like printed text or files in computer storage. The artifacts are

real much like actors, lighting instruments, and scenery in a theatrical play, but the working rules related to the representations of dramatic actions or interactions are distinct from the artifacts. Consequently, it is important to understand the fact that the notion of representation is the key to understand what one can do, the affordances attributed to the artifacts. Furthermore, their special status as representations affects human emotions about them, enabling experiences that are much more pleasurable than those we regularly feel in real life, as Laurel argues. The distinguishing characteristic of the emotions triggered in a representational context is that there is no threat of pain or harm in the real world, she adds. Finally, Laurel emphasizes the playful attitude of humans when interacting with such representations and warns against the dangers this attitude may have in certain situations:

> *Further, engagement entails a kind of playfulness: the ability to fool around, to spin out "what if" scenarios. Such "playful" behaviour is easy to see in the way that people use photo editing suites and document creation software. The key quality that a system must possess in order to foster this kind of engagement is reversibility; that is, the ability to take something back. In the age of the Internet, taking something back once it is published is nearly impossible. We and our children need to understand that; fooling around is playful, but publishing is forever.* [Laurel, 2013, p. 140]

In a footnote, Laurel further analyses this distinction between the uses of computers for entertainment from the uses in other contexts:

> *This principle suggests that activities like running a nuclear reactor or launching a spacecraft—things with real potential in the real world—should be taken off the table when we talk about dramatic interaction. For example, the control system on a nuclear reactor involves many, many representations of the state and operations of various system components, but in the context of real-world consequence, these representational affordances are much more about human factors and tele-operations than they are about the pleasure of interaction.* [Laurel, 2013, p. 140]

Form another point of view, however, dramatic interaction (or meaningful performance) is not related to entertainment alone. It is also present in other kind of human activities, much more serious, as in politics and social interactions in workplaces, education, economic transactions etc. In domains where the decisions taken and the actions initiated have very important real consequences that may not be reversible as in entertainment-oriented contexts while, at the same time, exhibit clear dramatic character. This is an important extension to Laurel's work that is contributed by the framework elaborated in this thesis as presented in Chapter 3. The framework, as already noted, adopts the concept of performativity

as the overarching term that links the social context created by digital technologies to the aspects related to worlds of representation, traditionally addressed by analysis pertaining to theatre.

2.4. From virtual communities to onlife communities

The term virtual community was coined by Rheingold [1987] in his seminal essay "Virtual communities – exchanging ideas through computer bulletin boards" where a virtual community is described is an emergent phenomenon initiated by a group of people that use networked computers to exchange messages or ideas. The members of the group may well meet physically or not. However, not all such exchanges of messages and ideas end up in the establishing of a virtual community, which is an emergent phenomenon adhering to certain criteria [Rheingold, 1987]:

> *"Virtual communities are **social aggregations** that **emerge** from the Net when **enough people** carry on those discussions **long enough**, with **sufficient human feeling**, to form **webs of personal relationships in cyberspace**."* [Emphasis added]

The above definition clearly emphasizes the social, subjective and time aspects of virtual communities: The social aspect is indicated by the observation that virtual communities are social aggregations where an adequate number of people participate and create personal relationships. The subjective aspect, i.e., the way each person experiences this connection with the others, is important and refers to the existence of sufficient human feelings without which there is no sense of belonging, no real connectedness between the members of the virtual community. Finally, there is a clear time aspect that is related to the emergence of the virtual community and its duration. Following this aspect, it is clearly possible in a certain situation to identify the existence of technology and possibly an adequate number of people that use this technology to connect with each other, but no community to establish or emerge because of the transient or temporary nature of the social and subjective context that is created. There are situations of transient or occasional social aggregations that do not have an adequate duration.

In light of the observations made so far, we believe that the term "virtual community" although widely used is not appropriate for our purposes. A first critique is that this term does not adequately address the performative aspect of human behaviour, especially as it is transformed by the advent of digital technologies. This is evident from Rheingold's definition cited above. This definition focuses on the structural aspects of virtual communities, i.e., that they are social aggregations around discussions. In this respect it is logically implied that the

community is essentially the network, the set of nodes (people) and links between them. However, from a performative point of view we should underline that if being is becoming, if self is something that is constantly changing, a dynamic process that is constantly (re)constructed then community is also a dynamic phenomenon and, consequently, a virtual community exhibits an even more dynamic evolution. In this respect, the emergence of a community, cannot only rely on vague criteria like "enough people" or "long enough" engagement in discussions and "sufficient human feelings". This vagueness is certainly related to the adjectives "enough" and "sufficient". How can we measure those quantities to decide if a virtual community has emerged or not? Why not give a chance to "not enough" people engaged "not long enough" in discussions to form a virtual community if "sufficient human feeling exists? Consider for example a casual encounter of just two persons, a man and a woman, that meet for some days or even only one night and, as a result of this encounter, a strong mutual love emerges that may bond these two persons for years in separation before they meet again (or never meet again). The literature is full of such stories! Why not consider such encounters as possible in the Net? On the contrary, a performative view would certainly account for such boundary cases on the basis that they have a significant impact on the participating persons: They are not the same persons after such kind of encounters, they become new persons. Indeed, this is a critical quality of any community: Its power to change its members. Actually, it is the presence of this kind of power that makes traditional communities what they are! Why not attribute such power to virtual communities as well?

Apart from failing to address the strong performative aspect found in traditional communities, the presented framing of virtual communities, suffers from yet another significant shortcoming: The word virtual is loaded with negative connotations in the way it is currently used in every day communication. According to Wikipedia, the word virtual is used to describe an item *"when it is a representation or non-tangible abstraction of the physical object, or is a functional emulation or simulation of it"*. Consequently, a virtual thing presents itself like something that exists (or could exist physically) but it does not really exist. It's a mere representation, an abstraction, a simulation. We want to study communities not as substitutes of physical communities, but as extensions of them, as a rich environment for social interaction that has a purpose and real consequences in the world. In this respect we seek a term that will make clear this intention we have.

In search for an alternative terminology, we turn into a recent development by philosophers and scholars that study how modern digital technologies are changing our world. These developments refer to the Onlife Initiative [2015] that started as a project envisioned

and implemented directly by the EC's Information Society DG in 2012. The project intended to explore the extent to which the digital transition impacts societal expectations towards policy making. The project outcome was the Onlife Manifesto [Floridi, 2015]. The baseline of this text is that the advent of digital technologies in all aspects of life has fundamental consequences in the human condition. It affects our reference frameworks, in a number of different domains including who we are, how we socialize, our metaphysics and our agency.

The members of the Onlife Initiative decided to adopt the neologism "onlife" that Luciano Floridi had coined some years ago in order to refer to the new experience of a hyperconnected reality within which it is no longer sensible to ask whether one may be online or offline. Within this new reality that is brought about by digital technologies and their ever-increasing pervasiveness important transformations are happening that blur the distinction between reality and virtuality as well as between human, machine and nature. Furthermore, these transformations result in a reversal from information scarcity to information abundance; and the shift from the primacy of entities to the primacy of interactions, thus opening up the way towards the adoption of performativity as a central concept in understanding the realities surrounding us within a context in which these realities change quickly and dramatically because of ICTs.

We adopt the term onlife from the Onlife Manifesto to signify the current reality expressed by the above-mentioned transformations that directly address *"the shift from the primacy of entities to the primacy of interactions"*. The major claims of the Onlife Manifesto can, then, trigger very interesting consequences when the concept of community is brought into play with respect to the double blurring (a) between reality and virtuality and (b) among human, machine and nature. Consequently, the term onlife community signifies the transcendence of "virtual communities" with the following definition:

> ***Onlife Communities are aggregations that emerge in hyperconnected spaces when humans engage with other humans as well as with machines and natural entities in mindful interactions with sufficient human feeling to form webs of personal relationships.***

Note here that this is an adaptation of the notion of "virtual communities" keeping only the absolutely necessary precondition (sufficient human feeling) and extending the domain of interactions to incorporate machines and natural entities. Machines, here, are to be conceptualized as universal objects that are superimposed on other machines, natural entities or even humans to provide causality over the underlying chaos of the physical reality as already presented with references to work from Brenda Laurel [2013].

Before presenting how the concepts described so far can be put together to assemble the PerFECt framework, the next sections, present the platforms and tools that are used in this thesis as a means to establish and sustain Onlife Communities following analyses, enhancements and processes informed by the PerFECt framework.

2.5. The Coursevo platform

Coursevo (http://coursevo.com/) is a multilingual multimedia educational platform for managing courses and supporting learning processes and learning communities through the Web. It has been developed following a spiral process as the evolution of Courses, a platform that has been initially created to support the courses at the School of Electrical and Computer Engineering at the Technical University of Crete, later know as MOLE i.e. Multimedia Online Learning Environment [Pappas et al., 2011; Mylonakis et al., 2011] Coursevo fosters distance learning by enabling communication between tutors/trainers and students, cooperation among students and access to coursework information and learning resources [Pappas et al., 2017]. It combines traditional classroom-based lessons and practical sessions, with self-study and eLearning. This "hybrid" or "blended" approach combines the immediacy of communication between educators and learners with the irreplaceable practical training in laboratories and the convenience, flexibility and self-regulation of personal study without time/space constraints.

Coursevo platform hides the complexity and frees trainers from system maintenance tasks, since a course or even a full functional learning site can be created in a few steps following the SaaS (Software as a Service) paradigm. In the main site, there are links to Coursevo Community Portal and to Coursevo Cloud, a directory of available e-learning site instances and course programs. To use Coursevo one may sign-in to create a local account or may benefit from the authentication mechanisms of popular social networks such as Facebook and Google+ (Figure 3).

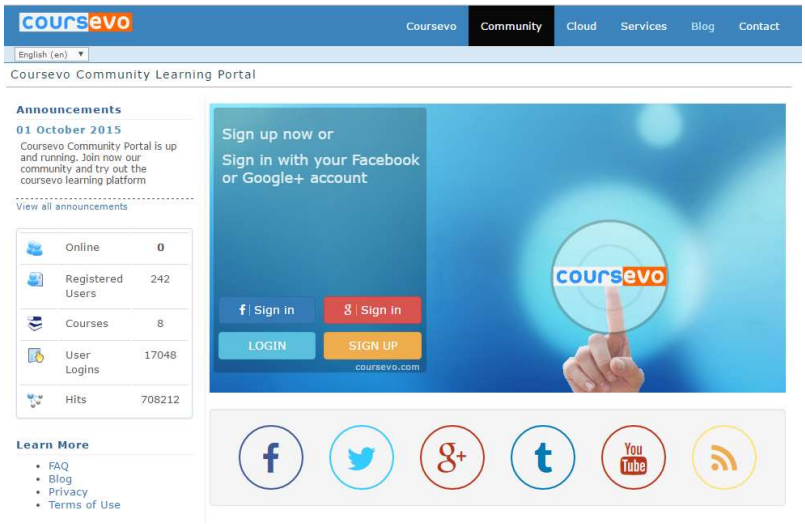

Figure 3: Coursevo Community Portal front page.

After log in, the user may browse the available programs or categories or search for and register in particular courses (Figure 4). Each user has access to a personal dashboard (Figure 5) where it is possible to have quick access to all the courses, he/she attends/manages. Furthermore, through the dashboard, the user is informed for various updates in courses via the available platform notifications.

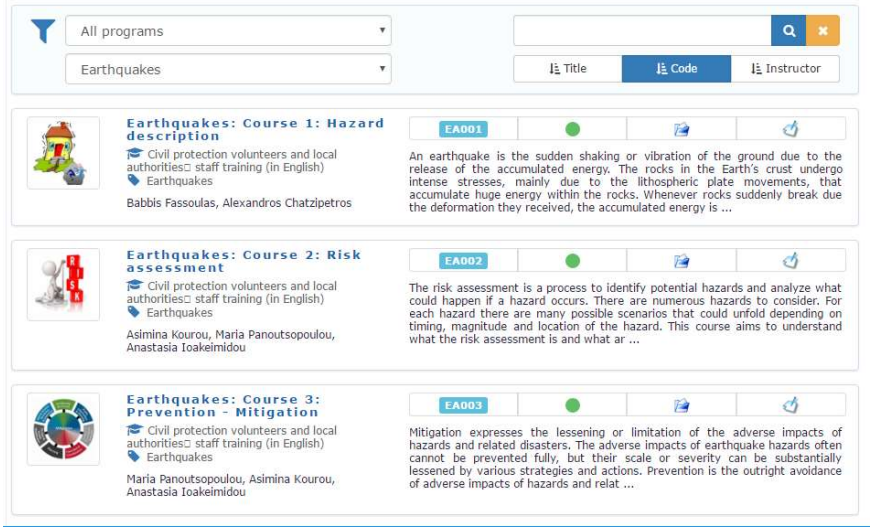

Figure 4: Coursevo catalogue with browsing and searching functionality.

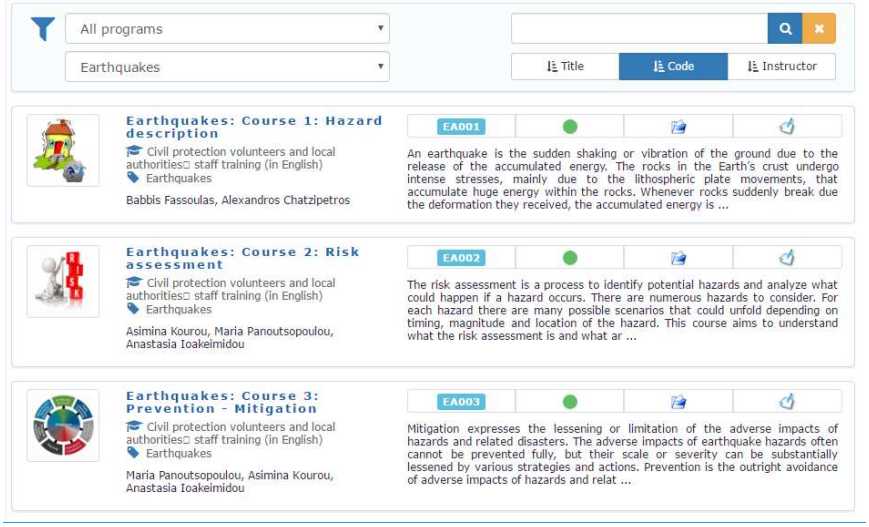

Figure 5: The user's personal dashboard in Coursevo.

Coursevo users are able to view the learning community that is shaped around each instance of the platform. Furthermore, each user holds a personal profile. This personal profile can be enriched with the desired personal information like full/short CV, personal photo etc. (Figure 6). The platform allows users to browse community directory, exchange personal messages, keep personal message boards and follow other members, enabling communication and formation of learning teams and sub-communities regardless specific course attendance.

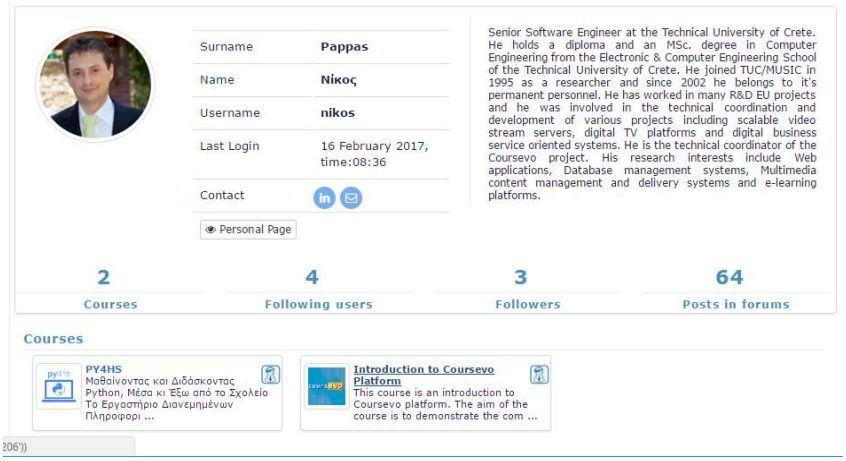

Figure 6: Public view of a Coursevo member profile.

Trainers are able to configure an instance of the platform to automatically issue certificates of successful attendance for specific training programs. A training program consists of one or more courses from multiple study programs or subject categories. The

successful attendance is tracked by the learners' performance on specific obligatory self-assessment tests. Each learner is able to view the available certificates (Figure 7) that can be issued based on course registrations as well as the personal progress and remaining assessments needed to be completed in order to earn the appropriate certificate.

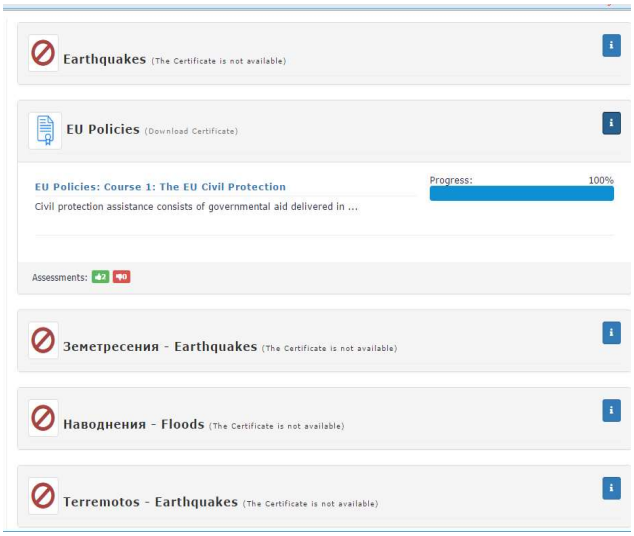

Figure 7: Training Program Certificates. Each learner can view the certificates that can be issued and the learning process progress.

The Coursevo platform has full multilingual support. New languages can be added dynamically and easily by authorized users, using the appropriate form-based translation service. The translation process is performed in the context of the provided system and course services and is assisted by a mechanism for automatic translation suggestions (Figure 8).

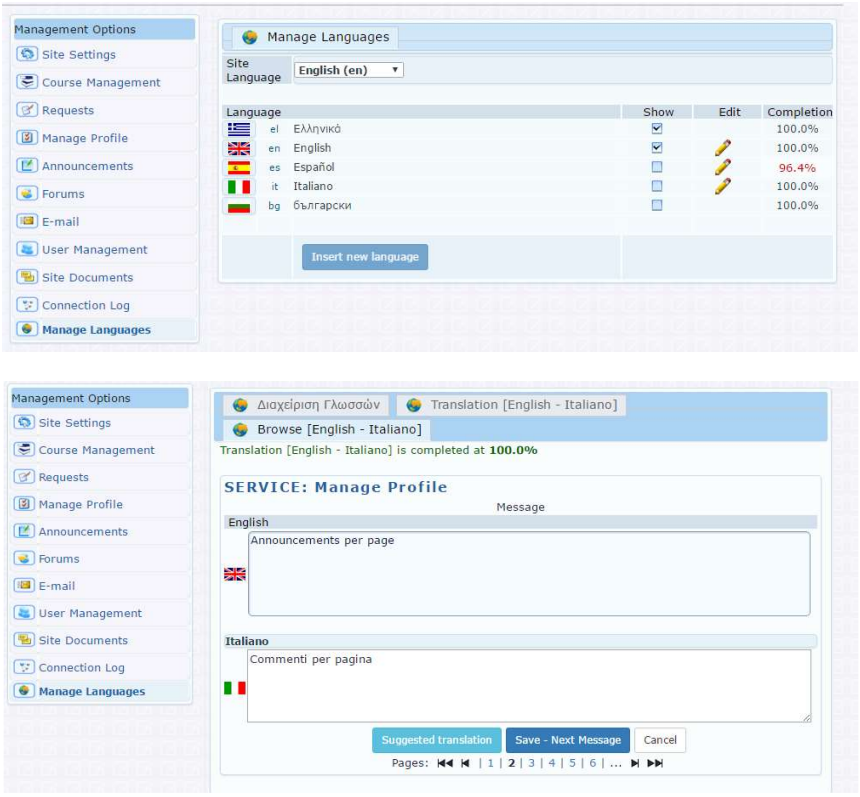

Figure 8: Multilingual support in Coursevo: Dynamic addition of languages supported by the translation service with automatic translation suggestions.

All the above features are built within a flexible architecture that enables customizable course services and multimedia features to promote effective personalized learning paths that can be packaged as needed to support diverse communities of practice. This architecture along with details about the platform implementation are described next.

2.5.1. Services offered by Coursevo

Coursevo offers a set of services for:

- **Organization and management of digital educational content:** Lectures' presentations and recordings, notes, exercises, technical lab material, literature, FAQs etc.
- **Course attendance:** Announcements, email messages, course calendar, personal rating, automatic track of exercises and deadlines, content update messages, course syllabus, learning path, assessment tests, and generation of course certificates.

- **Learning communities' communication and collaboration:** Course and group mailing lists, live chat rooms, forums, polls, personal messaging, instant messaging, annotation tools, file sharing, video conferencing and collaboration.
- **Educational activities:** Courses registration, lab teams' formation, exercise uploads and deadline management, assessment tests, multimedia presentations, resource scheduling and reservations.
- **Course monitoring:** Course usage statistics and class performance indicators.
- **Interoperability** with other educational platforms via SCORM Packages [Rustici Software Team, n.d.].

Each course can be configured to follow specific registration and content access policies. The educators are able to activate the proper subset of course services depending on the course needs depicted in Figure 9. They can use services and tools that allow for easy content creation and web publishing. They have the ability to use common office applications for document creation. These documents can be processed by Coursevo for indexing purposes and then published in a web friendly presentation format (Figure 10).

Besides office documents, educators are able to upload images, videos and SCORM Sharable Content Objects (SCOs) or quickly and simply re-use existing content in the web that is accessible in popular web platforms like YouTube, Slideshare and Wikipedia. All the above course content can be combined with other Coursevo services like video-lectures, forums, assessments etc. and organized in different learning paths in order to meet diverse educational needs.

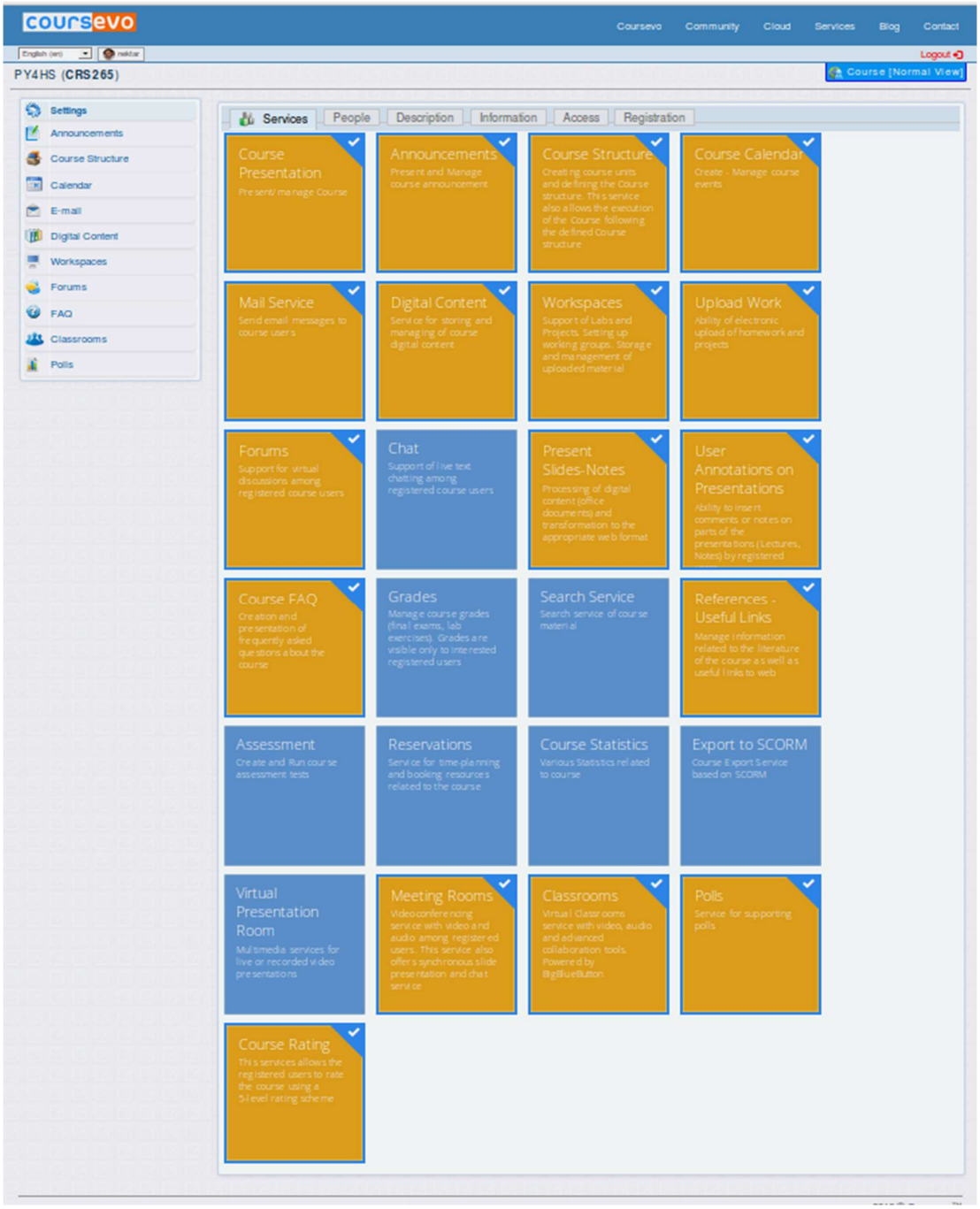

Figure 9: The Coursevo course administration panel to select the services that will be available in a certain course. The panel shows the full range of available services and tools that are available to course administrators.

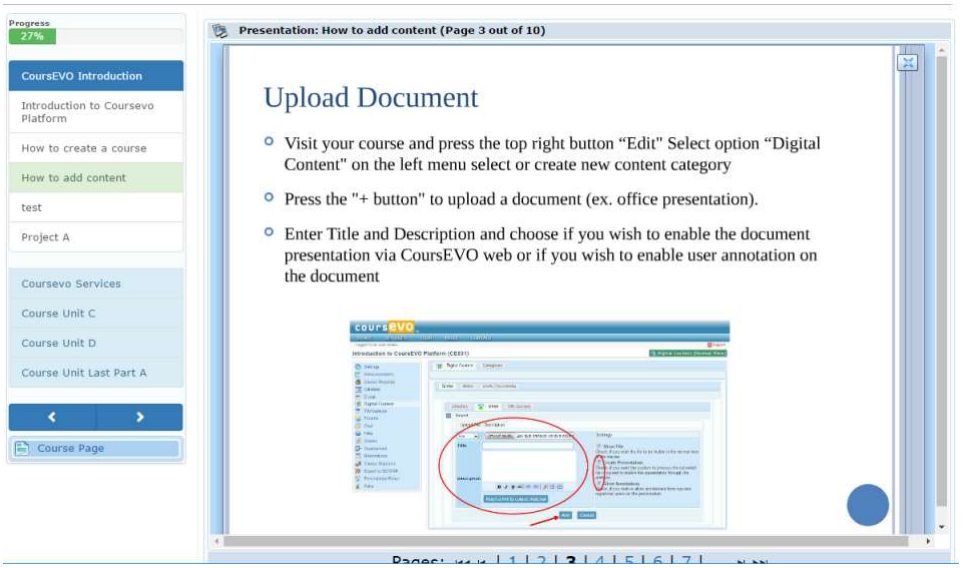

Figure 10: An example of educational content presentation, while a learner is following a course learning path.

2.5.2. Multimedia support in Coursevo

Coursevo provides an integrated educational environment for synchronous and asynchronous learning that offers significant advantages in comparison with other eLearning systems: It gives emphasis in the use of multimedia as a powerful learning means. Indeed, learning activities using multiple media can be more effective than doing it through a single medium (such as text), but what is important is combining media effectively. Effective multimedia for learning requires carefully combining media in ways that take advantage of each medium’s unique characteristics. The most effective multimedia provides learning experiences that mirror real-world experiences and let learners apply the content in various contexts. In particular, Coursevo supports efficient educational use of multimedia via:

- Effective support of multimedia and video/audio data streams management and mechanisms for the synchronization of multimedia presentations.
- Support of synchronous and asynchronous learning activities, support of live synchronized media transmission through the system, and access to the recorded multimedia content. Learners’ intervention in live sessions is also supported.
- Multimedia educational content creation in two ways: (a) through the Web-based interface without the need for specialized software installations; (b) through an autonomous desktop application (Coursevo Studio) for the offline creation of high-quality video presentations with automatic slide synchronization (Figure 11)

that can be easily exported and published at a later time. The Coursevo Studio supports also the generation of demonstrations and presentations of software by capturing the screen, recording the speaker and the presentation of slides.

- Communication tools to support educational communities such as: (a) live video chat between online users; (b) Video Conferencing Services (Figure 12) with collaboration tools employing BigBlueButton (http://bigbluebutton.org/); (c) asynchronous multimedia communication messages.
- Advanced multimedia collaborative annotation tools on educational materials.

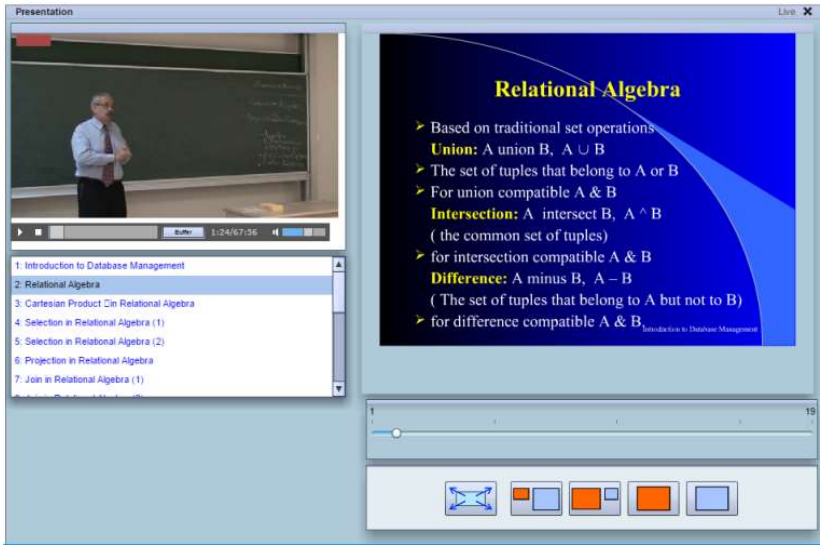

Figure 11: An example of Coursevo Video-lecture.

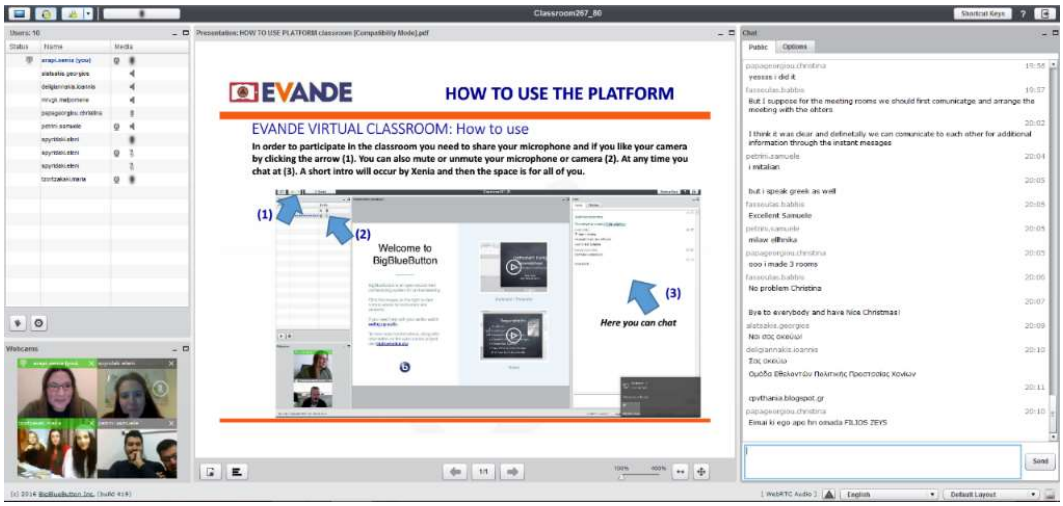

Figure 12: BigBlueButton is used in Coursevo to support video conferencing services.

2.5.3. The Multi-tenant architecture of Coursevo

An important characteristic of Coursevo is its multi-tenant architecture (Figure 13) that can support multiple instances of it using the same core to serve the needs of different projects or communities. This is an important aspect when establishing and sustaining a Community of Practice that needs its digital identity in terms of web space (each "tenant" or "instance" of Coursevo has its own URL in the form http://[community-name].coursevo.com), its particular repository of digital materials, communication services and courses' structure and supported services. Furthermore, each community could use external resources of digital materials and export selected content to external systems. All these are supported by Coursevo by employing the IEEE LOM [2002] interoperability standard and the OAI-PMH communication protocol [Open Archives Initiative, n.d.].

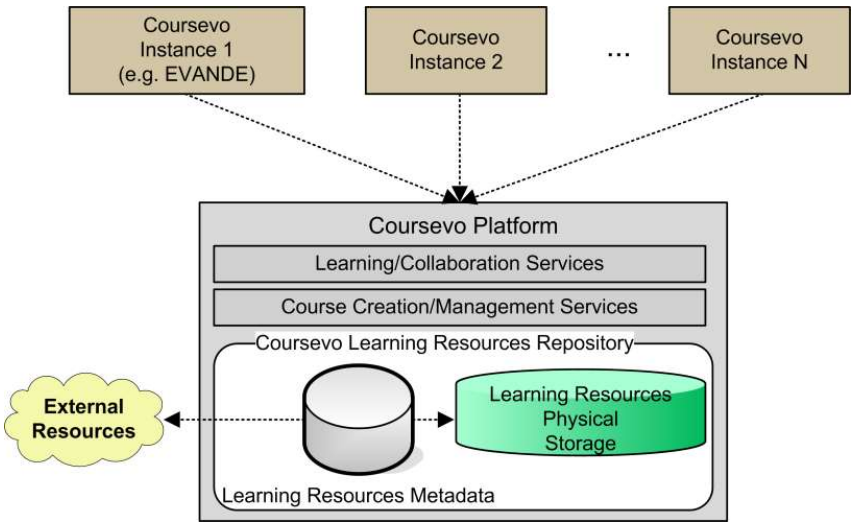

Figure 13: The Coursevo multi-tenant architecture enables the support of different communities and projects via multiple instances that use the same underlying infrastructure and content repository.

As it is shown in Figure 14, the Coursevo platform comprises core components that include the Document Processing Engine, the Data Manager, the Stream Server and the Video Engine. The stream server takes over the stream management and the delay sensitive data delivery to platform users. The Video Engine provides a rich set of codecs and video editing functionality and supports the content editing tools and the platform's stream transcoding needs for supporting heterogeneous stream clients. Some of the more interesting multimedia services of Coursevo are the following:

- The Multimedia Presentation Service: The platform supports live broadcasting of a presentation given by an instructor using video and audio synchronized with presentation slides. It is also possible to record the presentation and store it on the platform to be accessed by the learners at different times. The learner is able to navigate to the different parts of the presentation by selecting the preferred section from the list, while the slides and the video/audio of the presentation are synchronized accordingly.
- The Video Conferencing and Collaboration Service: This service makes possible for groups of learners to meet in virtual space and to communicate with video, audio and text. It also provides the opportunity for dynamic processing and uploading of presentation slides, where presentation is synchronized among the members of the conference call. Any registered member in the course can create a video conference room to start collaborating with other users on a specific topic. Educators and trainers have also the option to exploit advanced web conference services using the open source BigBlueButton system that has been integrated in the Coursevo platform (Figure 12).
- The Multimedia Annotation Service: The multimedia annotations feature allows users to navigate in the course lectures or notes, which have been previously processed and presented on the system. During the navigation they can leave comments, notes or upload/record audio/video data at several points on the presentation. These comments can be seen by other users and the instructor. It is also possible to create a comment or note in response to a previous comment of a user. This way the educational process is enhanced, since the opportunity of asynchronous communication between learners and instructor via comments or questions on specific points of the presentation of lectures or notes is provided.

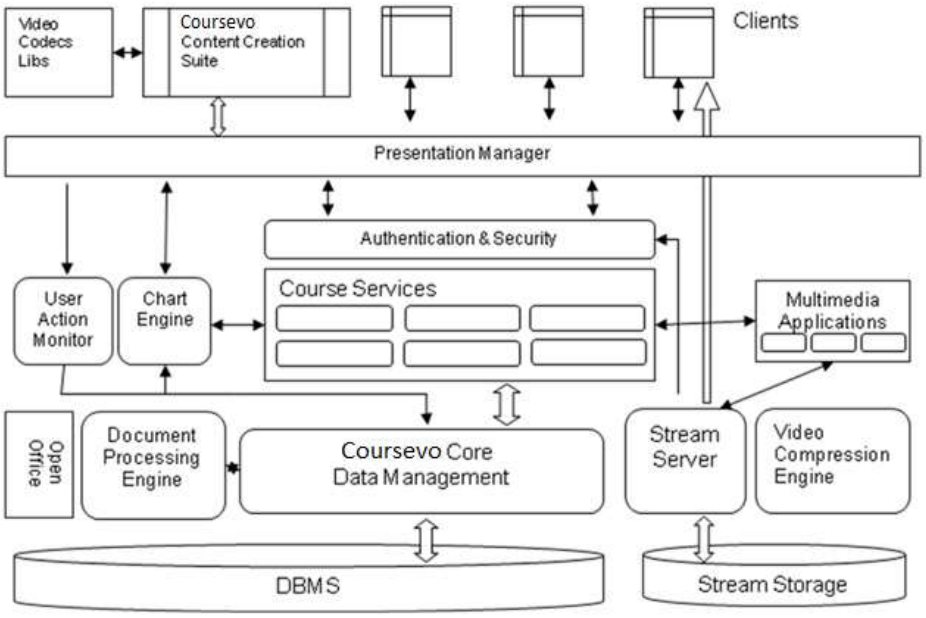

Figure 14: The Coursevo core components following a 3-tier architecture.

2.6. The ViSTPro platform

ViSTPro is a generic tool to enable the visualization of spatiotemporal processes. Such processes offer a unified model for representing various types of content knowledge ranging from historical developments, such as representations of battles and other historical events [Georgiev & Nikolova, 2021] to physical processes like the ones studied in geosciences, life sciences etc. [Pant et al., 2018; Siabato, 2017; Firat & Laramee, 2018]. Such processes are difficult for learners to conceptualize with traditional teaching and learning approaches due to their complexity and inherent dynamic nature [Resnick, 1997]. Consequently, a generic approach on dynamic spatiotemporal process modelling could be used in supporting many educational domains, promoting an active inquiry-based style to learning.

To address this need, important visualization principles are relevant [Roam, 2013] and interactive digital maps could be employed, on top of which appropriate active objects are overlaid representing real-world phenomena or events. This way, open exploration environments could be assembled and offered to learners as intuitive dynamic spatiotemporal models [Resnick, 1997]. The learner has the opportunity to create symbolic formations, move them, and determine their interaction with other entities. In other words, a “visual narrative” is developed, in such a setting, for the evolution of spatiotemporal processes trough the animation of imported, process-type specific, graphical symbols superimposed on maps.

Learners are familiar with this kind of animations because they regularly use digital applications with similar features [Lameras et al., 2017]. The transfer of this positive experience in a learning context brings pleasure and offers more opportunities for learner engagement.

2.6.1. Authoring and playback of scenarios in ViSTPro

To effectively support learning on spatiotemporal processes, careful design should be employed. ViSTPro employs the concept of scenario for modelling complex spatiotemporal processes [Sifakis et al., 2016; Sifakis et al., 2017; Moumoutzis et al., 2019b; Moumoutzis et al., 2021f]. This concept suggests the visual representation of the evolution of spatiotemporal processes. Explanations and semantic maps play an important role in this representation. ViSTPro distinguishes scenario authoring from scenario playback. During scenario authoring ViSTPro helps and guides the scenario author throughout the process. The scenario author initially selects a name and describes the new scenario. At the same time, active components of the scenario are determined (Figure 15).

A scenario contains groupings, types of entities and specific entities. Considering the case of the Battle of Marathon used in the evaluation of ViSTPro, a grouping may represent Greek or Persian troops, types of entities may relate to the infantry or cavalry and certain types of entities can represent leading figures such as Miltiades, the leader of the Greek army. The user selects the characteristic colour of each troop and the representation of each entity type and also can import additional icons. Specific types of entities are represented with a larger size in order to differentiate from other types of entities. In addition, the representation of the different states of the types of entities providing multiple views for each of them (e.g., killed, on-fire, etc.) can be supported, while the user can create custom states. These elements are contained in optional map legends to facilitate the explanatory power of the presentation.

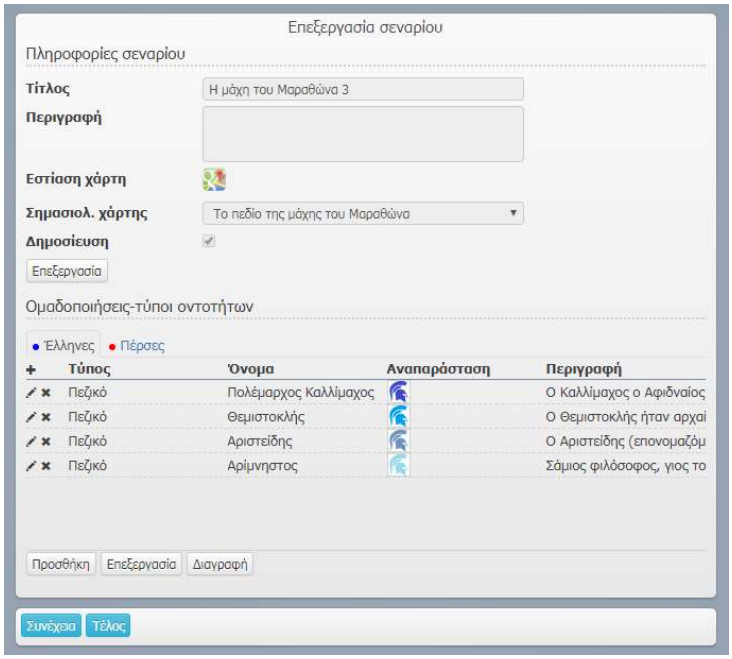

Figure 15: First step to create a scenario in ViSTPro.

The second phase of the authoring process is the structuring of the scenario. The structural elements of a scenario include activities, sub-activities and events. Activities correspond to main units of action (Figure 16). Each activity is connected with a title, a description, and may include other activities or elementary unities of action (sub-activities) where the action unfolds and the movements, actions and interactions of the active components are visually described. For each sub-activity several properties are available such as its name, description, start- and end-time, photos, recorded narration and related activities and other sub-activities of the scenario. Sub-activities may include events that represent a milestone or a particular incident. An event is identified by its title, description, timestamp and possibly its correlation with some type of entities, its state and a semantic object. Each scenario is thus modelled as a hierarchical structure of activities, sub-activities and events.

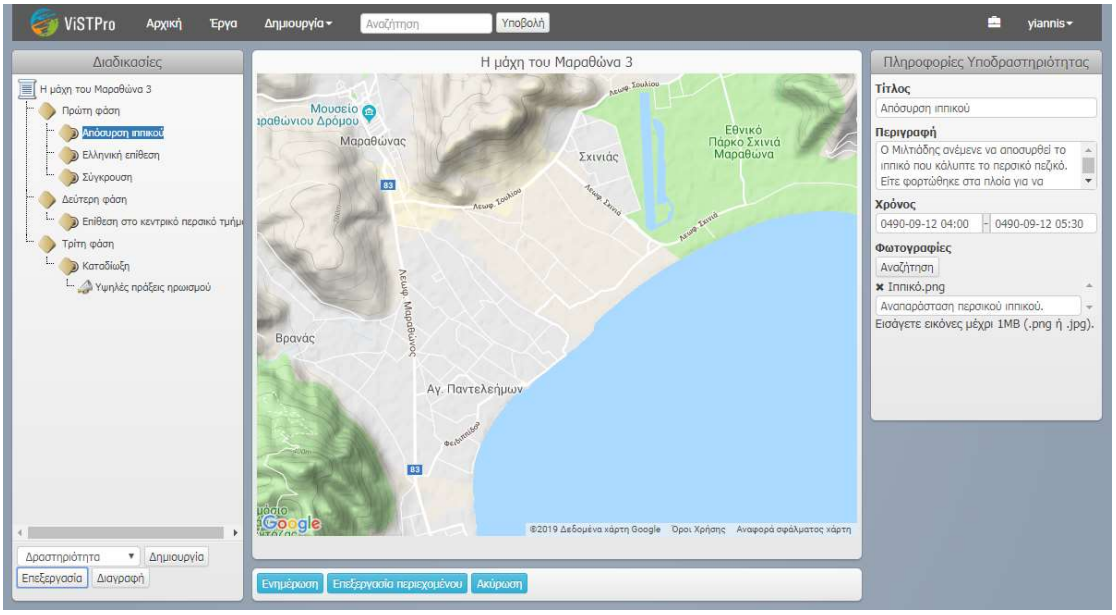

Figure 16: Structure of a spatiotemporal process in ViSTPro with its hierarchical structure (left pane), its visualization on top of google maps (centre pane) and descriptive attributes (right pane).

Another important scenario element is the set of formations that will be visualized. A formation is a set of entities handled as a whole. ViSTPro offers the necessary tools for the design of formations through predefined geometrical shapes (square, rectangle, circle, polygon, etc.), varying sizes, orientations, etc. After formation definition, entity types can be specified along with their size, location and density, in order to be included in the corresponding formations. Furthermore, the existence and position of one or more specific types of entities can be indicated.

The handling of a specific formation is possible through sub-activities. When a sub-activity is created, the scenario author chooses which formations will appear, defines the initial and final position and specifies the path that will be followed during scenario playback. Furthermore, there is a set of actions available for each formation. These actions are related to their behaviour and interaction during playback.

The representation of actions is displayed by means of suitable graphical elements, such as icons and arrows. A formation may change its state as it moves or performs an action or interacts with other formations during scenario playback. For this reason, during scenario authoring, it is possible to redefine the state of a formation by defining its size, shape and density of varying types of entities, while their state can be modified.

Another important modelling primitive is graphics. A set of graphical elements are available such as lines, arrows, and other predefined elements, which are overlaid on the map

during scenario authoring and they play a crucial role in the playback of a scenario. Semantic content is provided via title and description, and can also determine characteristics such as colour, size and orientation. During scenario playback the graphics can remain stationary or move. They can also change their shape in a manner similar to the state change of formations.

Process visualization addresses important elements such as human-made objects and significant locations of the surroundings. The presentation and provision of relevant information regarding these objects is done through semantic maps. Semantic maps are collections of important locations and objects of a region, which are represented on a map. The creation of a semantic map gives the possibility to create semantic objects each one described by its name, description, and one or more images. Thus, during scenario playback, it is possible to interact with the objects of a semantic map and examine their semantic content. Semantic maps are customizable by selecting certain objects and creating a new semantic map containing them. The new semantic map can be saved with a new name for future use. An original or customized semantic map can be used in one or more scenarios in the way described above.

During scenario playback individual learning needs are addressed through the provision of explanations for better understanding the evolution of the processes represented in each scenario. ViSTPro handles the movement of formations, involved in each sub-activity from an initial to a final position and provides an intuitive representation of state changes by changing the size, shape and density and status of the types of entities employing appropriate interpolations. Furthermore, during scenario playback each sub-activity title and description is presented possibly enriched with sound recorded narration. The playback can be paused to give time for examination of photos, related information that may have been registered in the sub-activity or even the physical surroundings. Events are depicted through entitled panels on the map, with location and time properly indicated. If an event is associated with a specific type of entities and/or a specific semantic object, those entities and/or objects are shown emphasized. Event-related additional information and pictures can be examined if scenario playback is paused.

During the playback of a scenario its hierarchical structure is displayed (left panel depicted in Figure 17). Through this structure one can switch to another scenario that describes in more detail the currently presented sub-activity. Finally, it is possible to speed up or slow down playback in order to adjust the speed to learner needs.

Figure 17: Scenario playback in ViSTPro.

2.6.2. ViSTPro advantages over similar tools

ViSTPro can be compared with similar tools that have been presented in the literature. A comparison reveals the strengths of ViSTPro. The comparison is made with five tools and summarized in Table 1. These five tools are described in the following paragraphs.

TimeMaps [Farrimond et al., 2008] is an application for historical spatiotemporal data visualization. To create a scenario, the user introduces a narrative as a sequence of sentences. The system analyses it in order to create the visualization. TimeMaps supports creation of entities, linking of entities with specific locations, grouping of entities through colour and their movement from one point to another through interpolation. The visualization tool presents the entities through small coloured circles that move onto a political map, includes video control buttons and provides the option of adjusting the playback speed. TimeMaps simplifies the creating process by the use of simple text. However, events are recorded linearly. This makes it difficult to capture the complex relationships between real world events. Furthermore, the presentation of the entities through dots could be proved poor since it deprives user from the opportunity to intuitively understand the information regarding their identity and type.

Inoue et al. [2014] present a visualization platform for historical events is presented, based on the causal relationships that connect them. Stories are structured hierarchically using multiple levels of timelines, while the user interface is interactive and uses three elements for

the visualization: arrows moving on the map connecting causally 2D icons-events, timeline and articles explaining events. The system supports multiple maps for each level of the hierarchy of the story and therefore the transition from one level to another implies a change in the map focus. This system is clearly better, in comparison with TimeMaps, since events are not structured linearly, but the existence of multiple timelines and the focus change on the map may be confusing for the user.

The GLOCAL system [Buschbeck et al., 2011] aims to visualize complex events structured hierarchically with the use of sub-events. Users can examine the structure of the events, to focus on individual events by applying filters and to view related videos and photos. GLOCAL goes beyond the linear recording of events and rejects the use of multi-level timelines. Additionally, it provides information by means of images and videos and it is not limited to narratives and articles. However, the classification scheme of individual elements of processes consisting of events and sub-events is proved poor and limits the users' options in creation. Furthermore, the structure of events is not accompanied by a map. This makes it difficult for users to perceive their place in the natural space.

TEMP [Prestopnik & Foley, 2012] is an educational tool for the visualization of historical battles. Entities are presented as points, labelled by name and type and coloured depending on the group they belong. The visualization includes a timeline, which is synchronized with the animation of the battle presented. Video control buttons enable the user to activate, interrupt, control the playback speed, and determine the type of information that is presented. TEMP has the disadvantage that the structure of the events is not shown during the animation. This results in a linear one-dimensional presentation. Moreover, there is no map to show moving units. This lack of appropriate maps deprives the learner important information about the spatial context in which the historical event took place.

Velikova et al., [2013] present a system using map visualization to support mass casualty incidents. Patients, vehicles and emergency stations are presented onto Google Earth, in order to improve situational awareness and increase of preparedness. Patients are presented with circles whose colour indicates the priority of their situation, stations are presented with black rectangles, while two-dimensional icons are used for the rest of the objects. Furthermore, reference is made to the visualization of natural disasters, such as fires, with the definition of the dangerous area using appropriate colour. According to the authors, the system evaluation suggested problems such as inconsistency in symbols, inability to design areas of any shape and con-centration of large amounts of information on the map.

Table 1 summarizes the characteristics of the above systems as well as ViSTPro to make the comparison with it more concise. The number codes of system characteristics used are the following:

1. Graph-based presentation of information.
2. Automatic presentation based on graph navigation.
3. Importing symbols for presentation of various entities.
4. Possibility to visualize the interaction between entities.
5. Visualizing entities' state involved in the representation.
6. Capability to design flexible shapes and routes.
7. Use of GPS points to create formations.
8. Importing models to support different processes (fires, floods, etc.) and customize the terminology regarding entities available for visualization.
9. Controlling playback and speed.
10. Interacting with the symbols of the presentation for the review of relevant information and explanations.
11. Focusing on specific parts for detailed presentation.
12. Using graphics to provide explanations.
13. Registration and use of semantic objects of the surroundings.

Table 1: Comparison of ViSTPro with other systems.

	System characteristics												
	1	2	3	4	5	6	7	8	9	10	11	12	13
TimeMaps	√	√							√				
Inoue	√	√	√	√							√		
GLOCAL	√	√	√							√	√		
TEMP									√	√			
Velikova					√					√		√	√
ViSTPro	√	√	√	√	√	√	√	√	√	√	√	√	√

ViSTPro contributions address several aspects (Table 1): Scenarios are structured hierarchically according to a flexible model of activities, sub-activities and events that capture complex relationships of real-world processes. Presentation of entities is intuitively more efficient through the types of entities, specific entities and formations and through the visualization of their state and their interaction. Custom symbols can be used, flexible design shapes and routes are supported (also via GPS points). The model and the terminology, in particular, can be customized to the needs of the visualization of any process. Finally, the use

of explanatory graphics and the registration of the semantic objects of surroundings enhance the visualization and clarify important aspects of spatiotemporal processes.

2.7. The eShadow tool

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 et al., 2016]. 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.

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 theatre so popular in many countries over time [Lu et al., 2011]. Traditional shadow theatre 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 theatre is a very popular form of entertainment. For older generations shadow theatre 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 theatre is a common link across generations: Children in Greece still watch traditional shadow theatre plays, learn about shadow theatre in school and also play with shadow theatre puppets.

The important impact shadow theatre 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 re-search process and with collecting and using information about different shadow theatre 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 theatre 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.

eShadow (http://www.eshadow.gr) is the digital version of shadow theatre [Moumoutzis et al., 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., 2018]. 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 et al., 2018; Moumoutzis et al., 2017b; Moraiti et al., 2016; Hatzigianni et al., 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., 2021b; Hatzigianni et al., 2021].

eShadow 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 [Helic, 2006] 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 [Vutborg et al., 2010]. 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 et al., 2018].

2.7.1. 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 18) that handles coordination between clients so that all clients see the same scene with the movement of digital puppets synchronized.

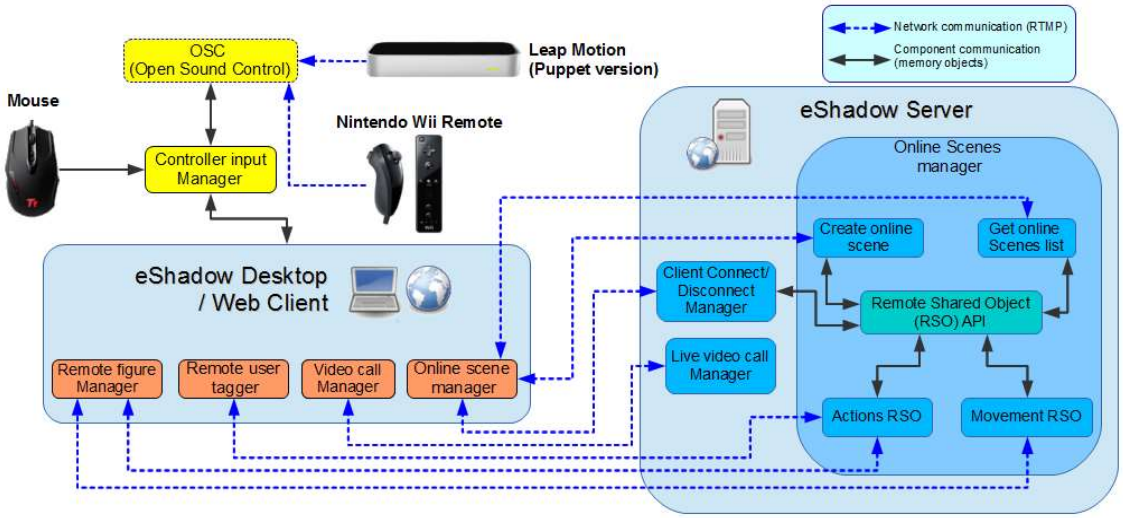

Figure 18: eShadow client-server architecture and input devices.

eShadow offers an intuitive way of setting up scenes and enacting them. The user can select the desired scenery objects and digital puppets (Figure 19) and then move them with mouse drag operations (Figure 20). 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.

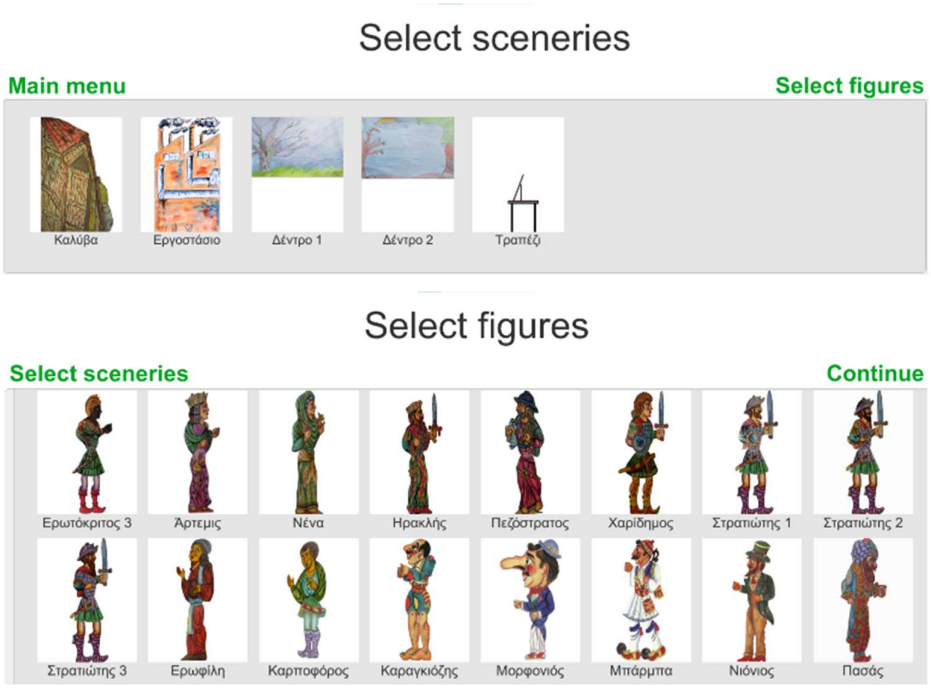

Figure 19: Selecting scenery objects (up) and digital puppets (down) in eShadow.

Figure 20: Enacting a scene with three puppets and two scenery objects (background picture and table) in eShadow.

eShadow gives emphasis in the realistic motion simulation of shadow theatre's puppets (Figure 20) 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 [Moraiti et al., 2016]. 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.

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 favourite 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.

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, appropriate design principles were adopted [Nielsen, 1994] and usability tests were conducted with real users. The results derived were then analysed 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 [Moraiti et al., 2016; Moumoutzis et al., 2018].

A special desktop application, 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 (Figure 21) 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.

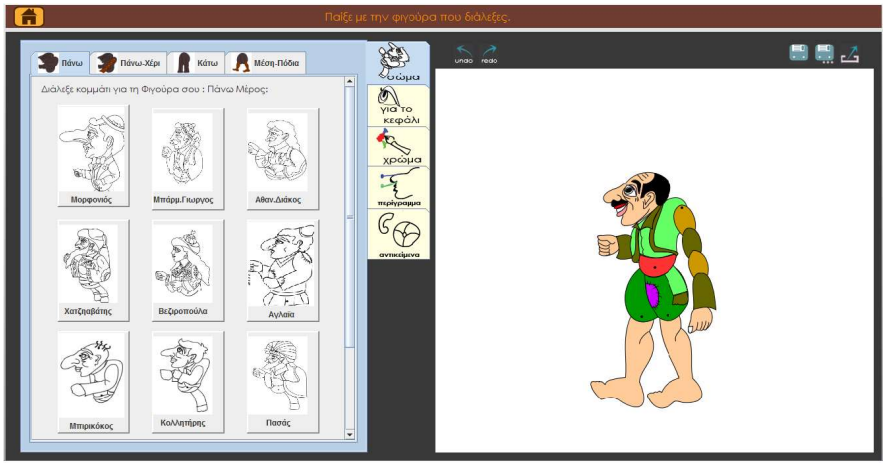

Figure 21: Remixing a digital puppet in eShadow editor.

2.7.2. Digital content production with eShadow

eShadow embraces the most inclusive flavour of cross-curricular learning through thematic units in order to bring forward several educational innovations. Within a certain theme, usually selected by the teacher, students create their own digital stories. This approach is based on research findings [Kearney, 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 [Filmmaking, 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 [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 pre-production 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 pro-cessing (optional) and video editing to produce the final digital story. The fifth and last phase is the distribution (sharing) of the digital story.

Figure 22 illustrates the 5-stage creativity process wrapping eShadow and eShadow editor, 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.

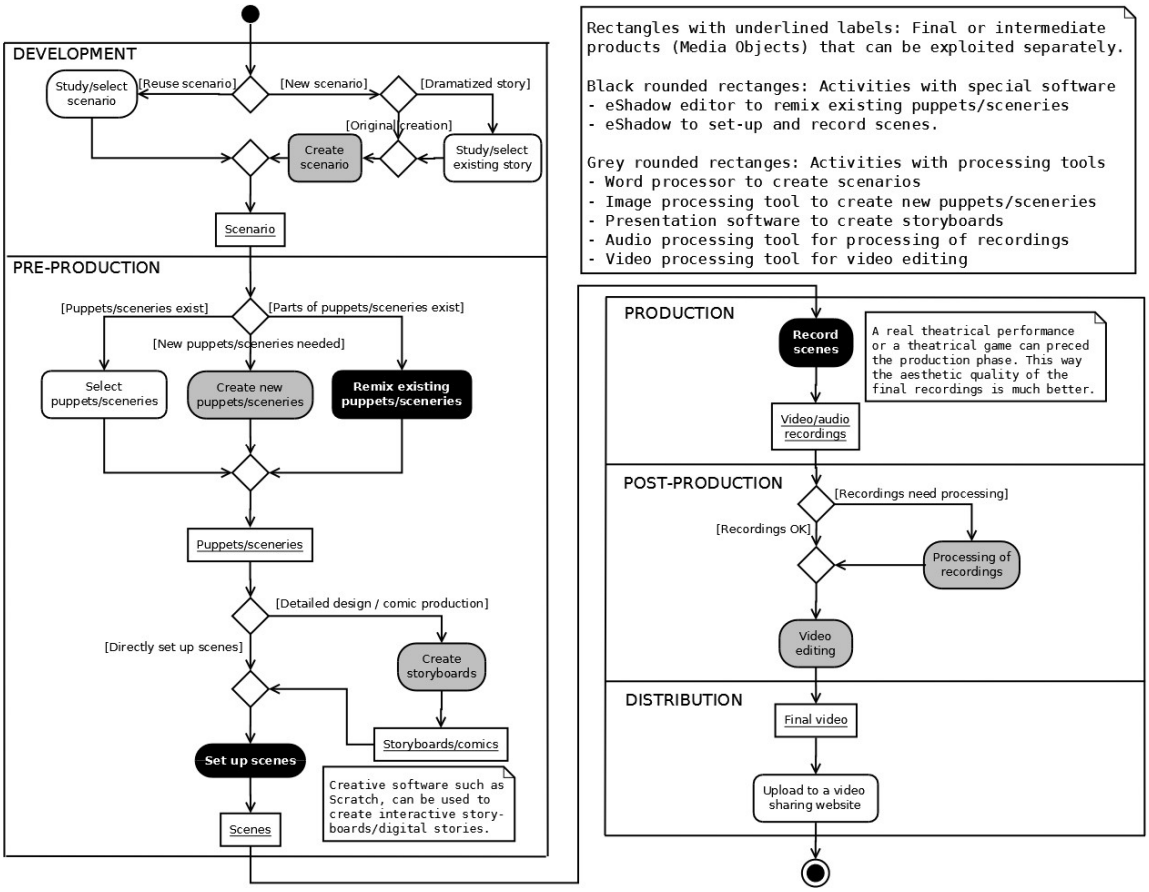

Figure 22: The process of creating a digital story with eShadow.
The five phases are adopted from the filmmaking process.

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 et al., 2010] for creating interactive storyboards or an alternative form of the digital story in inter-active 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.

2.8. Chapter summary

This Chapter presented the baseline of the thesis in terms of important concepts, problems and digital infrastructures that are targeting communities of users with objectives related to learning and education as well as in developing digital artifacts that enhance creativity and support artistic interventions.

Several issues have been presented including the concept of performativity, the links between theatre and computer studies within the Human Computer Interaction domain, and how digital systems can be used to enforce and enhance casual relationships, thus contributing to the idea of universality. Furthermore, a thorough analysis was given on how the idea of virtual communities can be extended by exploiting modern developments incorporated in the Onlife Manifesto. All these concepts and ideas are subsequently integrated within the PerFECt framework that is presented in the next Chapter.

Certain platforms and tools have also been presented in this Chapter so that the subsequent presentation of the PerFECt framework in the next Chapter can be better understood as it provides the ground for further developments and enhancements on the presented platforms and tools so that they can effectively support the establishment and sustenance of onlife learning and creative communities. The selected tools and platforms presented are:

- The Coursevo platform that offers ICT support for both blended learning and online training programmes.
- The ViSTPro platform that enables the authoring and playback of rich interactive scenarios that model spatiotemporal processes to offer engaging learning in various domains ranging from history and cultural heritage to emergency training.
- The eShadow tool inspired by traditional shadow theatre to offer an innovative digital storytelling approach as well as an environment for real-time improvisations and collaborative storytelling.

The above platforms and tools were presented in detail with all offered functionalities and underlying data models. Chapter 3 presents the PerFECt framework while Chapter 4 uses the framework to describe the new developments and enhancements that were implemented in the above platforms and tools that clearly demonstrate the applicability of the framework in community building and supporting engaging learning scenarios.

CHAPTER 3. PRESENTATION OF THE PERFECT FRAMEWORK

The Performative Framework to Establish and Sustain Onlife Communities (PerFECt) developed in this thesis is based on some important concepts one of which is the concept of performativity as already presented in Chapter 2. As exposed by Cabitza & Simone [2015] the concept of performativity emphasizes the fact that human behaviour can be understood and analysed by assuming that all human practices are performed so that actions can be seen as a public presentation of self. This is the conceptual basis of the methodological breakthrough titled the performative turn in cultural studies, social sciences, humanities and design. The term turn signifies the trend to reverse the ontological premises that reality corresponds to particular objects, entities, and configurations that exist in and of themselves exhibiting certain essential qualities towards a new central hypothesis that objects are textures of partially coherent and partially coordinated performances existing through multiple situated practices. Meaning making is essentially a social process. Knowledge is created through the actions of the members of a social structure. In this respect, there is a shift towards *"the active social construction of reality rather than its representation"* [Dirksmeier & Helbrecht, 2008, p. 4]. The roots of this approach can be attributed to the need to move beyond the prevailing focus on texts or symbolic representations to capture meaning.

Employing the above ideas and other concepts already presented in Chapter 2, this Chapter presents the components of the PerFECt Framework. In particular, the particular roles that enable the establishment and sustenance of Onlife Communities (end-users, expert-users, maieuta-designs and meta-designers) and the interactions among these roles that give rise to a co-evolution phenomenon that captures the dynamics between community members and the tasks that they are engaged in.

3.1. Components of the PerFECt Framework

As exposed in [Fischer et al., 2017; Cabitza et al., 2014; Cabitza et al., 2015], end-users of digital systems are increasingly more required to act as active contributors at use time, thus becoming "producers" of contents and functionalities. The term expert-user is used to signify a person that is an expert in a particular domain with main goal to develop the capabilities of available software tools. An expert-user subsumes all those roles denoting people in charge of carrying out 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, [Fischer et al., 2017; Cabitza et al., 2014] suggest the role of meta-designer to describe professionals who create the socio-technical conditions for empowering expert-users to engage in continuous system development. Meta-designers create open systems at design time that can evolve by their users acting as co-designers. Yet another important role is that of maieuta-designer who is mainly oriented at organizational and social related issues, rather than technical ones, for supporting the task of the expert-users: Ensuring the socio-technical prerequisites that are necessary for enabling expert-users work out new solutions by using the available technological means. This task undertaken by expert-users addresses as many end-users as possible in the process of continuous refinement of the available technology, thus promoting and strengthening participation, as the ultimate goal of maieuta-designers. The word "maieuta" is used in direct analogy to the well-known learning method employed by Socrates, the philosopher. It signifies the facilitation of people to address challenges by enabling them develop knowledge and self-confidence and ultimately transform themselves from passive consumers of technology to active creators, i.e., moving from the role of end-user towards the role of expert-user.

Starting from the above conceptualization of the user roles of meta-designers, maieuta-designers, end-users and expert-users, the PerFECt framework seeks to adapt these concepts within the so called hyperconnected context that is framed by modern digital technologies. This is captured in the term onlife that is borrowed from the Onlife Manifesto [Floridi, 2015] to describe the type of communities that this framework is trying to describe and establish. The Onlife Manifesto is the result of work within the Onlife Initiative that started as a project envisioned and implemented directly by the European Commission's Information Society Directorate-General in 2012. The project intended to explore the extent to which the digital transition impacts societal expectations towards policy making. The project outcome was the Onlife Manifesto [Floridi, 2015]. The baseline of this text is that advent of digital technologies in all aspects of life has fundamental consequences in the human condition. It affects our reference frameworks, in a number of different domains including:

- our self-conception (who we are);
- our mutual interactions (how we socialize);
- our conception of reality (our metaphysics); and
- our interactions with reality (our agency).

The neologism “onlife”, adopted by the Onlife Manifesto, refers to the new experience of the hyperconnected reality within which it is no longer sensible to ask whether one may be online or offline. Within this new reality that is brought about by digital technologies and their ever-increasing pervasiveness important transformations are happening that refer to the relationship between reality and virtuality, the information abundance, the man-machine and man-nature interactions and their importance that go beyond the traditional primacy of entities.

Following these developments, the PerFECt framework suggests the term onlife community to signify aggregations that emerge in hyperconnected spaces when humans engage with other humans as well as with machines and natural entities in mindful interactions with sufficient human feeling to form webs of personal relationships. Furthermore, by adopting the four user roles of end-user, expert-user, meta-designer and maieuta-designer it seeks to provide a certain structure to onlife communities and provide a mechanism to enable rich learning experiences.

To further analyse how these user roles are understood in their dynamics, it is important to note that they interact with each other and with digital artifacts and digital tools to form a co-evolution phenomenon. The meta-designer is focused on designing and providing the most effective tools that may sustain the co-evolution between end-users and expert-users. The maieuta-designer facilitates the migration from the role of end-user to the role of expert-user to empower end-users to appropriate and contribute to the use of available digital tools. In cases when an end-user is not interested or fails to evolve into the role of expert-user, the maieuta-designer may facilitate participation in system evolution by systematizing the reporting of shortcomings and system faults as identified by the end-user and proposing solutions that are handled by expert-users.

Consequently, the above four roles give rise to two co-evolution processes: The first one refers to the use of software targeted to the end-user where there is continuous (cyclical) interaction between the end-user and the system. This is depicted in Figure 23 (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. In an analogous way, there is a second cyclical process depicted in Figure 23 (right) that refers to the use of software components as building blocks of the system in continuous evolution from the perspective of expert-users. This process corresponds to yet another three homocentric cycles of the same nature: action-interpretation, task-object, and community-technology layers.

The inner interaction cycle in each co-evolution process refers to actions (triggered by the corresponding user or software) that are interpreted by the other party (software or user respectively). The task-object cycle in the middle refers to the co-evolution of the user task and the corresponding artifact within the boundaries of the system. Finally, an outer community-technology 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.

Before describing in more detail, the two co-evolution processes, one pertaining to end-users and the other to expert-users, we need to present the concept of universality. This concept refers to blends of machines and physical objects that generalize the notion of software or tool within a hyperconnected landscape. Universality addresses the issue of causality in digital representations, as we have already seen by referencing the corresponding ideas exposed by Brenda Laurel in her seminal book "Computers as Theatre" [2013, p. 94].

Consequently, a universal object is an artifact that presents itself in a way that is meaningful and understandable through casual relationships that enable the user of such an object to effectively manipulate it and understand it, i.e., link it to casual interpretations. A universal object can be acted upon to produce certain effects because its casual interpretation enables the user to know what will happen if certain manipulations are made. Furthermore, its response to certain manipulations is predictable and thus can be used to produce the desired effects within the context it is being used. The essence of digital technologies is, in this respect, to transform plain objects into universal objects.

Universal objects are considered a core element of the PerFECt framework and their use by end-users in combination with their development (as universalizing assemblies) by expert-users constitute the two aforementioned co-evolution phenomena in three co-eccentric cycles built around them to describe the relationship between end-users/expert-users and the end-tasks/expert-tasks that they engage in. This phenomenon has been first described in [Fogli & Piccinno, 2013] and has been linked to an approach to effectively address end-user needs during system design and evolution. End-user needs evolve as the end-users use a specific technology meaning that the system developers need to support the evolution of the systems as well so as to adapt and address the evolving end-user needs. In a similar way, expert-users' needs evolve as well.

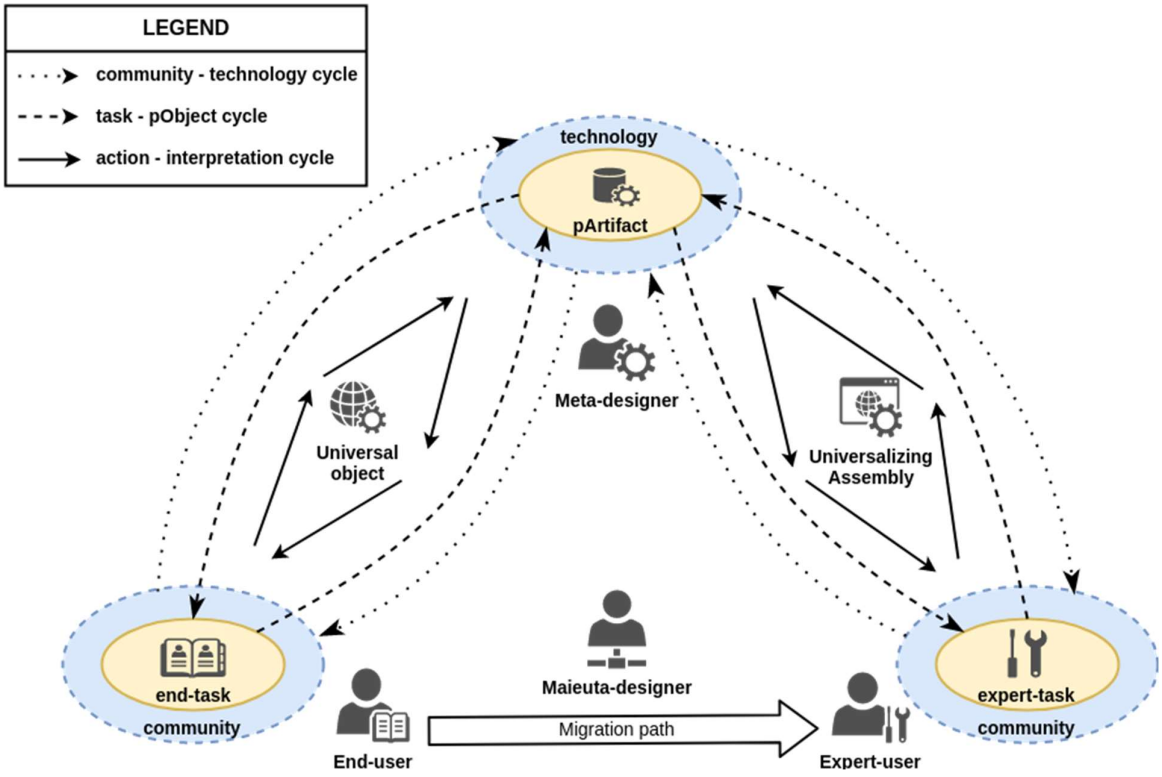

Figure 23: Main components of the PerFECt framework.

3.2. The co-evolution phenomenon around universal objects

Let us see in more detail the co-evolution phenomenon around universal objects as depicted in the left part of Figure 23:

1. At the higher level, there is the community-technology co-evolution cycle meaning that that the relationship of people and technology is dynamic and evolves as the people working with a certain technology evolve and learn how to do certain things and as a result of this evolution their expectations and conceptualizations with respect with the available technology change and give rise to evolution of the technology itself that triggers further evolution of the community of end-users. This higher-level co-evolution cycle entails the motives of people, i.e., their needs and how they satisfy their needs via their activities. By offering new interaction possibilities, technologies employed change end-user habits and this means that the social and work organization evolves with the use of certain technologies.
2. At a lower level, there is the task-artifact co-evolution cycle that refers to the tasks that end-users are able to do with a specific version of a system and the

corresponding artifacts that they manipulate or use during their work. Consequently, at this level, end-users articulate their behaviour towards certain goals that form a cause-effect chain in order to pursue the motives of the upper level. Furthermore, the use of certain artifacts to support end-users' tasks suggest in many cases new possible tasks and these new tasks mean that new artifacts should be created.

3. At the lowest level there is an interaction cycle during which end-users are expected to do certain operations to effectively use the available technological features. Such interactions call for a certain interpretation of their actions in order to be able to effectively use the available features. This lowest level cycle could thus be conceptualized by successive materialization and interpretation, representing meaningful actions that support and trigger the upper levels of the co-evolution phenomenon.

At the centre of the three end-user cycles (left part of Figure 23) the PerFECt framework suggests the concept of universal object, a concept that generalizes the concept of software and it is based on the concept of universality as already presented. Such universal objects, can be the result of the work of expert-users, as will be described next, to address the evolving needs of end-users within the wider context provided by the PerFECt framework.

The co-evolution cycles that address the expert-user role (right part of Figure 23) are structured around the concept of universalizing assembly. This is a complementary concept to the concept of universal object. A universalizing assembly is essentially a synthesis of performative artifacts (pArtifacts) that enables the creation of universal objects supporting the task of end-users. Consequently, the task of expert-users is to enable this universalization of plain objects by exploiting the available tools in the form of performative artifacts (pArtifacts) to account for the incorporation of the idea of performativity in digital technologies.

Performativity underlines the relationship between humans and the artifacts they create that is triggered by social interaction and continuously recreates the bonds that keep the society as a whole. [Niedderer, 2007] offers an interesting concept to capture this idea and link to purposeful and mindful use of physical objects: the concept of performative object, which is a special type of design object to facilitate mindful awareness of the physical and symbolic social actions and their consequences. Considering that performative objects are design objects, the framework presented here uses the term performative artifacts in a broader sense: all artifacts involve a certain level of performativity that is usually captured by their

affordances i.e., clues about how an object should be used, typically provided by the object itself or its context. However, this latter term, does not explicitly refer to mindfulness as a target during the design process. In this respect, the term performative artifact, is used here to capture the idea of intentional design for social interaction, to create and sustain social bonds and call for symbolic social actions that recreate the social contexts within which we live in. To conclude, the three levels of the co-evolution cycles in the case of the expert-users, are the following:

1. At the higher level, the community-technology co-evolution cycle captures the dynamics of the relationship of people and technology using pArtifacts to enable the universalization of certain objects. As expert-users evolve and learn how to do certain things (i.e., providing tools in the form of universal objects to end-users) their expectations and conceptualizations with respect with the available technology change and give rise to evolution of the technology itself that triggers further evolution of the community as a whole.
2. At a lower level, there is the task-artifact co-evolution cycle that refers to the tasks that expert-users are able to do with a specific version of a system and the corresponding pArtifacts that they use to create/extend the universalizing assemblies that constitute the target of their work. It is important to note that expert-users provide the ground for end-users to work within a cause-effect framework (this is captured by the idea of universalization). The evolution of expert-users is related to the evolution of end-users as well taking into account that the role of expert-users is to support the evolving needs of end-users. To this end, there is a critical contribution of maieuta-designers that facilitate the articulation of end-user needs and their effective communication to the expert-users.
3. At the lowest level there is an interaction cycle during which expert-users are expected to do certain operations when they are engaged in the use of the technological features offered by meta-designers. Such interactions call for a certain interpretation so that expert-users are able to use the underlying technologies in an effective way. At this level, the interaction between the expert-users and the underlying technologies are taken without direct reference to their social context as successive rounds of materialization and interpretation of certain actions that support and trigger the upper levels of the co-evolution phenomenon.

As a final note on how the PerFECt frameworks can enable the use of digital technologies in rich social contexts and providing the means to promote learning and creativity, the idea of de-design should be stressed. According to 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 not to be considered as an anti-theoretic or mindless stance, but rather a disciplined inaction that is intentional, thoughtful, purposeful, and impactful. De-design contrasts the positivistic attitude of traditional design in recognizing that a designer may well unhinge the effective ways people work and act and make impossible for them to exploit opportunities to create more diverse, tailored, and appropriate processes in situ than those designed at the abstract level of traditional design process, neglect different interpretations of the information that need to be considered in user practices, and hence also disregard the creative power of ambiguity. In the next chapter, specific example will be shown of how de-design can be employed to invent new ways of interacting with digital artifacts and offering new uses and enhancement of learning and creativity platforms and tools.

3.3. Chapter summary

This Chapter presented the Performative Framework to Establish and Sustain Onlife Communities (PerFECt) based on important concepts such as the concept of performativity that emphasizes the fact that human behaviour can be understood and analysed by assuming that all human practices are performed so that actions can be seen as a public presentation of self.

To summarize, an onlife community within the PerFECt framework captures the structure that is imposed by the four user roles of the framework: end-user, expert-user, maieuta-designer and meta-designer along with the artifacts, tools and even underlying physical objects to account for situations where technologies are embedded into an underlying reality. In other words, the adoption of the concept of community emphasizes the fact that all these user roles, through their interactions within the two co-evolution processes, create a bigger aggregation of humans that engage with other humans as well as with machines and natural entities in mindful interactions, thus creating the social contexts described as onlife communities to account for hyperconnectivity as well.

CHAPTER 4. RESEARCH REALIZATION AND IMPLEMENTATION

This Chapter elaborates on how the PerFECt framework can be employed in certain situations to establish and sustain onlife learning communities while the next one presents the corresponding experimental results that showcase the effectiveness of the framework and validate the software developments and learning designs presented here.

In the following sections of this chapter, the following research realization and implementation cases are presented:

- The case of using Coursevo for Computer Science learning communities: These are results on realization of the py4hs community consisting of a training programme followed by Computer Science teachers that were subsequently guided to establish and support computer coding clubs.
- The case of digital cultural heritage installations via the use of eShadow as a tool to offer informal learning experiences using mixed reality approaches that combine digital technologies and traditional arts and by employing a specialized tool to digitize puppets that are created on paper.
- The case on using ViSTPro for learning communities in history teaching. The ViSTPro platform as well as its learning effectiveness are addressed in several situations when students watch spatiotemporal scenarios modelling historical events as well as when students become authors themselves to develop their own spatiotemporal scenarios. This kind of usage is based on the concepts and approaches drawn from the PerFECt framework and subsequent experimental results demonstrate the superior effects when students become expert-users in the terminology of the PerFECt framework.
- The case of learning communities on principles of Computer Science following the work on learning communities on Coursevo. This additional work guided by the PerFECt framework aims to provide engaging learning experiences in a very important topic related to computer programming as well as to computer hardware: the binary system, as one of the core mathematical concepts in Computer Science.

In the following sections the above-mentioned research realization and implementation is presented in detail.

4.1. Computer Science learning communities with Coursevo

Coursevo has been used in several projects and initiatives that aimed at establishing Communities of Practice within professional training programmes including projects that targeted teacher training [Pappas et al., 2017]. By employing the PerFECt framework, it was possible to better design and validate its use in such interventions and, furthermore, identify a number of important enhancements that address elements of gamification as a means to offer more engaging learning experiences. The specific community that was designed using the PerFECt framework concepts and mechanisms is py4hs – Python for High School, a training program that targets Computer Science teachers in secondary education to enable them offer more engaging programming courses for their students inside and outside Greek schools [Moumoutzis et al., 2017a; Moumoutzis et al., 2021a].

4.1.1. Building communities to promote coding

An initial exploration on the potential of programming in education from the perspective of providing opportunities for students in primary and secondary education develop their own coding projects for learning was undertaken during the pSkills project (October 2009 – September 2011) [Ovcin et al., 2011]. The target was to build a community of primary and secondary teachers, mainly Computer Science teachers, to exploit modern educational programming languages in their courses [Smith et al., 2010]. The approach adopted could be described as a teacher training framework rather than a learning framework. This proved to be rather limiting in exploiting the full potential of the approach. However, the fact that most of the participants were Computer Science teachers made it possible for them to proceed very quickly with the appropriation of the underlying technologies and enter the classrooms successfully. Other teacher specialties faced significant problems and were unable to do the same.

The pSkills teacher training activities were structured as a three-step process: (a) initial training and community building workshops with over 400 participants in total; (b) pilot workshops, one in each one of the four participating countries with over 40 participants in Greece, Austria, Italy and Estonia; and (c) the pSkills Summer School, a one-week intensive training event with 10 participants. In all these phases, a training portal was used to host all materials and provide communication between the participants before and after the events, thus providing the basis of a blended-learning approach. Though its training activities, the project raised awareness and provided insight and inspiration through indicative learning

scenarios targeting courses in primary and secondary education. Furthermore, it offered materials to enable teachers guide their students through an engaging learning process during which they develop their own coding projects.

The focus of the training activities was on developing digital games using an appropriated educational programming language [Smith et al., 2010]. This process starts from the inception of a game employing brainstorming. The game design is facilitated by storyboards while testing by evaluation rubrics. Game development was based on Scratch [Maloney et al., 2010] and game distribution on the Scratch community site. The offered materials included:

- Brainstorming guidelines and selected Scratch projects to provide inspiration;
- Storyboarding templates in the form of slide presentations;
- Game skeletons in the Scratch platform [Maloney et al., 2010] along with introductory hands-on tutorials to enable game development;
- Worksheets for step-by-step development of simple games and ideas for their extension;
- Rubrics for peer assessment containing criteria regarding playability, usability and user experience qualities; and
- Links to Scratch community site pages with important information and additional links to related resources on the web.

The ultimate goal of the pSkills project was to foster a systemic change beyond the mainstream focus on the so-called IT literacy towards IT fluency. IT literacy is linked to surface technical skills related to office automation applications (word processing, spreadsheets, presentations etc.) and communication tools (email, web browsers etc.). IT fluency focuses on sufficiently foundational material with "staying power" to promote understanding of computers and their applications and the ability to fully exploit the potential of modern systems and computer applications through programming.

Towards the end of the implementation period of the project, an explosion of interest of Computer Science teachers on its themes was observed. Over 250 teachers participated in the local workshops held in Crete, Greece. Most of them started to apply the ideas into the classrooms and, more importantly, within the context of creative projects with their students. Following a viral pattern, the use of Scratch was soon spread in other schools and the student projects developed were enough to justify a first attempt to organize a Student's Digital Creativity Fest in 2011. Starting from Crete, this annual event has now reached most of the

Greek regions with more than 7000 participating students, around 1000 teachers and more than 400 schools. These developments had a notable contribution in firing a positive change in the national education system: In the new curricula for Computer Science at secondary education and the supporting textbooks, there is now an explicit focus on online learning games [Luchev et al., 2020; Makris et al., 2016; Márkus et al., 2018], game design, game development and the use of appropriate platforms such as Scratch [Maloney et al., 2010] and AppInventor [Wolber et al., 2011] that are based on the so-called block-based programming paradigm that has also been explored within the context of tertiary education [Kyfonidis et al., 2017]. This observed impact justifies our decision to adopt a bottom-up approach and provides evidence that small changes in everyday learning activities in the classrooms can trigger systemic changes as well.

Following the successful impact of the pSkills project, our focus expanded beyond Computer Science education to include other domains including non-formal and informal education. The opportunity for this was given within the context of the ALICE project [Moumoutzis et al., 2014] and its decision to include games as a creative language to be adopted by adult trainers along with Music, Digital Storytelling, and Children Narratives. ALICE targeted adult trainers with the aim to enable them design and implement intergenerational creative learning environments. The project designed and piloted a graduate programme for educators in Greece, Italy, Switzerland, UK and Romania. The programme was offered through a learning portal and included face-to-face sessions as well in each one of the five participating countries, thus adopting a blended-learning approach. The training consisted of six learning units and a final project. One of these learning units targeted digital games and a number of participants adopted games as a creative language to work on their individual projects during which they designed and implemented learning activities where adults and children they were invited to learn together in creative ways. The term gaming-literacy was adopted to signify a step towards the accommodation of a new way of thinking, working, collaborating, teaching and learning, as initially introduced by Zimmerman [2009].

The gaming literacy learning framework offered the opportunity to the ALICE participants to address topics on three levels:

- Understanding and evaluating games through critical analysis that promotes the acquisition of the language pertaining to technology, genres, values, stereotypes, production processes of games and their learning value.
- Critical consumption through reflection on gamers' behaviour in order to better exploit free time, foster learning and enrich human relationships. Time spent for

video game playing, game preferences, social aspects of game play, type of entertainment and learning offered are issues related to this critical self-reflection.

- Crafting digital artifacts using modern tools that enable non-technical people to invent their own video games and be engaged in their realization by creating rules, characters, narratives, graphics, audio, and animations.

4.1.2. fThe py4hs initiative: foster creative programming with Python

A third step towards supporting educators on the integration of new technological tools in their teaching practices emphasizes on digital skills and creative learning. This time, the focus is on general purpose programming language, not an educational or creative language as it was the case in the pSkills and the ALICE projects. In particular, the programming language adopted in this case is Python and its use as a first programming language for novices taking into account the parallel developments in the school curricula in Greece and the need to support Geek Computer Science teachers on their use of the Python language within a pedagogical framework that promotes active learning within engaging learning scenarios in coding clubs. Selecting coding clubs [Smith et al., 2014] as the pedagogical framework of our approach incorporates the positive prior experience on promoting coding in formal, informal and non-formal learning settings in pSkills and ALICE projects. This initiative was partially funded by Google CS4HS programme (http://www.cs4hs.com/).

A special course space has been created in the Coursevo community portal. In this course space, the members of the community form local study groups that are supported using the workspaces feature of Coursevo (Figure 24). A workspace essentially organizes teams of course participants following specific patterns of interaction and collaboration. Furthermore, it offers team discussions employing all the communication services of Coursevo (chat rooms, forums, video conferencing etc.). This way each team can work in a separate space while the community as a whole uses the central communication services of the course. py4hs effectively demonstrates the flexibility of Coursevo and its capability to support inner structure in a community via teams or workspaces (Figure 25).

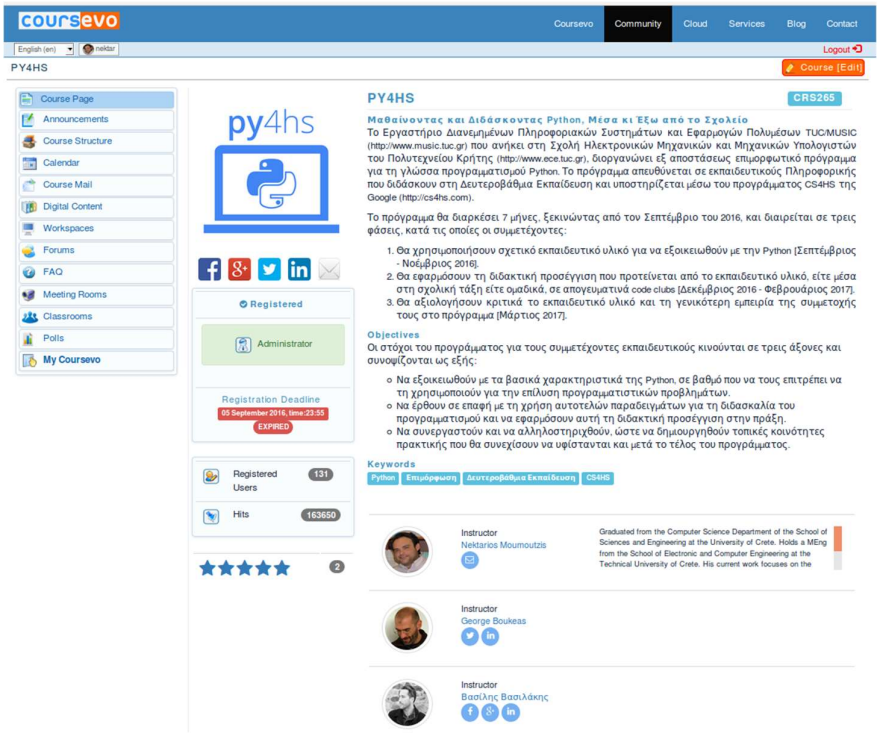

Figure 24: The Coursevo course supporting Greek Computer Science teachers that are adopting the Python programming language in the courses they offer in lower and upper secondary education.

Figure 25: An example of Coursevo workspace. The workspace enables the formation of teams from course participants, provides access to useful reference material, presents assignments and deadlines and provides the necessary collaboration tools (forums and virtual meetings).

The design of the training programme was based on the principles of social constructivism [Kukla, 2000]. Initially, participants explored the course material and develop Python skills, as they delved into the programming projects and tackled the assignments. The

assignments, meant to induce structure on the learning process, were implemented in groups exploiting the special features of the underlying learning platform. There were no lectures on Python programming. The course facilitators served as peer advisors, guides and coordinators. Following this initial phase of getting familiar with the Python language and the proposed pedagogical methodology, participants were asked to apply the knowledge and skills they have acquired, in workshops or coding clubs for their students, exploiting scenario-based pedagogical approaches. In this context, they eventually composed their own training material and developed strategies for cooperating with other participants from their regional group, learn from and support each other. In other words, the were facilitated by their trainers acting as maieuta-designers in the PerFECt framework terminology, to evolve from end-users to expert-user, i.e. from being able to use the Python language for themselves, to enable their students master the language and work on engaging projects. There was also a strong element of reflection, self- and peer-evaluation at the final phase of the project. As already stated, an important aspect of the training programme was its blended-learning approach to promote collaboration among Computer Science teachers in many locations parts of Greece including several remote areas.

4.1.3. Structure of the py4hs programme and evaluation

The program consisted of three phases. In the first phase (3 months) participants studied, explored and evaluated the course material, familiarizing themselves with Python and the programming projects approach. In the second phase (3 months) participants implemented the course material in coding clubs. The final phase (1 month) involved extensive reflection and evaluation of the course.

The kick off was done via a teleconference that presented the overall structure and objectives of the training programme. Every month there was a live online session with the course facilitators, where participant groups had the opportunity to make presentations or engage in structured discussions. During the course, participants also communicated via discussion forums, online chat rooms and videoconferencing facilities offered by the Coursevo platform. Participants worked together in regional groups and posted their assignments online, each group creating a portfolio that was reviewed by their peers. All results were documented and shared in the form of adaptable learning scenarios (i.e., project-based scenarios and/or lesson plans) that referenced teaching objectives of the Greek Computer Science curricula and were organized in a digital repository that is available to all

Computer Science teachers through a Creative Common license for further reuse after the end of the project.

4.2. Digital cultural heritage installations to promote informal learning

eShadow, as already presented, has been used for several years in many schools to promote project-based learning combining arts with a wide range of school topics ranging from language learning, history and humanities to mathematics, physical sciences and Computer Science [Moumoutzis et al., 2018; Moumoutzis et al., 2017b; Moraiti et al., 2016; Moumoutzis et al., 2021b; Hatzigianni et al., 2021]. The creation of such artworks with eShadow corresponds to a project-based process with three distinct stages that is generic and refers to any media artwork such as movies, digital games, interactive animations etc. In particular, these stages are the following: Preparatory actions (pre-production), subsequent development (production) of the main materials of the artwork, and final assembly (post-production).

One of the most engaging phases in this creativity workflow refers to the development of the puppets that will be used in a digital story. Note here that eShadow offers several ready-made digital puppets to facilitate rapid development of digital stories. In many cases, however, the themes of the stories or the educational objectives of the teachers open up the opportunity to engage in the creative process of developing new puppets. To facilitate this process a digital puppet authoring tool was initially developed for end-users and used in combination with eShadow [Moraiti et al., 2016]. Furthermore, an open architecture was adopted in the representation of the computer files corresponding to digital puppets so that external image processing tools could be used [Moumoutzis et al. 2018] by expert-users that wish to create digital puppets that do not conform to predefined forms.

A new need emerged during learning interventions undertaken in pre-primary education [Hatzigianni et al., 2021]. In particular, teachers participating in these learning interventions, during their interactions with maieuta-designers during training workshops asked for a way to facilitate digitization of paper-made shadow puppets using a simple mobile app. The whole process was organized on the basis of the PerFECt framework.

Before elaborating more on this app and its use, it is necessary to provide some details regarding the structures of eShadow puppets and their representation. Their structure is very similar to the structure of traditional shadow theatre puppets. In particular, they consist of two or more parts which are joined together by joints as shown in Figure 26.

Figure 26: Examples of shadow theatre articulated puppets. Red circles represent joints that connect puppet parts. The puppet on the left has two-parts with one joint while the puppet on the right is more complex having four parts and three joints that connect them.

The female puppet on the left of Figure 26 consists of two parts: the top and bottom of its body which are connected with only one joint. The male puppet to the right of Figure 26 consists of four parts: The main body, waist and two legs. There are three joints: one that connects the main one body with waist and two that connect the waist with left and right legs respectively. These two typical cases (with four or two parts) capture the structure of most puppets of traditional Greek shadow theatre. The corresponding parts of each one of these two puppets are shown in Figure 27 below:

Figure 27: Synthesis of shadow theatre articulated puppets. On the left, an example of a two-part puppet is shown with its constituent parts and the corresponding joint anchors (red circles) in each part. On the right, an example of a four-part puppet is shown. In both cases the red rectangles represent the boundaries of areas used to place each constituent part.

To synthesize such puppets, one has to develop their parts in certain material, cut them and join them together at the correct joint positions. The female puppet consists, as mentioned, of two parts which are associated with one joint. These two parts are illustrated separately in Figure 27 as well as their connecting points (joint anchors) to form the joint of the puppet. The selection of connection points, especially for the bottom part affects not only the aesthetics of the puppet but also its behaviour during handling due to the force of gravity. Wrong point selection will have as a result the lower part of the puppet to be unbalanced. Consequently, puppets are tested before the position of joints is fixed.

4.2.1. Extending eShadow with ePuppet

Employing the PerFECt framework, its concepts and user roles, to better understand the use of tools such as eShadow can be put within a wider context that accounts for the rich social interactions that could be promoted towards the establishment of onlife communities. In particular, eShadow can be considered as a representative tool on how a community can be established (in the field of cultural heritage and learning) that brings together:

- **Software developers** supporting the software and providing further enhancements to address the needs of the users.
- **Puppet creators** that prepare materials, such as puppets, that can be used to support other creators, those that use the platform to develop animations and stories on various themes.
- **Storytellers** that use materials offered by creators to develop digital stories.

Using the user roles' terminology introduced in chapter 3, the above categories of participants in an eShadow-based community can be reframed as follows:

- Software developers that support eShadow and implement further enhancements are the meta-designers of the PerFECt framework. As meta-designers, they are expected to offer an open system that can evolve by its users as co-designers. To enable this, eShadow offers an open representation based on json files to enable the creation of content such as digital puppets.
- Puppet creators that develop digital puppets are what the PerFECt framework describes as expert-users. They address the needs of end-users using the open system capabilities offered by meta-designers to develop new re-usable materials.
- Storytellers that use eShadow to develop digital stories are what the PerFECt framework calls end-users. They essentially use the creations of expert-users in the

form of universal objects, i.e., digital artifacts that exhibit a certain behaviour that simulates the behaviour of traditional puppets with all the corresponding causality stemming from the presence of gravitational forces.

Apart from the above-mentioned roles, which are directly related to eShadow as a tool simulating and extending a traditional creative environment, the PerFECt framework introduces yet another (fourth) user role: maieuta-designers. This role has a significant contribution in framing and supporting an onlife community addressing the social conditions for supporting the meta-task of expert-users and the transition from the end-user role to the role of expert-user. This transition and support of expert-users' tasks are essentially a learning process that takes place within a social context (i.e., the community of users). In the case of eShadow, a typical function of maieuta-designers is to organize workshops where eShadow users can be trained on how to understand and use the representations of digital puppets, how they can use existing image processing tools to develop their own digital puppets [Moumoutzis et al., 2017b] or remix existing puppets [Moraiti et al., 2016] to meet their particular needs.

After successfully implementing this approach in many primary and secondary schools, with very interesting results showcasing the educational potential of such technologies and their importance in reconnecting young generation with their cultural heritage, the need to develop traditional puppets before digitizing them was identified as a learning activity with significant pedagogical value, especially for little children that they need to develop their fine motor skills. Furthermore, there was a need to support users without skills and available time to engage in the process for preparing digital puppets using image processing software. Using the terminology of the PerFECt framework, this was a situation when maieuta-designers collaborating with end-users, revealed a need to communicate with meta-designers to ask for the development of a new generic component that will allow end-users adopt a new way of work in order to become expert-users, i.e., puppet creators. The result of this intervention was the design of ePuppet, the mobile application for facilitating the digitization of two- and four-part puppets. Assuming that a traditional puppet has already been created, its parts can be put on a flat surface with a constant colour background so that the ePuppet app can be used to take a photo of the parts after appropriate aligning them with predefined templates, one for two-part puppets and one for four-part puppets (Figure 28).

Figure 28: Digitization of shadow theatre puppets using ePuppet. The parts of the puppet are put on a flat surface with a constant color background (e.g., on a sheet of paper). The parts and the mobile device are moved as needed so that the parts are framed within the red boundaries shown in screen overlay and the joint anchors (red circles) are positioned correctly. Then, a photograph is taken that is transformed by ePuppet into a correct digital puppet representation.

The detailed steps followed by a user using ePuppet [Moumoutzis et al., 2019a; Moumoutzis et al., 2021b] are shown as a sequence of screenshots in Figure 29. In particular, initially the user provides a name for the new puppet and selects the corresponding template (if it will be a two- or four-part pup-pet). Next, the user activates the camera of the mobile devices and overlays a guiding template as a slide that is placed over the camera's image. Moving parts of the pup-pet as well as the devices left to right, up and down and back and forth full alignment of the points is achieved connecting the joint anchors (red dots) to coincide with the connection points of the real puppet parts. After aligning the parts, the user selects the appropriate control to make a photo of the puppet. In the next screen, the user is able to adjust the background colour levels to enable its automatic removal to clear the surrounding area of the puppet parts. After that, the application creates all necessary files so that the digital version of the puppet can be used in eShadow and lists the new puppet in the mobile app folder area.

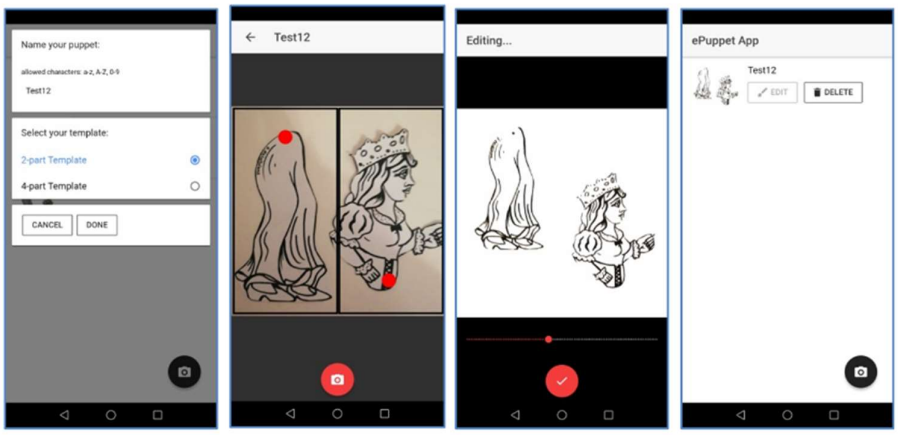

Figure 29: Steps for creating a digital puppet with ePuppet mobile app.

In particular, to create a digital puppet with ePuppet mobile app, the user follows four steps:

(a) gives a name to the puppet and selects a template to use;

(b) takes a photo of the physical parts of the puppet;

(c) adjusts background colour levels to automatically remove the background; and

(d) stores the files created.

The final output of this process, is the digital representation of the puppet. Two files are created:

- An image file (sprite sheet) with all the constituent parts of the puppet.
- A json file with the information about the placement of the constituent parts in the sprite sheet as well as the position of joint anchors.

Figure 30 below depicts the json file and the corresponding sprite sheet for the two-part puppet presented above. The representation of the four-part puppet is analogous.

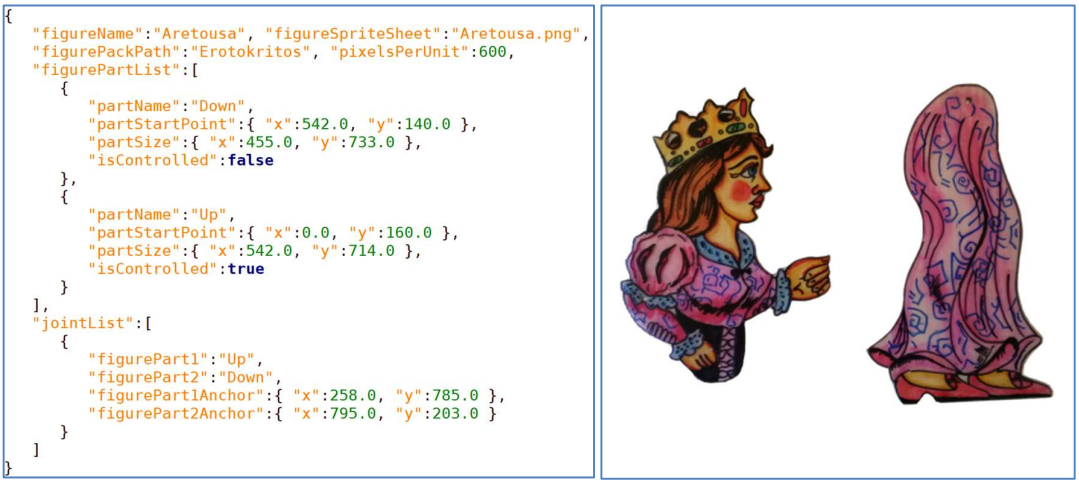

Figure 30: Digital puppet representation. On the left, the json file describing how the puppet is com-posed of different parts, where these parts can be found in the corresponding sprite sheet and where the joint anchors are placed. On the right, the corresponding sprite sheet is depicted.

4.2.2. Drama-based learning experiences combining digital technologies and traditional arts

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 [Moumoutzis et al., 2022a; Moumoutzis et al., 2022b] that are categorized within the overall framework of digital cultural heritage systems [Dochev et al., 2019]. This innovative use of eShadow relies on this close connection of learning and drama [Moumoutzis et al., 2022c]. 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 centre of the learning process.

When children are acting, they are essentially end-users (in the terminology of the PerFECt 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, analysing 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 (Figure 23) to account for any kind of object that can follow well-known rules and corresponding constellations of such objects.

This approach goes informed by the PerFECt framework goes beyond the production of digital stories with eShadow 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 digital shadow theatre 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. Two specific examples of such installations (trials) have been elaborated 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.

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 Figure 31) to offer a mixed reality learning experience that goes beyond the passive attendance of a pre-made 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.

Figure 31: Photos from the initial use of eShadow with mixed reality technologies during Science and Technology Day event at the Technical University of Crete.

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 (Figure 32) addressed the Battle of Crete that took place on late May 1941 when German troops invaded the island within the context of the German invasion against Greece.

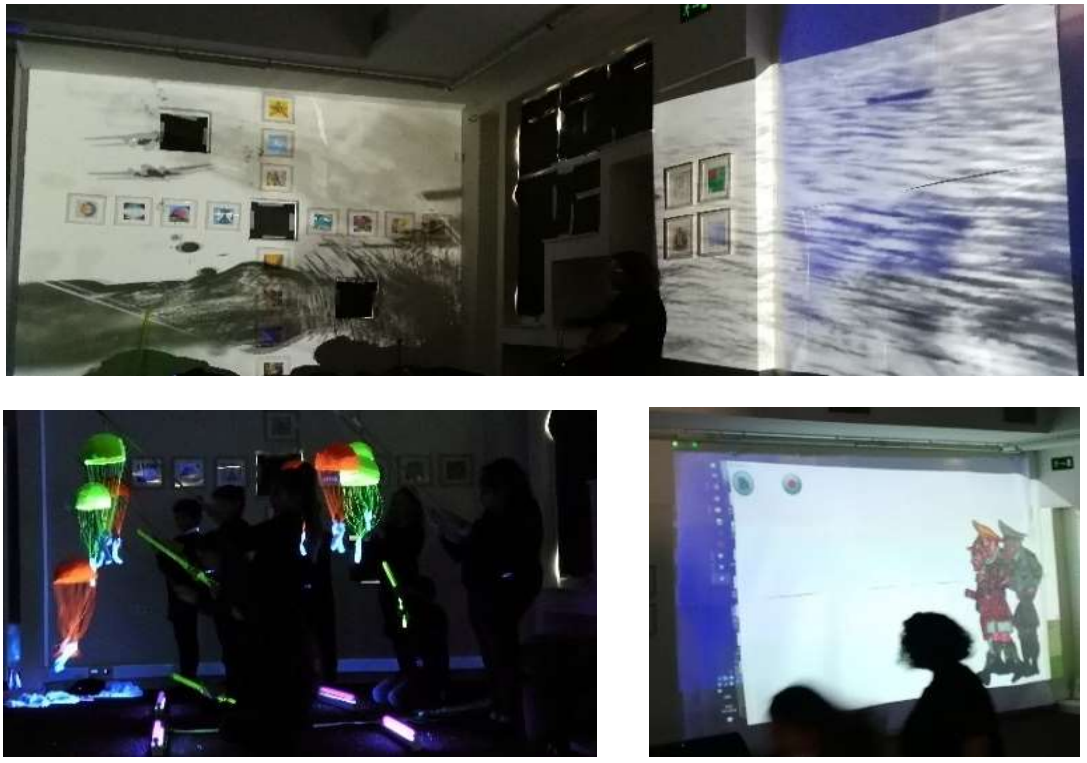

Figure 32: Photos from the first installation related to the historical events that took place during the Battle of Crete in World War II.

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 ViSTPro with detailed maps of the battle on top of Google maps [13]. After this introductory phase, the visitors entered the installation room. The installation used projection 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 et al., 2008]. In total, 14 questionnaires were filled. The results are presented in the next chapter and compared with the results from the second installation described next.

The second installation (Figure 33) 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.

Figure 33: Photos from the second installation related to the historical events that took place during the Greek Revolution of Independence in the island of Crete.

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.

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. 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 same questionnaire as in the first installation (i.e., the Usability Evaluation Questionnaire -UEQ). In total, 15 questionnaires were filled. The results are presented in the next chapter and compared with the results from the first installation.

4.3. Using ViSTPro to establish and sustain learning communities in history teaching

The ViSTPro platform presents features that can be analysed via the PerFECt framework concepts: It fosters active explorations of spatiotemporal processes as rich scenarios prepared by educators and offered to learners through a web-based player. Playing a scenario involves graphic representation of formations, movements and interactions on Google Maps. This way, learners interact with graphical entities in an intuitive manner. In contrast, traditional ways of learning depend upon a painful and difficult process to develop abstract mental images with no real-world direct mapping. Additionally, the platform enables learners to make questions and receive personalized explanations. Therefore, learners can watch the representation of the processes' evolution in space and time, and actively intervene. Furthermore, ViSTPro can offer new learning opportunities to leaners if they are enabled to use the functionality initially offered to teachers (scenario authoring). This means, the students can be supported to act as creators of their own scenarios, thus becoming expert-users, in the terminology of the PerFECt framework. This is an option that clearly demonstrates the applicability of the concepts of the framework to foster learning communities and facilitating a transformation process for end-users to become expert-users.

Employing the concepts and user roles of the PerFECt framework the use of software platforms such as ViSTPro can be put within a wider context that accounts for the rich social interactions that could be promoted towards the establishment of onlife communities. In particular, ViSTPro can be considered as a representative tool on how a learning community

can be established in the field of cultural heritage in general and history learning in particular [Paneva-Marinova et al., 2020a; Paneva-Marinova et al., 2020b] that brings together:

- software developers supporting the software and providing further enhancements to address the needs of the users,
- teachers that prepare animations of historical events, i.e., scenarios representing the corresponding spatiotemporal processes in ViSTPro along with semantic maps and digital materials explaining the details of the animated events, and
- students that use the scenarios prepared by teachers to learn about the animated historical events in a personalized manner.

Employing the user roles described by the PerFECt framework, the above categories of participants in a ViSTPro-based learning community can be presented as follows:

- Software developers that support ViSTPro and implement further enhancements to address the needs of teachers and students are the meta-designers of the PerFECt framework. As meta-designers, they are expected to offer an open system that can evolve by its users as co-designers. To enable this, ViSTPro offers several capabilities to use various media types, thus offering the capability to integrate digital materials coming from a diverse range of sources. Furthermore, it offers a flexible authoring environment as a means to support expert-users that wish to develop new scenarios, thus animating new historical events or providing alternative visualization for events that have been already described with existing scenarios. Finally, ViSTPro is also open with respect to creating semantic maps, i.e., providing semantic information about human-made objects and physical formations on top of Google maps. Semantic maps can be used within scenario playback to provide important semantic information that allow for deeper understanding of the animated events.
- Scenario authors (e.g. teachers, but also historians or even students that wish to engage in activities to apply their historical knowledge in developing ViSTPro scenarios) that create scenarios in ViSTPro are what the PerFECt framework describes as expert-users that address the needs of end-users using the open system capabilities offered by meta-designers to develop new components in the form of universalizing assemblies of digital objects that can then be used by end-users in their learning tasks. This is indeed what teachers are expected to do with ViSTPro: Using its features to develop scenarios for spatiotemporal processes that

represent important historical events. These scenarios capture knowledge about the corresponding historical events along with pedagogical content knowledge so that effective scaffolding can take place that will enable students develop their historical knowledge within a rich learning environment supporting social interactions and use of digital tools to make complex historical events more understandable.

- Students that use ViSTPro to see the animations of the scenarios (using its playback features) are what the PerFECt framework calls end-users. They essentially use the creations of expert-users in the form of universal objects, i.e., digital artifacts that represent and present causality within and across historical events to make the historical knowledge more understandable and justifiable.

Apart from the above-mentioned roles, which are directly related to ViSTPro as a tool supporting authoring and playback of spatiotemporal processes, the PerFECt framework introduces yet another (fourth) user role: maieuta-designers. This is an important role that has a critical contribution in framing and supporting an onlife community. In particular, maieuta-designers are addressing the social conditions for supporting the meta-task of expert-users and the transition from the end-user role to the role of expert-user. This transition and support of expert-users' tasks are essentially a learning process that takes place within a social context (i.e., the community of users). In the case of ViSTPro, as it will be described in the next chapter presenting the evaluation of the platform, the need for maieuta-designers emerges very naturally from the use of the tool in actual learning situations when students express their desire to develop their own scenarios (i.e., go beyond the end-user role toward the expert-user role) and thus learn deeper about the historical events they study. These enhanced learning results are documented by the actual evaluation following a controlled experiment approach in actual school settings presented in the next chapter.

Furthermore, teachers also express their belief that students can better learn when they are engaged in expert-user role tasks, thus creating their own portfolio of digital artifacts that can help them express their creativity and offer insights and motivation to find more information about the studied historical events using digital resources. Consequently, this approach is directly related to inquiry-based learning approaches and, more importantly, to constructionism: the learning theory that claims that learners learn better when they construct things [Kafai, 2018].

4.4. Establish and sustain learning communities on principles of Computer Science

Following the work on learning communities on Coursevo, further work was undertaken guided by the PerFECt framework to provide engaging learning experiences in a very important topic related to computer programming as well as to computer hardware: the binary system, as one of the core mathematical concepts in Computer Science. The work reported next demonstrates once more the applicability of the concept of de-design and the effectiveness of the PerFECt framework for the invention of innovative learning designs that can exploit traditional arts to promote engagement and deep learning.

The result of this work is the Human Calculator theatrical game. This game addresses the need to introduce participants to the binary system as the basis of modern digital computers by offering an alternative learning path beyond mainstream approaches that heavily rely on a math-based presentation of the binary system and possibly use electrical/electronic circuits as learning tools. The game not only allows participants to understand how to convert numbers in binary, but also enables them to explore strategies (i.e., algorithms) to perform arithmetic calculations.

The Human Calculator theatrical game relies on the close connection of learning and drama presented in Chapter 3 of this thesis. In particular, it provides a creative environment where participants can either be actors or members of the audience, in a spiral process, and have moments of experiencing phenomena pertaining to the binary system and how binary representations of numbers interact with each other, with moments of reflection, abstraction and, subsequently, planning for further action on the basis of the theatrical game that is at the centre of the learning process.

The theatrical game design captures and uses the main components of the PerFECt framework. When participants are acting, they are essentially end-users (in the terminology of the framework) that just need to follow certain rules with consistency. When participants are part of the audience guided by a facilitator (this is the maieuta-designer in the PerFECt framework) to explore and gradually develop their skills in manipulating the binary representation of numbers so that they could make arithmetic calculations, they are essentially in transition to become expert-users, as the PerFECt framework suggests.

A very interesting aspect on how the Human Calculator theatrical game 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] as it was the case for eShadow already presented. Recall that 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, the Human Calculator theatrical game, 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. This way, the game uses the human body to enact the operation of circuits implementing a binary calculator. Extensions of the basic theme of the game, can give rise to alternative rules so that the participants could creatively explore new situations and representations. In summary, the Human Calculator theatrical game, generalizes the notion of universal objects and universalizing assemblies (Figure 23) to account for any kind of object that can follow well-known rules and corresponding constellations of such objects.

Finally, the Human Calculator theatrical game closely follows the idea of theatrical workshops as a learning environment. In particular, it builds on the ideas of the Mathemart methodology and resembles the drama-based learning activities proposed by this methodology. Mathemart was created by Maurizio Bertolini in 2011 and employs the Social Community Theatre (SCT) methodology [Rossi Ghiglione, 2013; Jones et al., 2013; Schinina, 2004]. It addresses ways to bypass the fear of Mathematics and offers an engaging and playful way to deal with mathematical concepts of arithmetic, geometry and algebra. According to the details that can found at http://www.socialcommunitytheatre.com/en/projects/mathemart/ *"the SCT methodology is used to get immersed in the game of mathematics by means of an overall approach involving mind and body, inborn creativity and involvement. The theatrical setting conveys a creative, playful and trusting atmosphere enabling students to freely explore without judging what they are doing. It encourages learning from mistakes in a sequence of trial and error. If a student is scared of mathematics, he cannot allow himself to make mistakes. His fear freezes his brain and logic skills and he cannot think straight. But it doesn't mean that he is not really able to. A good theatrical setting can help students to forget that fear and to enjoy the possibility of learning by playing. In fact, within Mathemart training we*

do not talk about mathematics, we experience the subject by playing with mathematical relations and rules. Only after experiencing a concept, we will formalize it."

Following this methodology, the Human Calculator theatrical game is based on role playing and subsequent reflection on the phenomena that emerge [Moumoutzis et al., 2020a; Moumoutzis et al., 2020b]. Very simple rules are given to the participants to create an n-bit binary calculator using their bodies. To start the game, the facilitator splits the participants into two groups. One group (let us call it, the actors) enacts the Human Calculator while the other group (let us call it the audience) observes the operation of the Human Calculator explores its properties and reflects on the phenomena observed. The critical support of the facilitator is a prerequisite for the successful implementation of the activity. To enable the active participation of all, the participants alternate between the group of the actors and the audience.

After deciding on the group of the actors, the facilitator organizes them in a row, one behind the other, and asks them to learn and follow a simple rule: *"Stand up, raise your hand and touch the shoulder of the participant in front of you. Whenever somebody touches you, lower your hand. If somebody touches you again, raise your hand and touch the shoulder of the participant in front of you. Continue this way forever"*.

If eight (8) participants, following this rule, are arranged in a sequence from right to left, the binary representation of a number n from 0 up to 255 can be found by touching the rightmost participant n times. At the end, the digits of the representation are found as follows: Each participant with the hand raised and touching the next participant, represents a binary digit of zero. Each participant with no hand raised, represents a binary digit of one. Note here that if the leftmost participant raises his/her hand, he/she cannot touch another participant on the right. However, it stills represents a digit of zero in such a case. Figure 34 below depicts these two states for a participant in the Human Calculator.

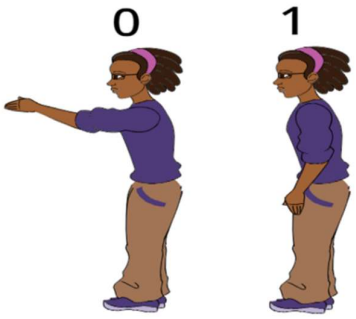

Figure 34: The Human Calculator theatrical game distinguishes between two states representing zero (hand raised to touch the next participant) and one (stand up without touching anybody).

Using only these two states and organizing the group of the actors in a row, it is possible to find the representation of a given number as well as to perform all arithmetic operations. This justifies the name: Human Calculator. A simulator has been developed in the Scratch programming environment [Maloney et al., 2010] and is available at: https://scratch.mit.edu/projects/410832633/ Screenshots from that simulator are used in Appendix 1 to present in detail how game works.

The board game that complements the Human Calculator theatrical game is based essentially on the idea of a binary counting table or abacus. The board of the game, depicted in Figure 35 is organized as five rows each one corresponding to an 11-bit Binary Abacus. To represent a number, chips are placed on the positions that correspond to 1's in the binary representation of a number. The board game complements the Human Calculator theatrical game and offers the opportunity to explore deeper the phenomena emerging from the arithmetic operations [Moumoutzis et al., 2020b; Moumoutzis et al., 2021d; Moumoutzis et al., 2021e]. The board game is also based on simple rules.

The Figure 35 below depicts the board of the game with number 5 represented in the first row and number three represented in the second row. In general, to represent a number in the board, the play put the corresponding chips to the positions that correspond to the binary digits of the number.

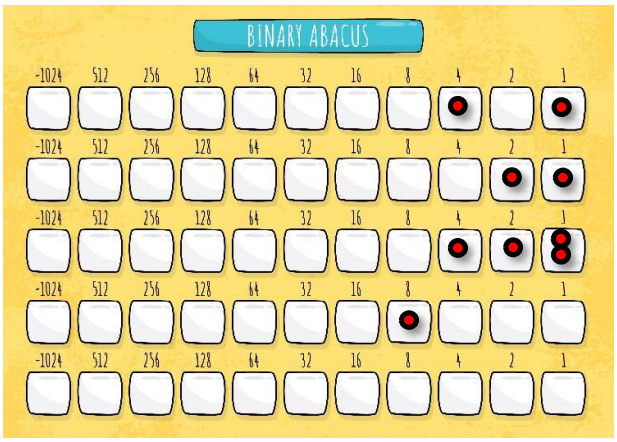

Figure 35: The Binary Abacus board game showing 5 rows each one corresponding to an 11-bit Binary Abacus. The example shown corresponds to the representation of numbers five (5) in the top row, three (3) in the second row, their sum in the third row and the final result (5+3=8) in the fourth row.

Addition, then is done by accumulating the chips of one of numbers. For example, the third row of the board depicted below, the numbers 5 and 3 are added together. The result is to have two chips in the right-most position. To handle this situation, the rule applied is that

whenever two chips are present in a certain position, they are taken out and a new chip is put in the next position to the left. If necessary, the rule is applied again to handle pairs of chips. Doing so in the board below results in the number depicted in the fourth row, which the result of the addition 5+3 = 8.

In appendices 1 and 2 all details related to the Human Calculator theatrical game and the corresponding Binary Abacus board game are presented. There is a close relation between the rules applied in the Human Calculator theatrical game and the Binary Abacus board game that essentially reflect to the mechanics of arithmetic operations. Each game presents a different viewpoint for understanding the underlying rules and offers different learning opportunities: The theatrical game is more appropriate for groups of learners that are learning together while the Binary Abacus board game is more appropriate for self-learning situations. However, using both of them in different situations can greatly enhance the learning results and this is the rationale behind their design, so that they can support the learning needs of students in different situations.

4.5. Chapter summary

This Chapter presented the application of the PerFECt framework in certain situations to establish and sustain onlife learning communities. The following research realization and implementation cases were presented:

- The case of using Coursevo for Computer Science learning communities, in particular the py4hs community consisting of a training programme followed by Computer Science teachers that were subsequently guided to establish and support computer coding clubs.
- The case on using ViSTPro for learning communities in history teaching addressing students, informed by the PerFECt framework to use the ViSTPro platform to watch spatiotemporal scenarios modelling historical events and, furthermore, acting as authors themselves to develop their own spatiotemporal scenarios.
- The case of digital cultural heritage installations via the use of eShadow as a tool to offer informal learning experiences using mixed reality approaches that combine digital technologies and traditional arts and by employing a specialized tool to digitize puppets that are created on paper.

- The case of learning communities on principles of Computer Science guided by the PerFECt to provide engaging learning experiences in a very important topic related to computer programming as well as to computer hardware: the binary system, as one of the core mathematical concepts in Computer Science.

In all the above four cases, the use of the PerFECt framework offers concepts and approaches that enhance the use of the corresponding tools and platforms, extending their initial usage scenarios. The next Chapter presents the experimental results achieved that demonstrate the superior effects of the enhanced tools and platforms, thus validating the framework and documenting its effectiveness for community building and promoting learning and creativity in rich social contexts.

CHAPTER 5. PRESENTATION OF RESEARCH RESULTS – DATA ANALYSIS

Following the detailed presentation of how the PerFECt framework can be employed in certain situations to establish and sustain onlife learning communities, this chapter presents the corresponding experimental results that showcase the effectiveness of the framework and validate that the software developments and learning designs presented in the previous chapter extend the learning opportunities of the corresponding communities.

In the following sections of this chapter, the following specific results are presented:

- Experimental results on using Coursevo for Computer Science learning communities: These are results based on detailed questionnaires answered by teachers participating in the py4hs community, after they have finished the training programme, as well as questionnaires answered by students participating in local learning communities (Code Clubs) established by the participating teachers.
- Experimental results on digital cultural heritage installations: These results address the use of eShadow as a tool to offer informal learning experiences using mixed reality approaches that combine digital technologies and traditional arts. Different installations, as presented in the previous chapter of this thesis, are compared and important results on the effectiveness of the adopted approach are presented.
- Experimental results on using ViSTPro for learning communities in history teaching: These results address many aspects of the platform as well as its learning effectiveness in comparison with the use of eShadow installations. The results clearly demonstrate a statistically significant progress in all cases, i.e., the much better results when using ViSTPro. The results are based on the concepts and approaches drawn from the PerFECt framework.

In the following sections the above-mentioned results are presented in detail.

5.1. Experimental results on Computer Science Learning Communities

The py4hs programme showcased how Coursevo can foster communities of practice as one the major case studies for this theses on how the PerFECt framework can be used to reflect on such experiences and provide orientation for future developments both from a technical point of view (evolve the Coursevo platform) and a social / organization point of view (how members of a community of practice can be effectively supported in their path to becoming capable of co-creating the technologies they use in their practices.

As ICT advances, there are many research and development efforts focusing on the design of learning and training frameworks that take advantage of digital technologies to offer effective blended- and distant-learning opportunities for all kinds of students as well as for professionals during their vocational training and subsequent life-long learning paths during their career. In many cases, over emphasizing the technological means to build such frameworks leads to poor results and increases the disbelief in technology. Our approach tries to set an equilibrium between technology and pedagogy by offering a platform that is pedagogically informed and combined with an approach that explicitly focus on professional training and continuous learning support. The characteristics related to the people targeted by the initiatives supported by Coursevo are varied but a common variable is the wide range in skill and use level of technology. Consequently, the design of learning has as much importance as the technology selection and human interaction between trainers and trainees as well as peer interaction is proving a necessary component in the learning stages.

The learning design for the training frameworks supported by Coursevo in the form of communities of practice has taken particular attention to using the platform that, in addition to supporting expected functions such as digital content repository, communication tools like personal messages, forums and teleconferences, it supports asynchronous and synchronous training sessions. The design has also taken particular care in integrating those features of Coursevo with an effective learning approach, where trainees develop their knowledge through a variety of interactive sessions involving information provision, discussion, evaluation and practical exercises. Trainees have the possibility to access the training material in the form of guides, documents, templates and are invited to develop their own material, whenever possible, with the opportunity to access mentorship at every stage of the process. The approach also promotes a mixture of virtual learning with face-to-face meetings in a blended-learning setting that tries to exploit the best practices of both modes of interaction.

Participants in the communities of practice supported by Coursevo demonstrate high motivation to continue the training and praise for the usability and learnability of the Coursevo platform. The material offered through the platform and the efficient combination of virtual-learning sessions with face-to-face meetings is considered important as well.

The results reported next, validate the applicability of the approach. Indeed, Coursevo enables communication between tutors/trainers and trainees, cooperation among trainees and access to coursework information and learning resources. It can combine traditional classroom-based lessons and practical sessions, with self-study and eLearning. Coursevo platform hides the complexity and frees the trainers from tedious system maintenance tasks,

since a course or even a full functional learning site can be created in a few steps following the SaaS (Software as a Service) paradigm. Furthermore, Coursevo integrates BigBlueButton (http://bigbluebutton.org/) to enable video teleconferencing. This proved very important for the implementation of the programme: One synchronous teleconference was organized each month to give guidance to participants, present best practices and examples, answer to questions and solve practical problems, especially for the organization of local code clubs that addressed a variety of programming domains including physical computing and robotics [Moumoutzis et al., 2021h]. Furthermore, the workgroup support offered by Coursevo was used and appropriately adapted to enable the coordination of work in each group (code club organizers) and facilitate the development and submission of assignments.

The evaluation of the training programme was based on three complementary elements: (1) a detailed questionnaire for the participating Computer Science teachers; (2) an initial and a final questionnaire targeting the students participating in code clubs; (3) a self-evaluation report for each one of the established code clubs that was prepared by the organizers, i.e. the Computer Science teachers participating in the training programme that collaborated in the design and implementation of each code club.

5.1.1. Teacher evaluation of the training

The teachers' questionnaire contained 4 sections employing Likert scale codification:

1. Demographic data;
2. Likert scale questions for the evaluation of the training programme;
3. Likert scale questions for personal and group evaluation;
4. Open-ended questions regarding the objectives of each participant and the degree of satisfaction as well as on the strong and weak points of the training programme.

Table 2 below summarizes the socio-demographic and professional profile of the participating teachers. There was equilibrium in gender while the vast majority of the participants were within the most active age-band for teaching (ages 36-55 sum up to 87.6% of the participants). Their distribution in terms of basic degrees, resonates with the overall distribution in Computer Science teacher community as a whole. Finally, their level of studies shows a high percentage of participants with postgraduate degrees, which is true for the Computer Science teacher community as a whole in Greece as well.

Table 2. Socio-demographic and professional profile of the participating teachers (N=80).

Variable	N	(%)
Gender		
Male	40	(50.0)
Female	40	(50.0)
Age band		
<=25	1	(01.3)
26-35	4	(05.0)
36-45	35	(43.8)
46-55	35	(43.8)
>=56	5	(06.3)
Specialization		
University graduate in Computer Science	61	(76.3)
Technological institution graduates in Computer Science	17	(21.3)
Other	2	(02.5)
Level of studies		
Bachelor	33	(41.3)
Masters	43	(53.8)
PhD	4	(05.0)

By the analysis of the answers to the teacher evaluation questionnaire (N=80) it is evident that the official goals of the training programme were met (Table 3 below). The training programme provided an opportunity for the participating teachers to make their first steps on the educational use of the Python language within a promising pedagogical framework. Using an online course made it possible to reach a much greater number of teachers (especially those living in remote areas) and, through them, have a considerable impact on students through the establishment of code clubs. The synchronous interaction with the course facilitators during the monthly sessions, the forming of regional groups and the systematic communication through the forums helped alleviate many of the disadvantages usually linked with online courses as it is evident from the analysis of the results from the teachers' questionnaires and the self-evaluation reports of the code clubs. The three-phase structure of the course enabled participants to gain practical, hands-on experience both while learning to program in Python themselves and while using it to teach programming to their students. The implementation of the course material by the participants ensured that the knowledge and skills acquired can be transferred into the classroom and put to practical use.

Table 3. Evaluation of the training programme as a whole (N=80).

Variable	1	2	3	4	5	mean
Training progr. success with respect to its initial objectives						
Familiarize with the basic characteristics of Python	0	1	4	44	31	**4.31**
Use self-contained examples in teaching programming	0	1	3	41	35	**4.38**
Enable sustainable local communities of practice	0	3	18	33	26	**4.03**
Evaluation of the learning material						
The learning material can be used without modification	2	5	16	45	12	**3,75**
Autonomous study of learning mat. is easy for novices	4	11	25	25	15	**3,45**
Introduces basic Python concepts in an engaging way	1	2	15	39	23	**4.01**
The content of the learning material is easy to understand	1	3	7	44	25	**4.11**
The learning material is attractive and appealing	0	3	11	40	26	**4.11**
Evaluation of the trainers						
They had adequate knowledge to support trainees	0	0	1	20	59	**4.73**
They effectively transmit their knowledge	0	0	6	28	46	**4.50**
They were supportive in the practical exercises	0	1	10	24	45	**4.41**
They responded to questions	0	0	4	16	60	**4.70**
They were adequately prepared	0	0	2	18	60	**4.73**
Evaluation of teleconferences						
Presentations were adequate and complementary	0	1	13	40	26	**4.14**
Presentations and discussion addressed my needs	1	9	24	31	15	**3.63**
Teleconferences triggered reflection and discussion	0	2	11	40	27	**4.15**
Teleconferences gave me interesting ideas	0	4	15	41	20	**3.96**
Teleconferences stimulated further study	0	3	24	37	16	**3.83**
Evaluation of the organization and workload of exercises						
The material was adequate for doing the exercises	0	2	4	44	30	**4.23**
There was adequate support for finishing the exercises	0	1	8	43	28	**4.23**
Adequate time was given for doing the exercises	1	13	8	35	23	**3.83**
Evaluation of the training platform (Coursevo)						
The platform is easy to use	0	9	15	40	16	**3.79**
The platform has adequate functionality	0	9	11	46	14	**3.81**
Content navigation is easy and effective	2	13	26	30	9	**3.39**
Support for teleconferences is effective	0	2	6	42	30	**4.25**
Searching for content is adequately supported	5	13	24	29	9	**3.30**
There is adequate support for working in groups	0	6	10	46	18	**3.95**
There is adequate support on technical issues	0	0	10	38	32	**4.28**
Overall evaluation of the training programme						
It had clear objectives	0	6	17	40	17	**3.85**
It had activities that reflect and follow the objectives	0	2	12	43	23	**4.09**
The duration was adequate	0	7	10	48	15	**3.89**
The workload was adequate	3	12	23	31	11	**3.44**
There was adequate guidance by the trainers	0	1	7	33	39	**4.38**
My expectations were fulfilled	1	8	22	34	15	**3.68**
I can apply what I have learned	0	1	5	42	32	**4.31**
Now I will perform better in my teaching duties	1	3	14	40	22	**3.99**
I will not need support to apply what I have learned	0	10	27	22	21	**3.68**

The coding club approach adopted for engaging students in programming projects was an important aspect of the training programme. It constituted its pedagogical background that differentiated it from other initiatives for Computer Science teacher professional development where training is usually decoupled from a certain student learning model. Coding clubs are ideal for implementing social constructivism and related pedagogical ideas that are considered very important for cultivating student initiative, creativity and innovative thinking. Students learn by creating things and teachers have a direct experience of organizing such structures and sustaining them.

Interesting findings were documented regarding issues related to the collaboration between participants in working groups and the establishment of code clubs as summarized in Table 4. The participants reported that they generally succeeded in reaching the goals of the programme especially with respect to familiarizing with the basic characteristics of Python and usage of self-contained examples in their teaching.

Table 4. Personal and group evaluation of the training programme (N=80).

Variable	1	2	3	4	5	mean
Training progr. success with respect to its initial objectives						
I familiarized with the basic characteristics of Python	0	2	11	47	20	**4.06**
I can use self-contained examples in teaching progr.	0	0	12	47	21	**4.11**
I was enabled to participate in a sustainable community	4	6	17	36	17	**3.70**
Evaluation of personal participation						
I was much interested throughout the programme	0	10	20	30	20	**3,75**
I was more interested in Python programming (phase 1)	5	11	20	24	20	**3.54**
I was more interested in code club creation (phase 2)	5	17	27	19	12	**3.20**
I actively participated throughout the programme	0	10	11	38	21	**3.88**
I was more active in Python programming (phase 1)	5	9	22	25	19	**3.55**
I was more active in in the code club creation (phase 2)	5	18	23	19	15	**3.26**
I generally did the exercises within the deadlines	2	2	12	34	30	**4.10**
I did all/almost all individual and group exercises	1	8	8	23	40	**4.16**
I assimilated all/almost all the content of the programme	1	8	9	42	20	**3.90**
I participated adequately in the preparation and implementation of the code club of my working group	4	3	11	23	39	**4.13**
Evaluation of my working group						
Adequate collaboration when studying the learning mat.	1	8	20	27	24	**3.81**
Adequate collaboration during code club creation	1	5	12	28	34	**4.11**
Adequate collaboration during group exercises	1	9	9	34	27	**3.96**
Effective distribution of workload among group members	4	6	21	23	26	**3.76**
Fair distribution of workload among group members	7	13	16	24	20	**3.46**

Their interest and participation were adequately focusing on the different phases of the training programme with a slightly more emphasis on the first phase. This is mainly due to certain problems some participants had in combining their professional obligations with the code club creation phase. Positive evaluation of the collaboration of working groups was also reported. However, it was in some cases necessary for the trainers to intervene in working groups to help activities run smoothly. This is important in such blended learning activities: The trainers should proactively and appropriately intervene to avoid problems in working groups. The training platform used offered adequate support for this monitoring taking into account the organization of the training through the use of particular services and the capability to send personal messages to individuals or group messages to members of working groups.

An important aspect of the evaluation is that coding club establishment was seen as a complex and risky task initially while at the end of the programme, the organizers were in many cases surprised by their students asking to continue with the code club and even extend its theme and contents in many other topics exploiting the wide range of uses of the Python programming language. This finding was documented by the self-evaluation forms of the code clubs (prepared by the participating teachers) providing detailed description in free text of their experience. Furthermore, the self-evaluation reports document that the requirement to use and adapt appropriate worksheets to support autonomous learning and personalization during the code club activities, although it was initially confronted with doubts, proved to be extremely effective. Furthermore, the approach to focus on self-contained projects instead of artificial examples and small programming exercises promoted student engagement and contributed to the creation of an atmosphere of meaningful learning.

5.1.2. Student evaluation of the training programme

Following the initial teachers' training phase, the groups that have been already formed were guided to establish local code clubs, recruit students, design a number of sessions and implement them. In each session the organizers were asked to prepare appropriate worksheets possibly reusing the ones used during the initial training or creating new ones. 28 code clubs were established all over Greece with a total number of participants exceeding 500 students ranging from K7 to K12 (12 to 18 years old) including students from vocational education schools. The evaluation of the code clubs was done an initial and a final questionnaire.

Table 5 summarizes the socio-demographic profile of the participants, their participation in the code club and their expectations and previous experience in coding. 69.9% of the participants were boys and 30.1% girls. Grades K-9 and K-10 represented almost 55% of the participants. Participants were mainly informed from their Computer Science teacher at school. The main motivation for participation was their interest in coding. A high percentage expected to learn to code without help and learn something different than in school courses. Most of the participants could not see any obstacle in their participation in the code club and were determined to participate in all sessions of the code club. Finally, most of them had a first coding experience at school.

Table 5. Socio-demographic profile and code club participation (N_{pre}=465).

Variable	N	(%)
Gender		
Male	325	(69.9)
Female	140	(30.1)
Grade		
First grade of Gymnasium (K-7)	15	(3.2)
Second grade of Gymnasium (K-8)	13	(2.8)
Third grade of Gymnasium (K-9)	116	(24.9)
First grade of Lyceum (K-10)	139	(29.9)
Second grade of Lyceum (K-1)	45	(9.7)
Third grade of Lyceum (K-12)	16	(3.4)
First grade of Professional Lyceum (K-10)	32	(6.9)
Second grade of Professional Lyceum (K-11)	42	(9.0)
Third grade of Professional Lyceum (K-12)	18	(3.9)
Other	29	(6.2)
How were you informed about the code club?		
From my Computer Science teacher	298	(64.1)
From a friend	38	(8.2)
I saw the code club poster in my school	17	(3.7)
From an announcement during a class at school	16	(3.4)
From my parents	10	(2.2)
Web page / social media	8	(1.7)
Other	8	(1.7)
No answer	70	(15.1)
Why did you decide to participate in the code club? (multiple answers)		
I like to code	252	(54.2)
I like learning new things and Python is interesting	162	(34.8)
Curiosity	116	(24.9)
I want to become a programmer	96	(20.6)
My friends participate too	42	(9.0)
I have used Python in the past and I like it	41	(8.8)
I have taken similar courses in the past	24	(5.2)
My parents encouraged me to do so	10	(2.2)
What do you expect to achieve with your participation? (multiple answers)		
Create small programs in Python without help	223	(48.0)
Learning something more/different that school classes	188	(40.4)
Be able to develop my own games in Python	140	(30.1)
Know better how to code to see if I can be a professional programmer	139	(29.9)
Know better how to code because I want to be a professional programmer	123	(26.5)
Develop my own programs to show to friends and relatives	88	(18.9)
I want to participate in more sessions and learn more things	47	(10.1)
Get to know the other participants in the code club	38	(8.2)
I have no specific expectations	17	(3.7)
What are possible obstacles to your participation?		
I cannot imagine any obstacle	192	(41.3)
I do not have enough free time	117	(25.2)
I do not have enough technical knowledge	92	(19.8)
I do not have a computer at home	21	(4.5)
I do not like to collaborate with others	14	(3.0)

Variable	N	(%)
No answer	29	(6.2)
Do you plan to participate in all sessions?		
I will come to all of them; I do not cancel what I start!	167	(35.9)
There are not so many sessions, I believe I can participate in all of them	89	(19.1)
If I see that I can make I will continue for certain	84	(18.1)
If I like it in the first session, I will come to all of them	58	(12.5)
Other	5	(1.1)
No answer	62	(13.3)
First coding experience (age)		
In Gymnasium (age 12-15)	232	(49.9)
Last grades of Primary School (age 10-12)	110	(23.7)
In Lyceum (age 15-18)	61	(13.1)
I have no previous coding experience	34	(7.3)
First grades of Primary School (age 6-9)	28	(6.0)
Your first contact with coding was:		
In school	299	(64.3)
Out of school, on my own	74	(15.9)
I have no previous coding experience	35	(7.5)
Out of school, coding with friends	18	(3.9)
Out of school with the help of a relative of mine	16	(3.4)
After school courses	12	(2.6)
Other	11	(2.4)

Table 6 presents the programming environments used in the participants' previous coding experience, mainly Scratch [Maloney et al., 2010], Microworlds [Gough, 1996] and Python [Van Rossum,1995].

Table 6. Previous coding experience (N_{pre}=465). Percentages are shown for Likert scale values.

Variable	Not at all	Very little	Somewhat	Very much
Programming environments you used in school				
Microworlds / Turtle world	52.0	15.9	21.3	10.8
Scratch	26.7	18.7	24.9	29.7
AppInventor	80.6	9.7	5.2	4.5
Pseudolanguage	69.5	15.1	9.0	6.5
Pascal	84.9	8.0	4.5	2.6
GameMaker	88.2	7.1	3.7	1.1
Alice	84.5	6.2	5.2	4.1
Kodu	84.9	4.5	4.1	6.5
Python	56.8	17.4	16.1	9.7
To what extent you have used the programming environments in/out of school				
Microworlds / Turtle world	74.8	12.3	8.8	4.1
Scratch	46.5	20.2	14.0	19.4
AppInventor	82.8	10.1	3.9	3.2
Pseudolanguage	78.9	13.5	3.2	4.3
Pascal	87.3	8.0	2.2	2.6
GameMaker	84.7	10.3	2.2	2.8
Alice	88.6	7.3	1.3	2.8

Variable	Not at all	Very little	Somewhat	Very much
Kodu	89.2	4.5	3.4	2.8
Python	61.3	21.7	10.3	6.7

Table 7 presents the self-evaluation of the students regarding their existing coding skills before their participation in the code club. Most of them believe that their coding skills are rather low. The opinion of the majority about coding is that it is a useful skill, challenging, helps in analytical thinking and is fun. Students would like to create mainly action games, mobile apps, robotics apps and games of logic and secondarily programs to solve mathematical problems and educational apps.

Table 7. Coding skills and opinions (N_{pre}=465). Percentages are shown for Likert scale values.

Variable	N	(%)
Rate your coding skills		
1	75	(16.1)
2	146	(31.4)
3	144	(31.0)
4	73	(15.7)
5	27	(5.8)
In your opinion, coding: (multiple answers)		
is a useful skill	296	(63.7)
is challenging	241	(51.8)
helps you think analytically	206	(44.3)
is fun	193	(41.5)
presupposes knowledge of mathematical concepts	103	(22.2)
is like a puzzle	102	(21.9)
is hard	81	(17.4)
can help you get better at school	66	(14.2)
other	8	(1.7)
What kind of programs would you like to create? (multiple answers)		
Action games	263	(56.6)
Mobile apps	258	(55.5)
Robotics apps	200	(43.0)
Games of logic	172	(37.0)
Programs to solve mathematical problems	114	(24.5)
Educational apps	90	(19.4)
Other	12	(2.6)

Table 8 presents the findings after finishing the code club. The positive impact on all variables is evident. The participants report that they now better what coding is and they have a better understanding of what kind of programs they would like to create.

Table 8. Coding skills and opinions (N_{post}=358). Percentages are shown for Likert scale values.

Variable	N	(%)
After finishing the code club sessions, I believe that: (multiple answers)		
I have learned more/new things than school classes	274	(76.5)
I know what coding is to decide if I will be a programmer	261	(72.9)
I can create small Python programs without help	258	(72.1)
I can create my own Python games	94	(26.3)
In your opinion, coding: (multiple answers)		
is a useful skill	277	(66.7)
helps you think analytically	264	(73.7)
is challenging	262	(73.2)
is fun	243	(67.9)
is like a puzzle	147	(41.1)
presupposes knowledge of mathematical concepts	131	(36.6)
can help you get better at school	131	(36.6)
is hard	101	(28.2)
Other	8	(1.7)
What kind of programs would you like to create?		
Mobile apps	217	(60.6)
Action games	207	(57.8)
Games of logic	176	(49.2)
Robotics apps	172	(48.0)
Programs to solve mathematical problems	129	(36.0)
Educational apps	94	(26.3)
Other	12	(2.6)

Table 9 presents how the participants evaluate the code club and the teachers. All variables are given in 5-value Likert scale and it is evident the positive evaluation in all of them. The table also shows the self-evaluation of certain parameters regarding the participation. Again, all evaluations are positive or very positive. Finally, the table presents how the participants evaluated the Python language and its learning potential, with positive results as well.

Table 9. Evaluation of the code club and the teachers, self-evaluation and evaluation of the Python Language (N_{post}=358). Percentages are shown for Likert scale values.

Variable	Not at all	Very little	Some-what	Much	Very much
Code club objectives were clear	1.7	4.2	15.9	41.1	37.2
Teachers were:					
well prepared and organized	0.8	2.8	10.6	33.8	52.0
clear and understandable	1.4	3.1	14.8	30.7	50.0
easy to collaborate with whenever necessary	1.1	3.1	6.1	21.8	67.9
Learning materials were:					
connected to real world	4.2	13.1	27.4	32.7	22.6
fun	3.9	7.3	22.3	28.8	37.7
interesting	2.2	5.9	16.2	26.5	49.2

Variable	Not at all	Very little	Some-what	Much	Very much
possible to be used without help	7.8	21.2	30.4	23.7	16.8
Code club duration was adequate	4.5	17.0	32.7	30.4	15.4
I collaborated with my peers	5.9	10.3	19.3	30.2	34.4
What I learnt will help me in school	9.8	14.5	24.3	31.6	19.8
I showed my programs to friends, classmates or parents	16.7	16.7	33.3	8.3	25.0
I want the code club to continue	3.6	9.2	17.6	23.2	46.4
I would advise my friends to enrol to a code club	4.7	7.5	15.1	30.7	41.9
I am now ready to code and create	6.4	14.0	32.1	33.2	14.2
My expectations were fulfilled	3.6	8.9	24.9	42.2	20.4
Python coding seemed easy	0.8	9.2	38.5	35.8	15.6
Python is a language to start coding	1.7	6.7	24.0	31.3	36.3
Python should be used in schools	3.6	7.5	18.4	25.7	44.7
I would like to continue with Python on my own	10.1	14.8	26.8	26.3	22.1

The code clubs had a very positive impact on students in terms of developing programming skills and positive change in their attitude towards programming which is seen as an important professional pathway. Table 10 demonstrates these findings presenting the change in students' attitudes on the questions of pre- and post-questionnaires.

Table 10. Attitudes of students towards programming before and after their participation in the local code clubs (Npre=465, Npost=358). Post testing results are shown in reversed type. Percentages are shown for Likert scale values.

Variable	1	2	3	4	5	mean
I believe that:						
Girls and boys are equally	09.9	15.3	65.4	03.4	06.0	**2.80**
competent in coding	07.8	12.6	65.6	06.4	07.5	**2.93**
I can collaborate with others	06.5	08.4	24.3	26.7	34.2	**3.74**
when coding	05.0	07.0	21.8	29.1	37.2	**3.87**
I can code by myself	12.5	23.7	24.9	20.2	18.7	**3.09**
without help	05.3	15.4	27.9	30.4	20.9	**3.46**
It is probable that I follow	13.5	17.8	23.0	17.8	27.7	**3.23**
a computing profession	10.9	12.3	21.8	21.2	33.8	**3.55**
Only future computer	34.4	26.9	19.6	09.0	10.1	**2.34**
professionals should code	27.7	24.9	25.7	11.7	10.1	**2.52**

5.2. Experimental results on digital cultural heritage installations

The experimental evaluation of the digital cultural heritage installations described in the previous chapter combining digital technologies and traditional arts to offer a mixed reality experience within the context of informal learning settings, employ an appropriate evaluation tool, namely the User Experience Questionnaire (UEQ) [Laugwitz et al., 2008]. This is the questionnaire used in both the trials described in section 4.2. 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 details for each trial and how the PerFECt framework used to design and implement them, have been presented in the previous chapter (section 4.2).

The UEQ contains 6 scales within which its 26 questions (Figure 36) 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).

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

Figure 36: 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 Figure 37.

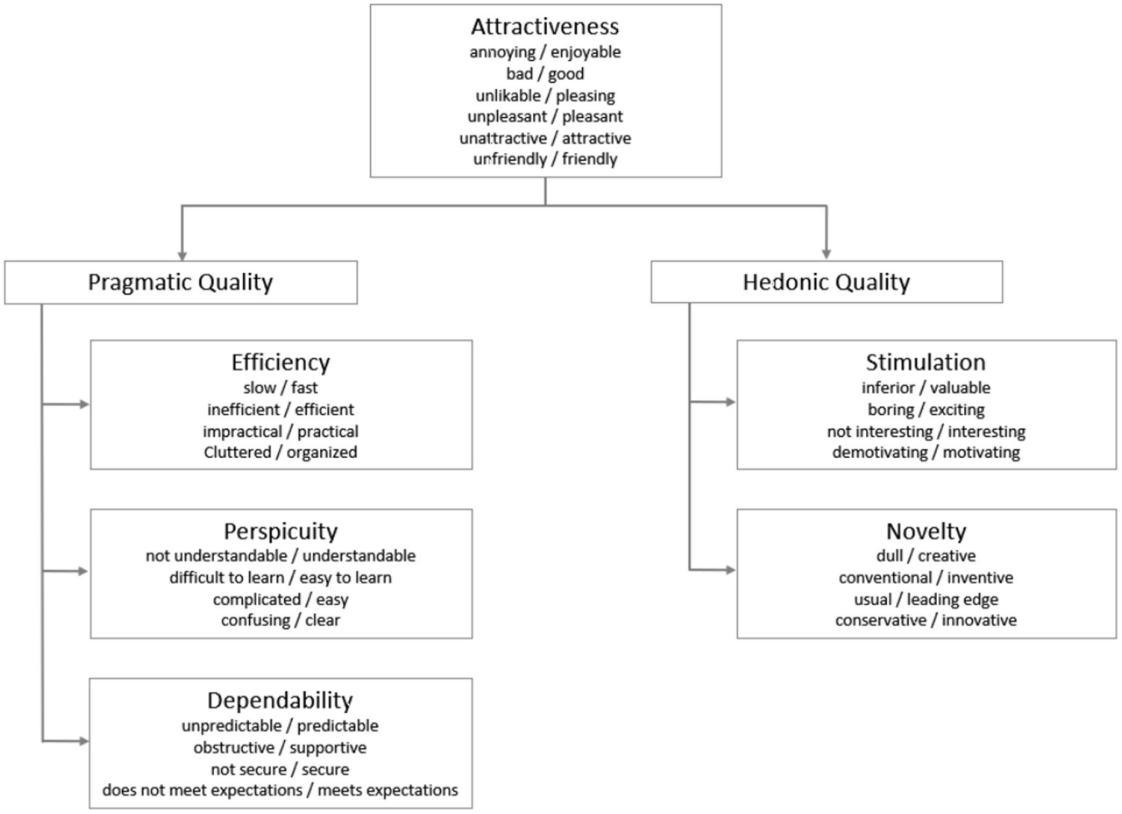

Figure 37: User Experience Questionnaire scales and corresponding questions.

Figure 38 presents the overall results from the first trial. The mean value of all six scales is positive. The comparison of the scores with the standard benchmark of UEQ is shown in Figure 39.

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. Furthermore, during the second trial, the participants that had the opportunity to create their own puppets, digitize them and use them from the eShadow tool.

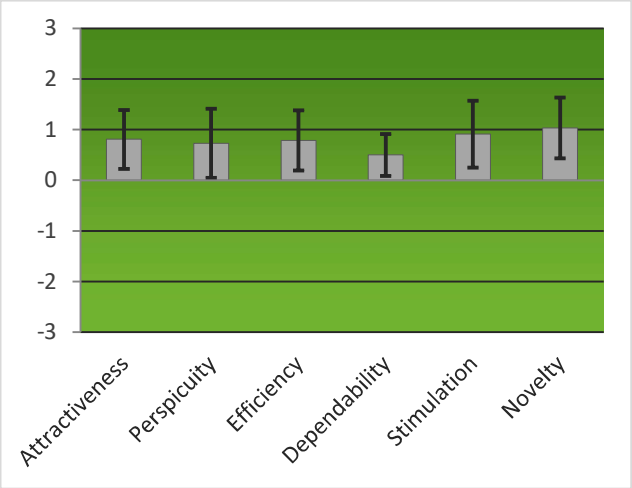

Figure 38: The mean value and standard deviation for the six scales of the User Experience Questionnaire from the first trial.

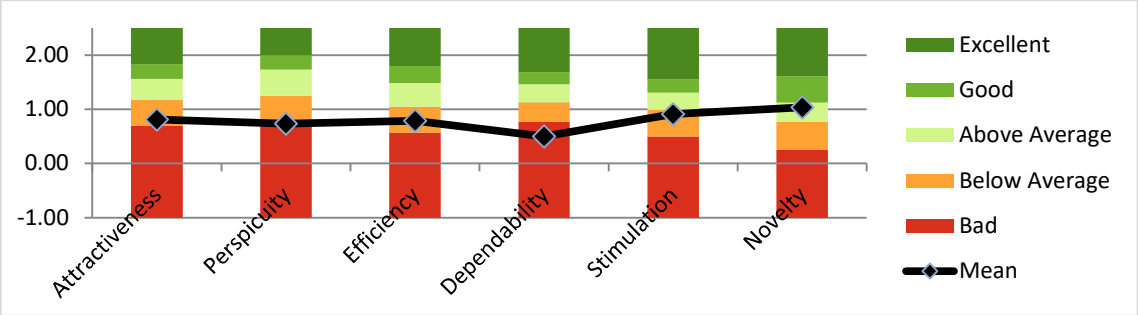

Figure 39: Comparison of first trial results against the benchmark of the UEQ.

During the second trial 15 UEQ questionnaires were collected. The results are shown in Figure 40. The comparison of the scores with the standard benchmark of UEQ is shown in Figure 41. 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.

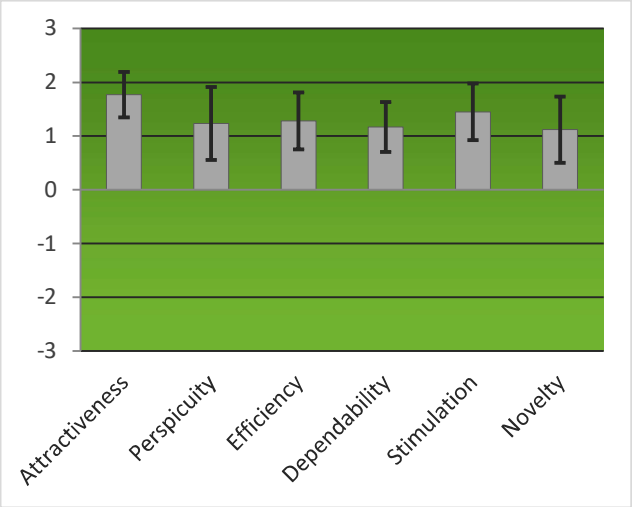

Figure 40: The mean value and standard deviation for the six scales of the User Experience Questionnaire from the second trial.

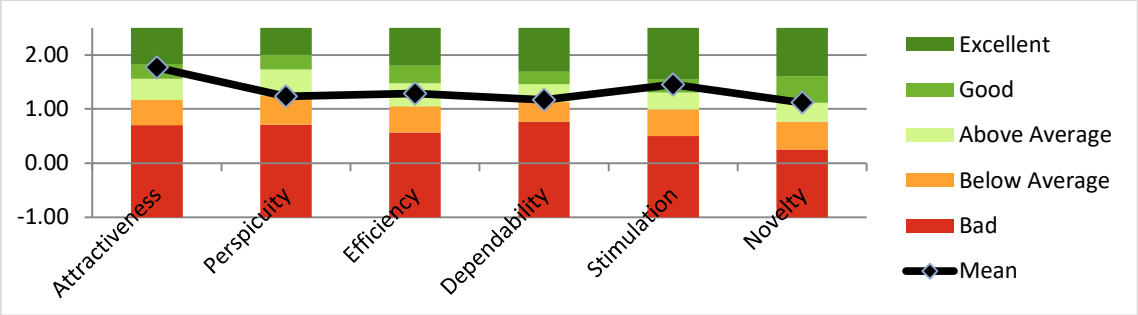

Figure 41: Comparison of second trial results against the benchmark of the UEQ.

Figure 42 compares the results between the first and the second trial while Table 11 shows the results of a 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.

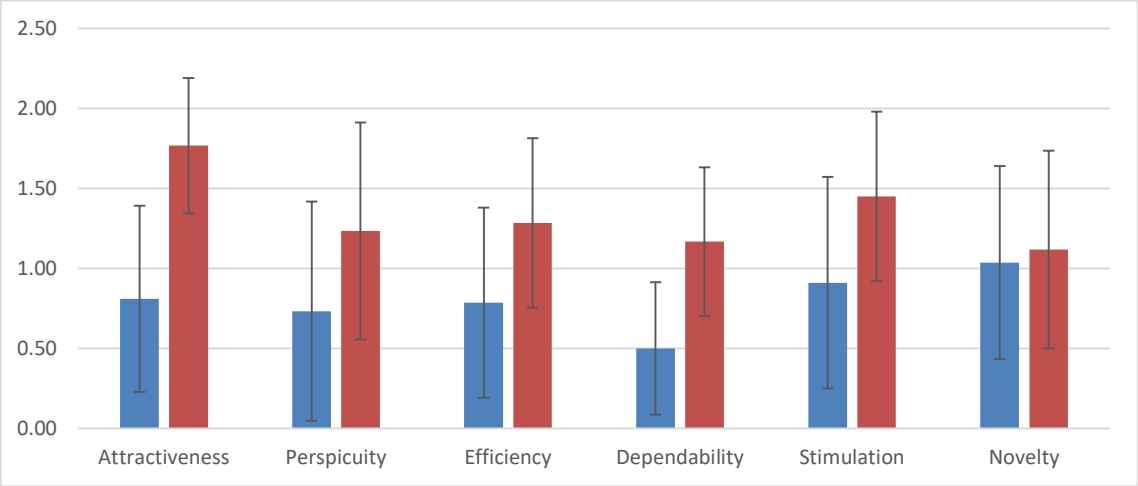

Figure 42: Comparison of UEQ scale results between the first (blue) and second (red) trials.

Table 11 - Alpha values of UEQ Scales comparing the results the results of the first and second trials.

UEQ Scale	***Alpha value***	***Characterization***
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

As it is evident from the results presented, the proposed approach effectively combines digital technologies and interactive graphics to renovate shadow theatre tradition and offer a creative digital platform in tune with current trends of learning pedagogies. It enables children and adults to engage again with their national culture in a way that combines digital technologies in a creative and educationally significant framework. Through the use of innovative tools, students undertake various roles, cultivate social and cognitive skills while developing their psycho-emotional world.

eShadow promotes playful learning scenarios that motivate and entertain children. It supports an inclusive learning framework that enables teachers to design and implement interdisciplinary theme-centered projects showcasing intra- and inter-sectorial/branch correlations in a variety of subjects (language, history, music, computing, etc.). The framework adopts the phases of the filmmaking process in a flexible way to promote cross-

curricular (horizontal) skills: speaking and writing skills, social cooperation and research skills, digital and metacognitive skills.

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 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, this approach can be engaging for participants if carefully designed installations are employed that immerge the participants and provide them space and time to experiment by themselves with the software, developing their own creations, see them animated and use them in eShadow.

5.3. Experimental results on learning communities in history teaching

Teaching spatiotemporal processes, as it is the case for history courses in school, can be quite difficult and challenging if traditional approaches are employed. This is due to the fact that the teaching of these subjects forces the student to create a complex cognitive structure. The task of correlating spatiotemporal information that is presented linearly when using traditional means is left to the student to handle without any significant help. E.g., the description of a battle in a history textbook presents the related events in a certain sequence although, in many cases, these events may take place in parallel and trigger other events in complex causal relationships. Consequently, traditional teaching results in the construction of a vague cognitive structure, which makes it difficult to absorb the knowledge of complex spatiotemporal processes. Using ViSTPro in teaching and learning of such kind of processes, can offer significant advantages and the evaluation presented here aimed to study the performance of the system in facilitating students to understand spatiotemporal processes. Specifically, the evaluation addressed the use of the system by teachers and students in the teaching and learning of historical events that correspond to complex spatiotemporal processes. The aim was to investigate whether ViSTPro promotes the effective learning while also offering engagement and opportunities for creative expression. Thus, the investigation addressed both the use of ready-made scenarios and the creation of new scenarios by the students to demonstrate their knowledge and exercise their creativity.

The evaluation of ViSTPro was carried out in comparison with the use of eShadow within the context of the first trial reported in the previous section that addressed the historical events that took place during the Battle of Crete in 1941. In particular, the participants had the opportunity to learn about the events using specially developed ViSTPro scenarios and then attend the eShadow installation as well. The same questionnaire (UEQ) was used for both ViSTPro and eShadow installation. The events presented span several days and their presentation exploited the advanced features of ViSTPro to provide the necessary information about their time structure along with appropriate animations and presentation of semantic information on top of Google maps. Students were guided through the process of scenario authoring as well, thus taking the role of expert-users and being able to study the underlying historical events in more depth.

During the trial 29 UEQ questionnaires were collected. The results are shown in Figure 43. The comparison of the scores with the standard benchmark of UEQ is shown in Figure 44. All but the Dependability scale are characterized as Excellent. The Dependability scale is characterized as Good.

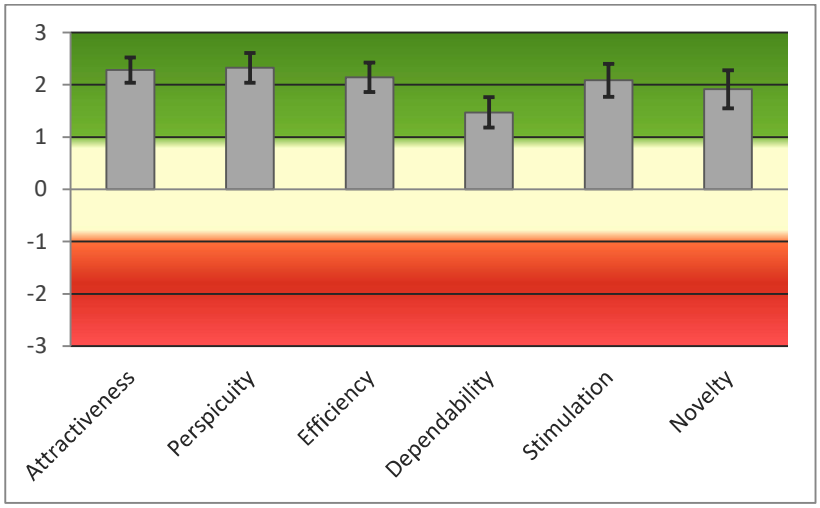

Figure 43: The mean value and standard deviation for the six scales of the User Experience Questionnaire from the ViSTPro trial on teaching local history (Battle of Crete, 1941).

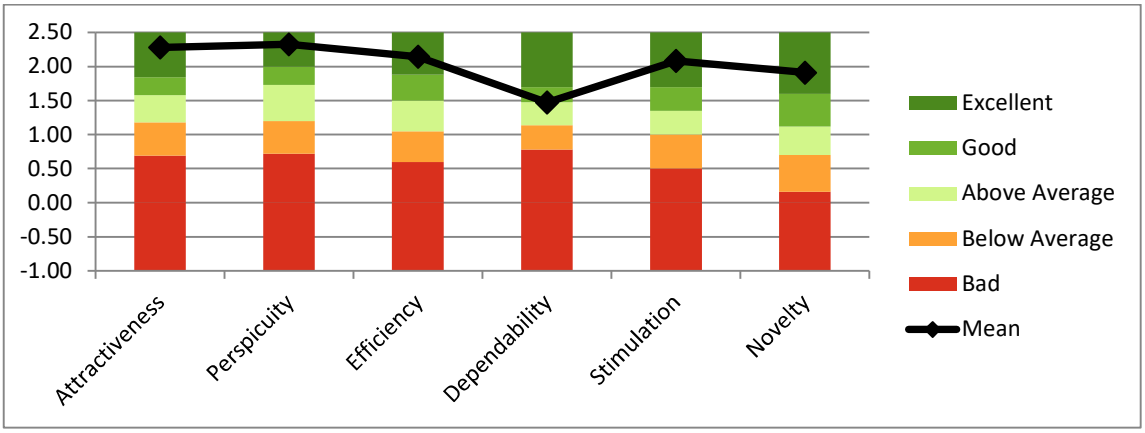

Figure 44: Comparison of the ViSTPro trial results against the benchmark of the UEQ.

Figure 45 compares the results between the ViSTPro and eShadow trials while Table 12 shows the results of a 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 all UEQ categories with ViSTPro usage is proved to be much more effective in all scales.

As it is evident from the results presented, the proposed approach on teaching history via spatio-temporal process authoring and visualization effectively combines digital technologies and interactive graphics to offer a creative digital platform in tune with current trends of learning pedagogies within a performative framework informed by the PerFECt framework.

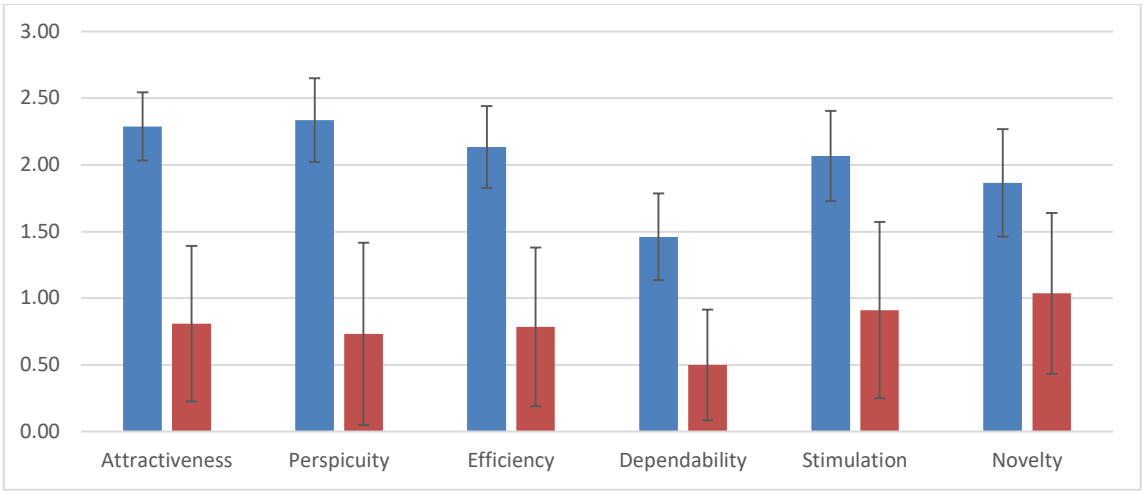

Figure 45: Comparison of UEQ scale results between the ViSTPro (blue) and eShadow trials on teaching local history (Battle of Crete, 1941).

Table 12 - Alpha values of UEQ Scales comparing the results between ViSTPro and eShadow trials on teaching local history (Battle of Crete, 1941).

UEQ Scale	*Alpha value*	*Characterization*
Attractiveness	0.0002	Significant Difference
Perspicuity	0.0005	Significant Difference
Efficiency	0.0008	Significant Difference
Dependability	0.0013	Significant Difference
Stimulation	0.0063	Significant Difference
Novelty	0.0342	Significant Difference

5.4. Chapter summary

This Chapter presented in detail the experimental results that validate the applicability of the PerFECt framework and demonstrate its effectiveness on extending and enriching the opportunities to establish and sustain onlife communities that are powered by appropriate digital technologies and tools.

In particular, the experimental results presented correspond to the use and enhancement of the following tools and platforms:

- The Coursevo platform offering the means to organize activity spaces that correspond to content repositories, courses and projects. The results presented were based on detailed questionnaires answered by teachers participating in the py4hs community, after they have finished the training programme, as well as questionnaires answered by students participating in local learning communities (Code Clubs).
- The eShadow tool for enacting digital stories and developing interactive installations employing mixed reality approaches. Different installations were presented and compared and important results on the effectiveness of the adopted approach were presented.
- The ViSTPro platform for learning communities in history teaching. The results presented compare ViSTPro with eShadow in the case of the presentation of historical events about the Battle of Crete. The results show that ViSTPro outperforms the eShadow installation.

The overall conclusion is that in all cases above, the PerFECt framework offers a robust methodological framework for analysing the use of digital platforms and tools and

providing guidance to extend their functionality to offer new learning opportunities to their users in an effective and engaging way.

CONSLUSION

In this thesis the use of modern digital technologies to promote creativity and learning within rich social contexts is thoroughly studied and analysed with the aim to describe and validate a framework that enables ICT experts collaborate with the users of their technologies in order to address their needs in a way that is informed by current developments in fields related to computer supported collaborative work, participatory design and end-user development. In other words, the aim of this thesis is to set up the ground for a systematic analysis and subsequent enhancement of digital systems in close connection to the communities that use these systems to achieve certain objectives and carry out certain tasks.

The thesis builds on previous work related to the so-called performative turn in design that embraces the concept of performativity emphasizing the fact that all human practices are performed, in contrast to the ontological premises that reality corresponds to specific objects. In this respect, knowledge is created through the actions of the members of a social structure. This line of work is combined with previous research on Human Computer Interaction that links computer systems to theatre as a way to explain how computer systems exists and evolve as worlds of representations that enable their users to produce effects in the real world by manipulating the corresponding digital representation or artifacts. This way of interacting with reality, brings forth the concept of universalization, a way to explain the reality by reference to cause-and-effect relations and changing the reality by manipulating such relations.

An important aspect that is underlined by parts of the work on this thesis is the concept of de-design, i.e., 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.

The main result of the thesis is the PerFECt framework that integrates and systematizes the above concepts in order to enable the analysis of how onlife communities are established and evolved, how they can be enhanced and how the digital tools and platforms that they use can be analysed, extended and enhanced. The term onlife that is employed is

borrowed from the Onlife Manifesto and reflects the new reality that is brought about by current developments in ICT where people are nowadays always online, i.e., interacting in one way or another with digital systems including systems that are pervasive or embedded and thus not directly visible when interacting with physical or artificial entities.

In the implementation of Task 1 (documenting the baseline for this work in terms of concepts, platforms and tools) the following results were achieved:

- Analysing important concepts that provide the baseline for the PerFECt framework including performativity, the relation between computers and theatre, the concept of universality providing a causal interpretation of behaviour of humans and their interactions and the definition of Onlife Communities.
- Presenting the Coursevo platform with all its features to support onlife communities as conceived and analysed by the PerFECt framework.
- Presenting the ViSTPro platform with its special features to enable the visualization of spatiotemporal processes and comparison with similar tools.
- Presenting eShadow and how it supports the creative process of developing digital stories.

In the implementation of Task 2 (Presentation of the PerFECt framework) the following results were achieved:

- Study the main technological affordances that bring forth new community affordances as digital technologies evolve and create new opportunities for communication and collaboration.
- Analyse the concept of Onlife Communities to justify the use of the term “onlife” and present its connotations in terms of basic premises of the Onlife Manifesto and its intention to foster a rethinking of our societal concerns in the digital transition.
- Develop a conceptual framework to describe Onlife Communities employing performative models that identify and clarify the significant roles and interaction patterns between these roles.

In carrying Tasks 3 and 4, i.e., experimentation, evaluation and improvement of established tools and services) the following results were achieved:

- Starting from the PerFECt framework, we systematically address how learning communities can be supported by means of Coursevo, a learning platform that offers a variety of communication services, content organization services and

community building features, based on the PerFECt framework. In particular, we analysed the technical details of supporting such communities in the field of Computer Science teaching and learning and apart from the technical part of the work, we systematically analysed how participants in such communities, i.e., teachers and students, can be effectively organized adopting the concept of code club to promote teaching and learning of the Python programming language (Ref. Chapter 4, section 4.1).

- Subsequently, the community building approach for establishing the Python programming code clubs was validated via a questionnaire study that addressed both teaches and students. In particular, the evaluation was based on questionnaires and self-assessment for teachers and a pre-, post-questionnaire evaluation of the students that participated in the coding clubs established. Focusing on engaging programming projects rather than relying on artificial exercises addressing the syntax and the structure of Python (as it is the case in traditional classroom teaching) highlights a wide range of higher-level concepts ranging from functional abstraction and problem-solving strategies. It should be noted that participating teachers were supported through distant-learning facilities to study special material on the Python programming language and thus gain confidence in using an alternative, engaging methodology which can serve as a springboard for exposing their students to Computer Science practices and concepts, thus strengthening the community building aspect, as the PerFECt framework promotes (Ref. Chapter 5, section 5.1).
- The digital cultural heritage domain was addressed by the eShadow tool. The tool provides animation features inspired by traditional shadow theatre, and its design and use are informed by the PerFECt framework to develop mixed reality installations that combine digital technologies with traditional arts and demonstrate the applicability and effectiveness of the de-design concept of the PerFECt framework as well. In particular, by careful de-design it was possible to invent a new way of using the tool by combining projection mapping and body shadows in an interactive way as well as using analogue puppet making to develop digital puppets via a specialized tool, ePuppet, that was the result of the analysis and enhancements undertaken (Ref. Chapter 4, section 4.2). Following a careful experimentation, it was possible to validate that 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-centred pedagogies. Beyond formal learning settings, eShadow can be effectively combined with mixed reality technologies to offer experiential learning experiences in information learning settings. This approach can be extremely engaging if carefully designed immersive installations are employed that enable participants to experiment by themselves with the software, developing their own creations, see them animated and use them in eShadow (Ref. Chapter 5, section 5.2).

- As another concrete result on how the PerFECt framework promotes creativity and learning, the domain of cultural heritage, history teaching and learning in particular, is addressed based on the ViSTPro platform for the visualization of spatiotemporal processes. This line of work employs the concepts of the PerFECt framework and in particular the specific user roles of the framework: maieuta-designers, end-users, expert-users and meta-designers. The use of the maieuta-designer role, reveals a critical contribution in framing and supporting an onlife community. In particular, maieuta-designers are addressing the social conditions for supporting the meta-task of expert-users and the transition from the end-user role to the role of expert-user. This transition and support of expert-users' tasks are essentially a learning process that takes place within a social context (i.e., the community of users). In the case of ViSTPro, the need for maieuta-designers emerges very naturally from the use of the tool in actual learning situations when students express their desire to develop their own scenarios (i.e., go beyond the end-user role toward the expert-user role) and thus learn deeper about the historical events they study (Ref Chapter 4, section 4.3). These enhanced learning results are documented by comparing ViSTPro with eShadow in engaging students in learning interventions that address a specific historical event, the Battle of Crete in 1941 (Ref. Chapter 5, section 5.3).
- The concept of de-design within the overall PerFECt framework was also used to invent and develop in detail a theatrical and a board game targeting the mathematical principles underlying Computer Science, in particular the binary system. These two games provide an intuitive and engaging way to explore the binary representation of numbers, explore the mechanisms of the four arithmetic operations and the transformation of binary numbers to other positional systems, especially the decimal system. The initial feedback from teachers on these

developments demonstrate its effectiveness but detailed experimentation has been left for future work due to restrictions due to the Covid pandemic. However, the feedback from teachers that have already used it is that it increases engagement, creates a positive atmosphere in the classroom and offers several outdoor learning opportunities. Several features of the two games propagate constructivist learning and engage students to learn the mathematics of number systems in general and binary system in particular by direct inquiry, experimentation and self-discovery of the mechanisms for arithmetic operations. (Ref. Chapter 4, section 4.4).

CONTRIBUTIONS

- Studies and practically oriented analyses of key concepts and actual principles of the modern digital technologies promoting creativity and learning within rich social contexts and focusing on current developments in computer supported collaborative work and participatory design:
    - study of the so-called performative turn in design with specific orientation to link computer systems to theatre in order to evolve worlds of representations enabling their users to produce effects in the real by manipulating the corresponding digital representation or artifacts;
    - analysis of the concept of universality and its relation to causality and how it is promoted by digital technologies as well as of the concept of de-design, linked to the arguments of the Onlife Manifesto.
- Development of PerFECt, a Performative Framework to Establish and Sustain Onlife Communities based on a conceptual framework, incorporating models and specific guidelines for using digital systems to empower communities, enhanced as a result of the performed anlyses. Organizing a number of communities building initiatives that employ the PerFECt framework related to specific digital tools and addressing specific learning and creativity domains.
- Development and enhancement of the eShadow tools inspired by Greek traditional shadow theatre and usage in order to establish and sustain communities in digital cultural heritage.
- Development and enhancement of ViSTPro, a spatio-temporal process visualization platform that enables rich learning experiences in diverse domains including cultural heritage in general and history learning in particular.
- Development and enhancement of Coursevo, a community building, distant training and learning platform that facilitates the building and support of communities of practice and communities of learning.
- Applied practical directions for the implementation and experimentation with the proposed community building structures and services within the context of specific experimentation settings that employ a standard tool (UEQ) in combination with specialized questionnaires to assess the view and evaluate experiences of members of the studied communities.

DELCALARATION OF ORIGINALITY OF RESULTS

I declare that the present dissertation contains original results obtained in my research with the support and assistance of my scientific advisers. The results obtained, described and / or published by other scholars are duly and in detail cited in the bibliography.

This dissertation is not applied by obtaining a scientific degree in another higher school, university of scientific institute.

Signature:……..

(Nektarios Moumoutzis)

DISSEMINATION OF THE RESULTS AND FUTURE WORK

The framework presented in this thesis and the corresponding development work on Coursevo, ViSTPro and eShadow software, has been exploited in several EU and national funded projects. In particular:

- The TIM project (Erasmus+ code 2018-1-IT02-KA201-048139) where the Human Calculator theatrical game has been initially designed and used in the projects' pilot activities.
- The e-ARTinED project (Erasmus+ code 2015-1-SE01-KA201-012267) where the Coursevo platform was used to establish a Community of Practice on the integration of arts in school curricular subjects following the principles of the PerFECt framework and adjusting the community services to reflect the experimentation reported in chapter 5 of this thesis. This community was further expanded and enhanced within the context of the rhythm4inclusion project (Erasmus+ ID Erasmus+ ID 2018-1-SE01-KA201-039032) focusing on the use of rhythm-based arts (dance and music) to promote social inclusion and engaging learning experiences.
- The CaravanNext project (Creative Europe code 559286) where eShadow has been enhanced and used to develop new types of digital puppet interactions to reflect the control model of digital marionettes in order to enable learning scenarios in countries with storytelling traditions different than shadow theatre.
- The MultiLib (Erasmus+ code ID 2016-1-SE01-KA201-022101) and MUSILIB (Erasmus+ code ID 2018-1-FI01-KA201-047196) projects where eShadow was used to develop digital stories based on traditional and modern children stories collected by these two projects.
- The Bulgarian Ministry of Education and Science under the National Research Programme "Cultural heritage, national memory and development of society" and the National Scientific Program "Information and Communication Technologies for a Single Digital Market in Science, Education and Security" approved by DCM №577/17.08.2018 where the PerFECt framework was supported.
- The EVANDE project (contract number ECHO/SUB/2014/693261) and the projects DISCOVER (Erasmus+ code 2017-1-BG01-KA202-036327) and MAKER SCHOOLS (Erasmus+ code 2020-1-BG01-KA201-079274) where the ViSTPro was used to set up learning communities on domains related to

spatiotemporal processes and further work on communities on learning computer programming was done and events were organized that applied the PerFECt framework.

- The CLaDA-BG, the Bulgarian National Interdisciplinary Research e-Infrastructure for Resources and Technologies in Favor of the Bulgarian Language and Cultural Heritage, Part of the EU Infrastructures CLARIN and DARIAH, Grant number DO01-301/17.12.2021.
- The Bulgarian Ministry of Education and Science under the National Scientific Program "Information and Communication Technologies for a Single Digital Market in Science, Education and Security" approved by DCM №577/17.08.2018.
- The Google CS4HS programme (https://www.cs4hs.com/) partially supported the work for the development of the py4hs community using the Coursevo platform.
- The Bulgarian NSF under the research project № DN02/06/15.12.2016 "Concepts and Models for Innovation Ecosystems of Digital Cultural Assets" partly supported the work on the development of the PerFECt framework presented in this thesis.

Moreover, parts of this thesis have been presented in several scientific publications (Ref. LIST OF THE AUTHOR'S PUBLICATIONS RELATED WITH THE PHD THESIS) as follows:

A. International scientific conferences:

- Digital Presentation and Preservation of Cultural and Scientific Heritage – DiPP2018;
- Digital Presentation and Preservation of Cultural and Scientific Heritage – DiPP2019;
- International Conference on Interactive Mobile Communication, Technologies and Learning – IMCL 2019;
- IEEE International Conference on Computers, Software, and Applications – COMPSAC 2020;
- International Conference on Interactive Collaborative and Blended Learning – ICBL2020;
- Digital Presentation and Preservation of Cultural and Scientific Heritage – DiPP2020;
- IEEE Global Engineering Education Conference – EDUCON 2021;

- Digital Presentation and Preservation of Cultural and Scientific Heritage – DiPP2021;
- International Conference on Interactive Mobile Communication, Technologies and Learning – IMCL 2021;
- IEEE International Conference on Computers, Software, and Applications – COMPSAC 2022;
- Digital Presentation and Preservation of Cultural and Scientific Heritage – DiPP2022;

B. Book chapters and scientific journal publications:

- Informatics and Automation (SPIIRAS Proceedings) Journal (Информатика и автоматизация)
- Mind and Matter - Challenges and Opportunities in Cognitive Semiotics and Aesthetics, London: Intech Open; 2021.

The results obtained in this thesis are actively extended and further developed in the following areas:

- Gamifying Onlife Communities with the context of the GAME IT project (Erasmus+ code 2020-1-BG01-KA202-079103), to offer more engaging learning experiences and address needs of special target groups including students with low school performance. This work applies the principles and concepts of the PerFECt framework on extending the Coursevo platform with a system of rewards, points and badges along with its existing certification system. More details about this work and the corresponding design and implementation can be found at [Moumoutzis et al., 2021c].
- New approaches in STEM education [Yoshinov & Kotseva, 2016] by establishing learning communities on principles of computer programming and algorithms employing visual representations of food recipes. This approach is titled Cooking STEAM to signify the linking between STEM education and the art of cooking as well as with the arts of music and drama. Cooking STEAM is also linked to cultural awareness and social inclusion. More details about this line of work and current status can be found at [Moumoutzis et al., 2021g]. This work will be further expanded to focus on learning communities for mathematics, exploiting the Human Calculator theatrical game and the Binary Abacus board game within

the context of the M2-Cm project (Erasmus+ code 2021-1-SE01-KA220-SCH-000032733).

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ABBREVIATIONS

CS: Computer Science

CS4HS: Computer Science for High Schools

GPS: Global Positioning System

ICT: Information and Communication Technologies

IT: Information Technologies

LOM: Learning Object Metadata

MOLE: Multimedia Online Learning Environment

OAI-PMH: Open Archives Initiative Protocol for Metadata Harvesting

PerFECt: Performative Framework to Establish and Sustain Onlife Communities

PY4HS: Python for High Schools

SCO: Sharable Content Object

SCORM: Sharable Content Object Reference Model

SCT: Social Community Theatre

STEAM: Science, Technology, Engineering, Arts and Mathematics

STEM: Science, Technology, Engineering and Mathematics

TIM: Theatre in Mathematics

UEQ: Usability Evaluation Questionnaire

URL: Unified Resource Locator

APPENDIX 1 – THE HUMAN CALCULATOR THEATRICAL GAME

This appendix presents in detail the operation of the Human Calculator theatrical game presented briefly in section 4.4. Figure 46 below depicts the Human Calculator initialized. Eight participants are organized in a row and all of them are in state 0 with their left hand raised and touching the next participant on the row. Figure 46 and all figures that follow are screenshots taken from the simulator of the Human Calculator theatrical game available at: https://scratch.mit.edu/projects/410832633/

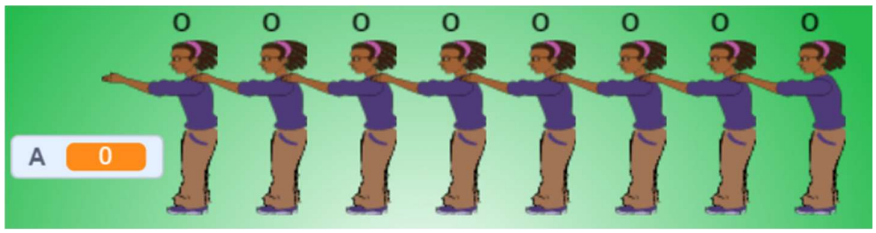

Figure 46: The Human Calculator theatrical game started: Eight participants, one behind the other, are organized in zero states, i.e., touching the participant in front of them. Note that the leftmost participant does not touch anyone else. Its state is zero as well.

Starting from this initial configuration, a binary representation of a number n can be found by touching the rightmost participant n times. Note that a participant changes state if someone touches it, following the rule of the game: *"Stand up, raise your hand and touch the shoulder of the participant in front of you. Whenever somebody touches you, lower your hand. If somebody touches you again, raise your hand and touch the shoulder of the participant in front of you. Continue this way forever"*. Apart from the previous participant touching the next one (whenever it moves into state 0), the operator of the Human Calculator can also touch it to make him/her change state. In the simulator, the operator is essentially the user of the simulator and touching a participant is simulated by clicking the corresponding graphical representation of the participant with the mouse.

During the actual game, the role of the operator is initially undertaken by the facilitator. At any point, any participant from the audience could also step in and undertake this role to interact with the Human Calculator.

Let us see now what happens if the operator touches the rightmost participant. As soon as the participant feels the touch, following the rule of the game, it changes state to 1, as depicted in the figure below. The Human Calculator now represents number one in binary $(00000001)_2$ as shown in Figure 47 below.

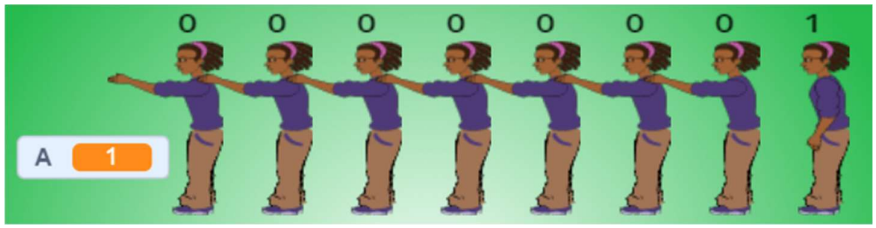

Figure 47: The Human Calculator theatrical game initiated to represent number 1.

If the operator touches the rightmost participant again, the participant will move from state 1 to state 0, thus touching the next participant to the left. As soon as the second participant feels this touch, following the rule of the game, will go to state 1. This is depicted in Figure 48 below. The corresponding number represented is two $(00000010)_2$. Two is also the number of times the operator touched the first participant so far.

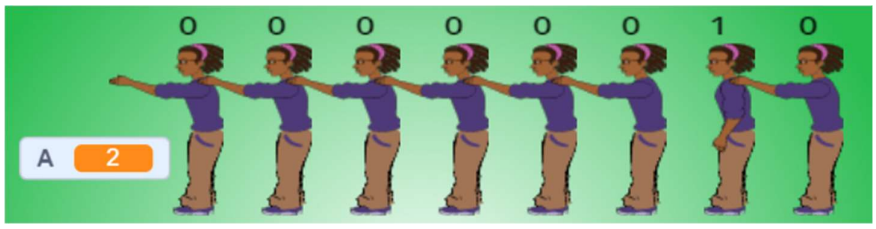

Figure 48: The Human Calculator theatrical game: Representing number 2.

Let us see now what will happen if the operator touches the first participant from the right, for a third time. The participant will change state from 0 to 1, lowering its hand. The second participant will feel no touch so it will remain in the same state (1). The result is depicted in Figure 49 below. The new set up corresponds to number three represented as $(00000011)_2$.

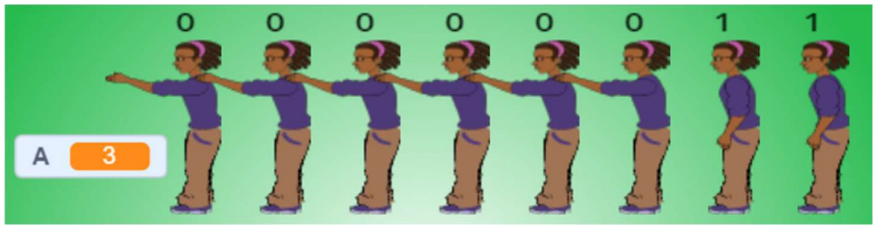

Figure 49: The Human Calculator theatrical game: Representing number 3.

Let us depict what happens in one step more, when the operator touches for the fourth time the rightmost participant. The rightmost participant changes state, after the operator touches it, and raises its hand to touch the next participant. In a similar way, this action will result in the second participant changing its state to 0, raising its hand as well and touching the third participant that will change its state from 0 to 1. The final setup is depicted in Figure 50 below:

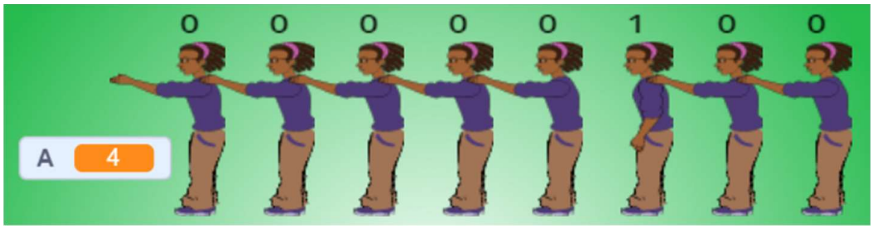

Figure 50: The Human Calculator theatrical game: Representing number 4.

The process can continue until the desired number of touches has been made. Figure 51 below depicts the situation after 13 touches to the rightmost participant.

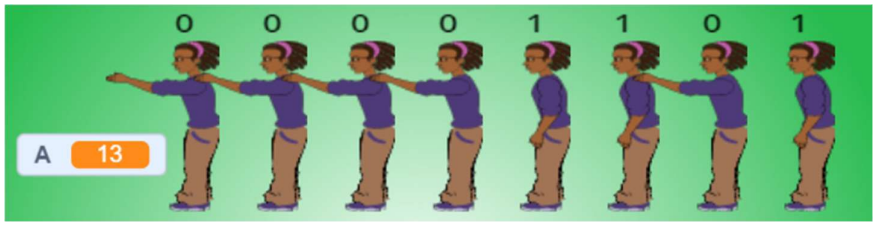

Figure 51: The Human Calculator theatrical game: Representing number 13.

At this point, the facilitator can invite the participants from the audience to experiment with the Human Calculator operation by interacting with it and see the binary representation of the numbers they choose. Furthermore, exploiting their natural curiosity, the facilitator guides to participants to explore what happens if they try to touch any participant in the row apart from the rightmost participant. The objective is to understand and explore the consequences of this strategy: Each participating actor in the sequence can be linked to a certain numerical value that corresponds to a power of two. The first participant from the right corresponds to $1=2^0$. The next participant corresponds to $2=2^1$. The next one to $4=2^2$, the next one to $8=2^3$, etc. Consequently, to set up the Human Calculator to the binary representation of a certain number n, the operator can directly touch the actors that represent the 1 bits in the

binary representation of n, if this binary representation is already known. This is the basis of performing additions and multiplications, as explained next.

A. Addition and Multiplication in the Human Calculator theatrical game

After mastering the basics of binary representation and being able to directly use binary representations of small integers, the Human Calculator theatrical game can be further used to introduce the participants to the algorithms for performing addition and multiplication in the binary system. Note here that the algorithms are essentially the same with the usual algorithms taught in primary schools for the decimal system. The only difference is that their binary counterparts are far easier to perform and, by exploiting the interactivity of the Human Calculator theatrical game, they can be more easily enacted using the bodies of the participants instead of doing the same algorithms with pen and paper.

Let us see, then, how addition can be performed. We will assume again that the Human Calculator has been initialized with eight participants, thus allowing the representation of up to 8-bit numbers. Recall from the previous section, that if you start from the representation of number zero the binary representation of a certain number n can be directly "loaded" by touching the participants that correspond to the 1 bits of the number n. Each participating actor in the row corresponds to a certain value of power of two, as already explained in the previous section. When a participant is touched, the corresponding power of two is added to the previous contents of the Human Calculator. Consequently, to add a number x to the current contents of the Human Calculator, the participants that correspond to the 1 bits of the binary representation of number x should be touched. The sequence of touching them does not matter.

In Figure 52 below, we show such a case of adding 13 with 3. We present the complete picture of the simulator of the game as it is organized to facilitate the exploration of operations. In particular, the simulator presents three rows of participants, the top row stands for the first operand (A), the bottom row stands for the second operand (B) and the middle row stands for the operation result (A?B) as it is gradually formed by the actions of the operator. The screenshot below depicts the set up after entering the two operands, 13 at the top row (A=13) and 3 at the bottom row (B=3). The middle row is not set yet.

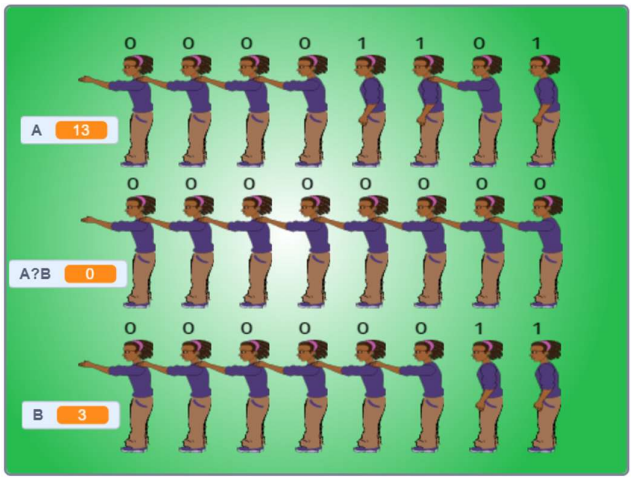

Figure 52: Perform the addition 13+3: Representing the two operands.

The first step to do the addition is to load the first operand in the middle row. This is accomplished by touching, one by one, the three participants that correspond to the 1s in the binary representation of number A=13. This is shown in Figure 53 below.

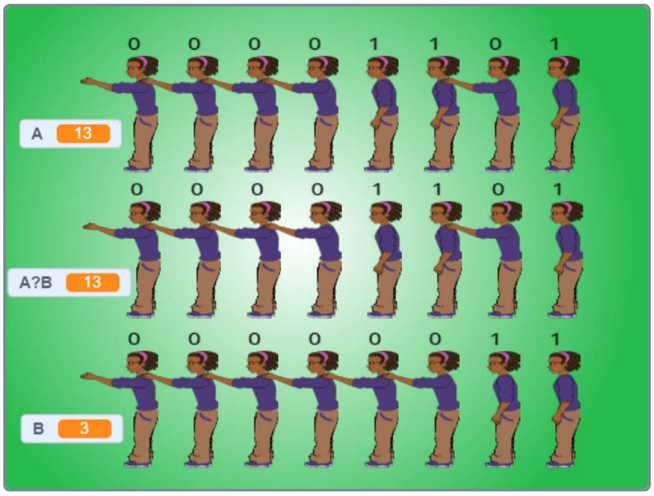

Figure 53: Perform the addition 13+3: Copying the first operand (A=13) to the middle row of the simulator that represents the desired result (A?B).

Next, we need to add the values that correspond to the two 1s of the binary representation of 3. We will first put the leftmost 1, i.e., the bit that corresponds to the value of $2 = 2^1$. This is done by touching the second participant from the right at the middle row. Initially, this participant is in state 0 (as shown in the figure above). After the touch the state is 1 as it is shown in the next figure. The corresponding partial result in the middle row is 13+2 = 15 as depicted in Figure 54.

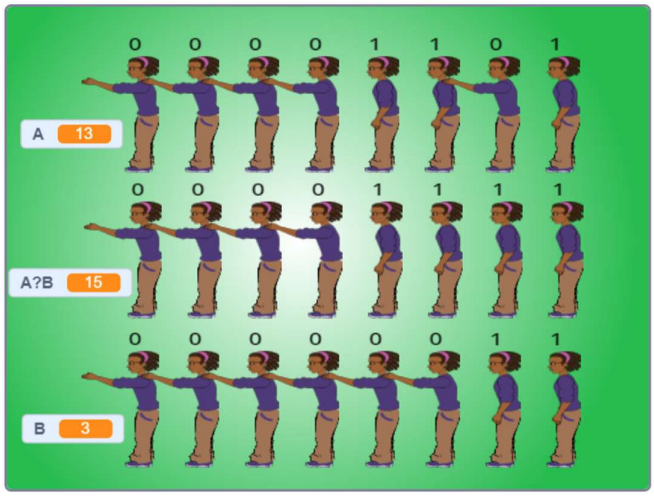

Figure 54: Perform the addition 13+3: Adding the second operand (B=3) to the middle row of the simulator that represents the result (A?B). To do so, the leftmost bit of the binary representation of 3 is added first, giving a partial result of 15.

Finally, we need to add the rightmost bit of operand B=3, i.e., the bit that corresponds to value $1=2^0$. This is done by touching the rightmost participant in the middle row. Following the rules of the game, all four participants at the right of the middle row will move to state 0 and the fifth participant will move from state 0 to state 1. The final result is depicted in Figure 55. The result of the addition has been calculated: 13+3 = 16.

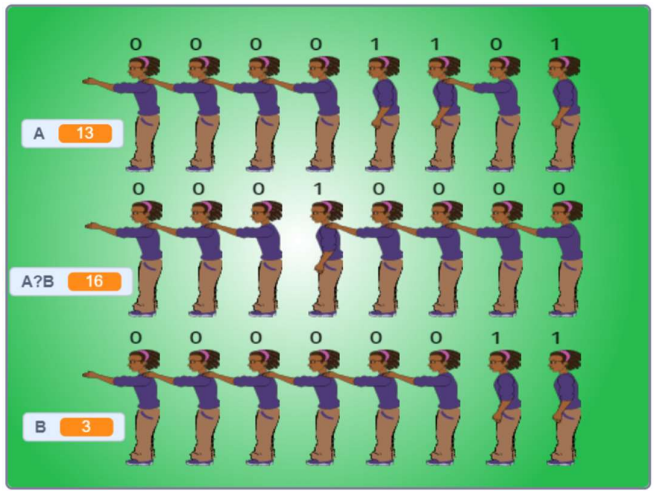

Figure 55: Perform the addition 13+3: Final result after adding the leftmost 1 bit of the second operand (B=3) to the middle row of the simulator that represents the desired result (A?B).

The process described so far for addition can continue to add any sequence of numbers. Each time, we add to the partial result so far, the next number of the sequence. The

facilitator can invite the participants from the audience to experiment with different ways of copying the 1 bits of the operands to the partial result and justify why there is no difference on which bit is copied first.

After exploring addition, the facilitator can invite the participants to play with multiplication. The most straightforward way of making a multiplication in the Human Calculator is by starting with the multiplicand and adding it k times where k is the value of the multiplier. This is something that the participants in the game are encouraged to find and explore for themselves. Then, they are guided to find a more efficient way of doing this series of multiplications exploiting the binary representation of the multiplier.

In particular, the participants are first invited to explore how a given number can be doubled by shifting its bits one position to the left. To multiply a number by $4=2^2$, its binary representation needs to be shifted to the left by 2 positions. And to multiply by 2^n a shift to the left by n positions is necessary.

After understanding the rules of multiplying by powers of two, the general procedure for multiplication can be presented: Perform a series of additions of the multiplicand shifted appropriately so that each 1 bit of the multiplier is used. For example, to multiply 12 by 5 start by setting A?B to 12 (i.e., the multiplicand shifted by 0 positions to correspond to the rightmost 1 digit of the multiplier) as shown in Figure 56 below:

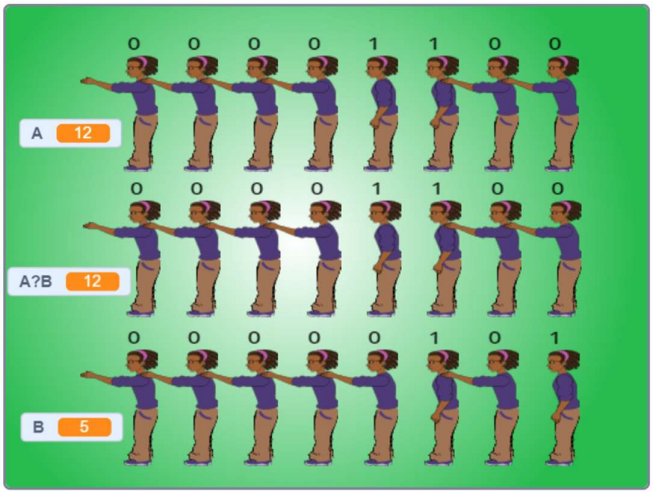

Figure 56: Perform the multiplication 12 X 5: The multiplicand is entered in the first row (A=12) and the multiplier in the third row (B=5). The middle rows, starts from 0 and is first loaded with number 12 shifted by 0 positions, corresponding the rightmost bit of B=5.

Next, we add the bits of A=12 shifted by 2 positions (corresponding to the leftmost 1 digit of 5). This essentially adds the number 12 X 4 = 48 to the previous partial result (A?B=12) reaching the final result of 60 (i.e., A?B = 12 X 5 = 60) as depicted in Figure 57:

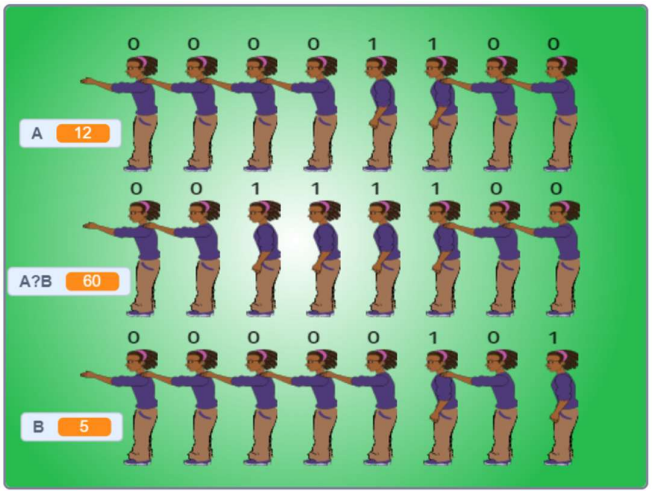

Figure 57: Perform the multiplication 12 X 5: In the final step, the multiplicand is added in the middle row shifted by two positions. The value in the middle row becomes 60, which is the desired result.

B. Subtraction and division in the Human Calculator theatrical game

To implement subtraction, the rule followed by the participants in the Human Calculator theatrical game is changed as follows: *"Whenever somebody stops touching you, lower your hand (stop touching the participant in front of you). If somebody stops touching you again, raise your hand to touch the participant in front of you. Continue this way forever"*. To enact the subtraction rule, the Scratch simulator available at https://scratch.mit.edu/projects/410832633/ supports two operational modes that can be activated by pressing the spacebar: The addition mode, presented with green background (as shown in the screenshots of the previous section) and the subtraction mode, presented with orange background. In the live version of the game, the change of mode can be signified by changing the lighting of the room, using flags that are visible from all participants or using oral instructions, whatever is more convenient and effective.

Let us see what happens if number A=13 is first loaded and then subtraction mode is activated. The situation after entering the subtraction mode is depicted in Figure 58:

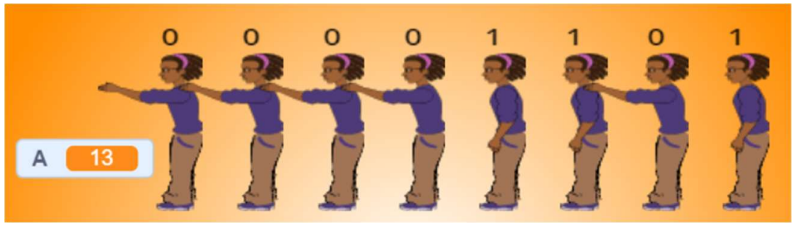

Figure 58: Entering subtraction mode with a row of participants representing number 13. The subtraction mode is depicted with orange background in the Human Calculator theatrical game simulator.

Let us see what happens if the rightmost participant, representing the value of $2^1=1$ changes state. To do so, the operator has to touch and then stop touching the participant. Following the subtraction rule, the participant feels that somebody stops touching him/her and changes state from 1 to state 0 by raising its hand to touch the next participant. The next participant does not change state (as it would have happened in addition mode) because it feels somebody to touch him/her. But the subtraction rule orders to change state only when you feel somebody stops touching you. The result is depicted in Figure 59 below.

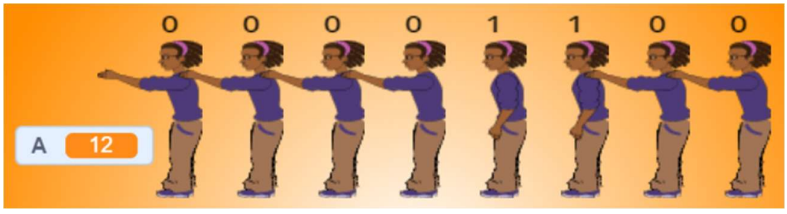

Figure 59: Subtracting 1 from 13 results in number 12.

Let us see next what happens if the leftmost participant changes state once more, following the command of the operator. This time, he/she changes state from 0 to 1, meaning that the second participant from the right will feel the participant behind him/her to stop touching it and consequently he/she will change state from 0 to 1. The third participant, then, will also change state going from 1 to 0. The final situation is depicted in Figure 60.

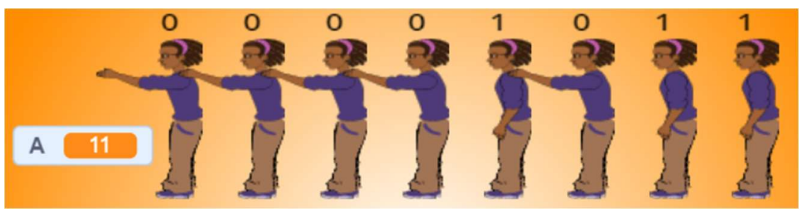

Figure 60: Subtracting 1 from 12 results in number 11.

It is not hard to see that whenever the rightmost participant changes state, the subsequent application of the subtraction rule to the participants on the left, brings the row of the participants in a situation that corresponds to the binary representation of the number n-1 where n is the number that was previously represented. Following similar observations and arguments as in the case of addition, it can be easily seen that each participant on the row represents a value of power of two and changing his/her state, corresponds to subtracting the corresponding value from the number represented on the row.

The following screenshot depicts how an actual subtraction is performed in the Human Calculator theatrical game simulator. As in the case of addition, operands A and B are initialized and the A?B row starts with the contents of the A operand. This is all done in addition mode. Then the subtraction mode is activated. This is depicted in Figure 61 where we want to perform the subtraction 13-3.

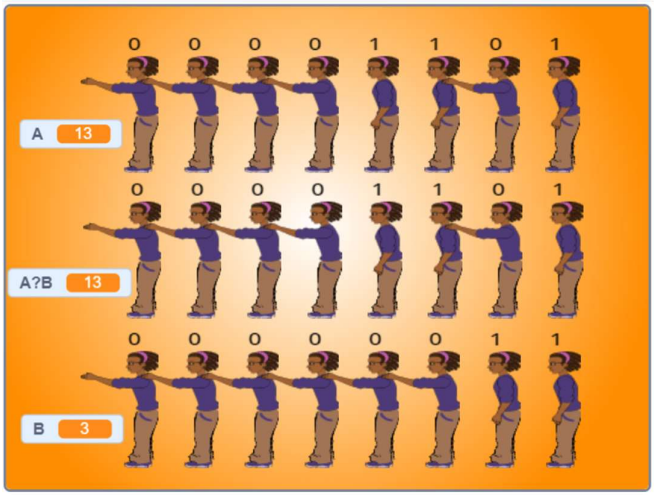

Figure 61: Perform the subtraction 13-3. Initialize the operands and the middle row to 13.

Then, to perform the subtraction, the 1 bits that correspond to operand B=3 should be transferred to A?B, i.e., $1=2^0$ and $2=2^1$ should be subtracted from the binary representation of 13. Following the subtraction rule, when the rightmost bit of 13 changes from 1 to 0, nothing more happens to the other bits. When the second bit from the right is changed from 0 to 1, following the subtraction rules, the third bit is also changed from 1 to 0. The fourth bit remains unchanged. The final set up is shown in Figure 62.

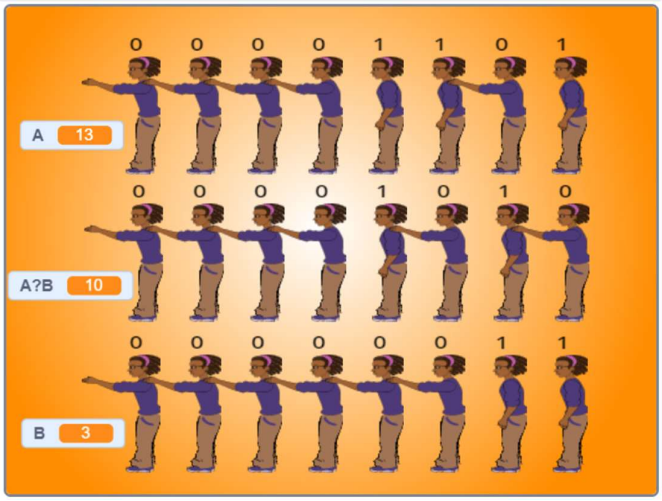

Figure 62: Perform the subtraction 13-3. Subtract the values (powers of two) that correspond to 3 from 13 to find the final result A?B=13-3=10.

After mastering subtraction, division can be explored as a series of subtractions. In its simplest form, division corresponds to repetitive subtractions starting from the dividend and subtracting the divisor until zero is reached or a remainder (a positive number less than the dividend) is found. The number of subtractions made is the quotient of the division. We can speed up the process by following the long division algorithm or even explore other division strategies. Finally, the representation of negative numbers can be explored. Following the rules of subtraction, if the Human Calculator is initialized to zero, the two's complement representation of negative number can be found.

APPENDIX 2 – THE BINARY ABACUS BOARD GAME

This appendix presents details for the Binary Abacus board game including the mechanisms for binary number representation, transformation from and to binary system, and the four arithmetic operations.

A. Addition

Let us see first how addition is performed in the board game. Figure 63 depicts the board of the game with number 5 represented in the first row and number 3 in the second row. To add these two numbers together, the player has to start from a clear row and put chips that correspond to the chips of the two numbers that are added. For the 5+3 example, this is done in the third row of the board in Figure 63.

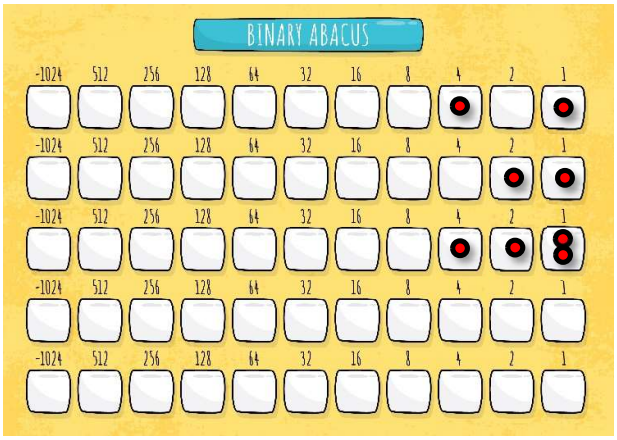

Figure 63: The Binary Abacus board game showing 5 rows each one corresponding to an 11-bit Binary Abacus. The example show corresponds to addition 5+3.

The next step is to handle possible pairs of chips that may appear in a position, as it is the case for the rightmost position of the third row in the example. The rule is that such pairs are removed from the board and a new chip is added to the position on their left. If this move creates a new pair, the rule is applied recursively until all pairs are promoted, this way, to chips to the left. This is depicted in the figure below for the example addition 5+3 presented above. The final result is the recursive promotion up to the fourth position from the right that represents 8. So, the result is 5+3 = 8 and the corresponding binary representation of the result is $(1000)_2$ as shown in Figure 64.

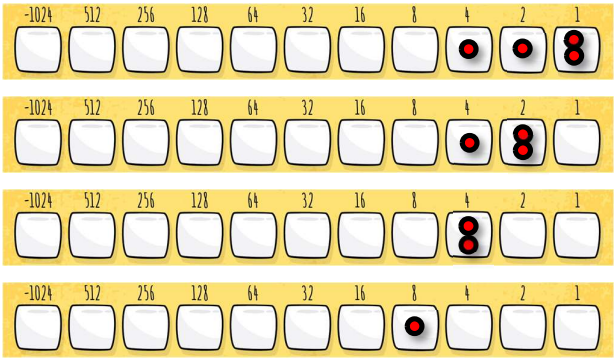

Figure 64: Handling pairs of chips during addition in the Binary Abacus board game.

B. Multiplication

Multiplication can now be done in a way that directly corresponds to the way already presented for the Human Calculator theatrical game. In particular, multiplication is done as a series of additions. The way to present it is by making a sequence of copy operations followed by an addition. Let us see the copy operation first and how it can be used to find multiples of a number that correspond to powers of 2. Let us start with number 5 as shown in the first row of Figure 65. If this number is copied into an empty row, one position to the left (second row of Figure 65), the result in number 10, i.e., number 5 multiplied by 2. If it is copied two positions to the left (third row of Figure 65), the result is number 20, i.e., 5 x 4 = 5 x 2^2. If it is copied three positions to the left (fourth row of Figure 65), the result is number 40, i.e., 5 x 8 = 5 x 2^3. In general, if a number is copied in an empty row at n places to the left, the result is the initial number multiplied by 2^n.

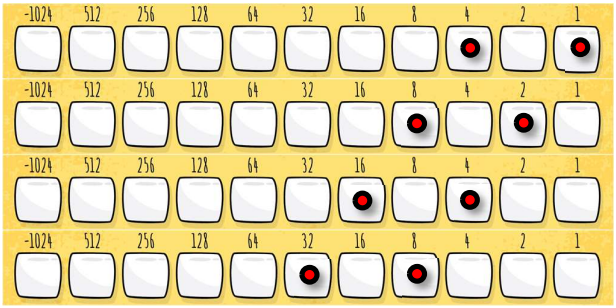

Figure 65: Finding multiples of a number that corresponds to powers of two
by copying and shifting the number to the left in the Binary Abacus board game.

Based on the above idea of copying, a multiplication can be done as follows: Copy the multiplicand using the positions of the chips in the multiplier. Each chip in the multiplier,

corresponds to one copy of the multiplicand shifted to the corresponding position. Then, add all these copies together to find the result. The addition of the copies could also be done one by one. Figure 66 demonstrates the multiplication 6 x 5. The first row shows the multiplier (6) while the second row shows the multiplicand (5). The third row shows the multiplicand copied one place to the left to correspond to the first chip from the right of the multiplier. The fourth row shows the multiplicand copied two places to the left to correspond to the second chip of the multiplier. Finally, the fifth row represents the result of the multiplication by adding the two copies together (rows three and four). The result, as can be seen, is $(11110)_2$, i.e., 30 in decimal (6 x 5 = 30). In this particular example there was no need to handle pairs of red chips in the same position of the result. In case there are such pairs, the process or promoting to units of the next place to the left is done as needed.

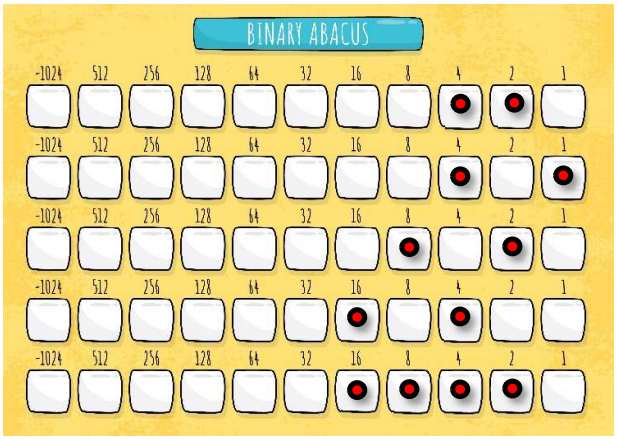

Figure 66: Multiplying 6 X 5 in the Binary Abacus board game.

C. Subtraction

Subtraction in the board game can be done by introducing a second type of chips to represent negative units. These are blue chips in Figure 67. The first row of the board represents number 5. The second row represents number -3. The third row, is used to find the result. Initially it contains a copy of each chip of the numbers that participate in the operation.

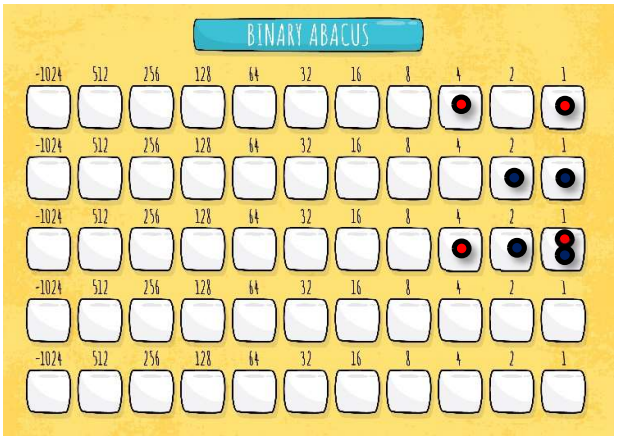

Figure 67: Performing subtraction in the Binary Abacus board game. Example shown: 5-3.

To find the result of the subtraction, chips of only one colour should remain on the board. If only red chips remain, the result is positive. If only blue chips remain, the result is negative. Whenever two chips of different colours appear on a certain position, they are eliminated (1-1=0). If chips of different colours remain at different positions, the chip that is at the leftmost position is demoted (i.e., substituted with two chips in its right side) and this is done recursively until a two chips of different colour appear so that they can be eliminated. The example in Figure 68 demonstrates the process for making all necessary eliminations to find the binary representation of 5-3. Initially, the two chips in the rightmost position are eliminated. Then two chips are left, one red to the third position and one blue to the second position from the right. The red chip is demoted and two red chips are put in the same position with the blue chip. Then yet another pair of chips is eliminated, one red and one blue. This results in one red chip left at the second position from the right. The final result is thus found corresponding to 5-3=2 or $(10)_2$ in binary representation (Figure 68).

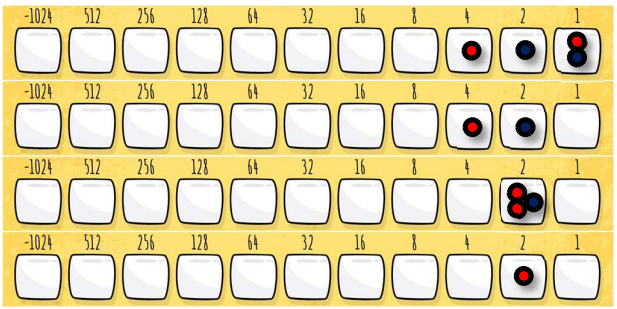

Figure 68: Finding the binary representation of 5-3.

D. Representation of negative numbers

The subtraction presented above, essentially relies on a representation of negative numbers that is known as one's complement. This is accomplished by introducing chips of negative value (blue chips). Another option that is essentially the way negative numbers are handled by the Human Calculator theatrical game, is two's complement representation. This representation does not need a new type of chips (only red chips are used). However, it needs to adopt a different value for the leftmost position in each row: the negative value of the corresponding power of two. This is why the leftmost position in the Binary Abacus is signified with a negative value (-1024).

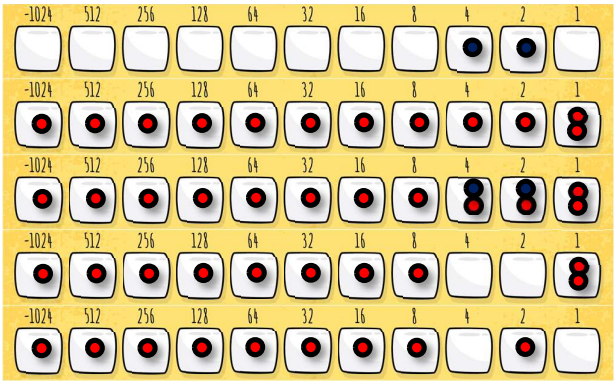

Figure 69: Transforming the one's complement representation of -3 to two's complement representation in the Binary Abacus board game.

To transform a negative number represented in one's complement (blue chips used) into two's complement representation, the player needs to put a red chip in each one of the places of the Binary Abacus. This is the representation of number -1. In the right-most place, a second red chip is added. This corresponds to number 1. In total, all these red chips together represent 1-1 = 0. After this, the operator proceeds by eliminating pairs of red and blue chips and, if needed, processes any pairs of red chips that remain by promoting one chip to the next place to the left. Figure 69 demonstrates this process by showing how the one's complement representation of -3 is transformed into the corresponding two's complement representation step by step from top to bottom.

To make the reverse transformation, from two's complement representation back to one's complement representation, the procedure is exactly the same with the red and blue chips in opposite roles: The player starts by the two's complement representation and adds one blue chip in each place of the Binary Abacus. In the right-most place, the player puts yet

another blue chip. Then the necessary eliminations and pair of same colour chips promotions are made.

E. Division

Division, as already noted in the Human Calculator theatrical game, can be implemented using subtraction. It produces two numbers as result: the quotient and the remainder. The quotient is essentially a number that represents how many times the divisor can be subtracted from the dividend before the remainder becomes less than the divisor or zero. Using multiples of the divisor that correspond to powers of 2, in analogy to the use of such multiples in the multiplication, can speed up the operation.

F. Transformation of numbers from binary to decimal

An important aspect of the effective use of the Binary Abacus board game in actual learning scenarios is the need to support the transformation of numbers from the binary system to decimal and from the decimal system to binary. The approach to this transformation that is usually taught in secondary and tertiary education, is based on the decimal system: To transform a binary number to decimal, the digits that correspond to 1's in the binary representation are evaluated as powers of 2 and they are added using their decimal representation. For example, to find the decimal representation of $(10111)_2$, this approach will compute the following sum corresponding to the powers of 2 composing the number to be transformed:

$(10111)_2 = 1 \cdot 2^4+0 \cdot 2^3+1 \cdot 2^2+1 \cdot 2^1+1 \cdot 2^0 = 16+4+2+1=23$

An alternative approach to do this conversion is to employ successive divisions of the initial number in its binary representation, i.e. $(10111)_2$ divided by $(1010)_2$, which is ten in binary. These successive divisions will produce the digits of the decimal representation of the number as the successive remainders. For example, dividing 23 by 10, i.e. $(10111)_2$ by $(1010)_2$, will result in quotient $(10)_2$ and remainder $(11)_2$. This means that the initial number has two tens and three units, i.e., it is number 23 in decimal. If the number is bigger, and the tens computed this way are more than nine, the process should continue, with further dividing the number of tens by $(1010)_2$ to find the hundreds (the remainder of this second division will represent the tens) and if necessary, more divisions to find the thousands etc.

G. Transformation of numbers from decimal to binary

The usually taught method to transform the decimal representation of numbers to binary, is by performing successive divisions by 2, the base of the binary system, and recording the remainders. For example, to transform 23 into binary, the successive divisions are given below. The process records the remainder of each division to the right and the

quotient underneath the initial number. The process continues until a quotient of zero is found. At this point, the binary digits of the number can be read from the most significant digit (last remainder to the bottom of the right column) to the least significant digit (first remainder in the right column):

23	1 (least significant digit)
11	1
5	1
2	0
1	1 (most significant digit)
0	

To avoid this kind of manipulation in the board game, the transformation of a number from decimal to binary can be done as follows: First the digits of the decimal number are represented from the least significant (top) to the most significant one (bottom) in the Binary Abacus as shown in the example in Figure 70 where the number 23 is depicted by putting three units as $(11)_2$ in the first row and two tens as $(10)_2$ in the second row. Then, the tens are multiplied by ten, i.e. $(1010)_2$ as depicted in Figure 71. Finally, the two numbers are added to produce the binary representation of 23 (Figure 72).

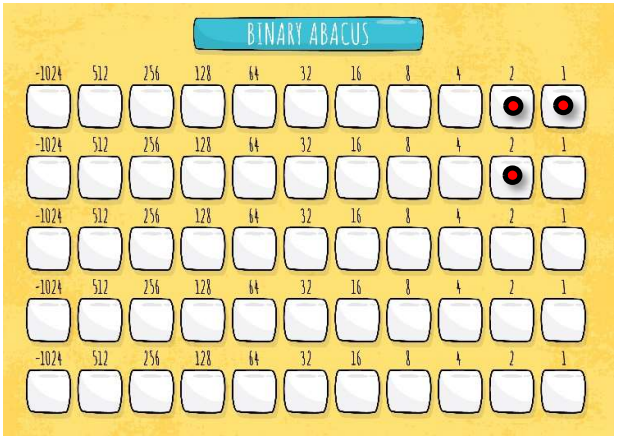

Figure 70: Representing the decimal digits of number 23 in binary.
The first row corresponds to units and the second one corresponds to tens.

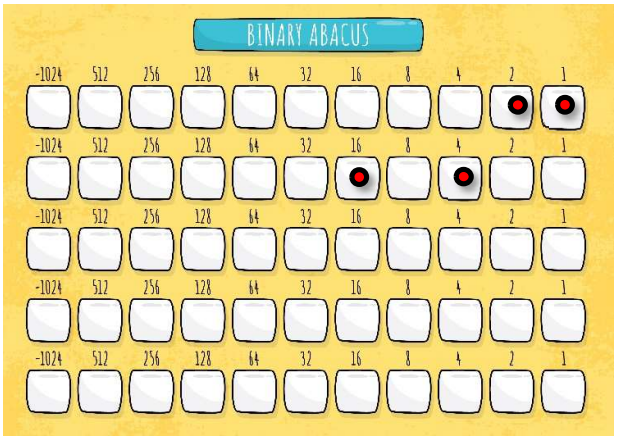

Figure 71: Following the representation of number 23 in Figure 70, to find its binary representation the first step is to compute how many units correspond to the two tens (second row) by multiplying 2 X 10.

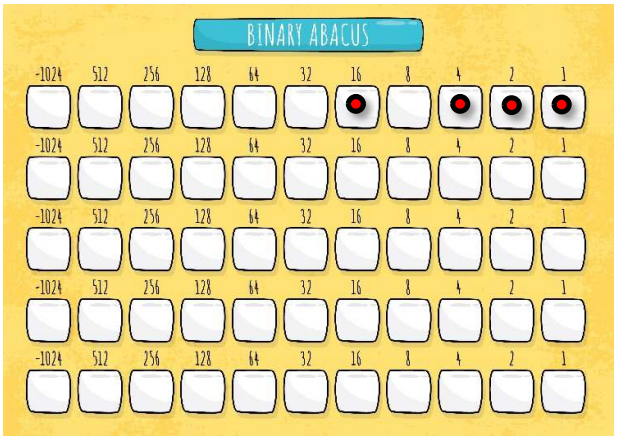

Figure 72: The final result of computing the binary representation of 23 by adding together the partial sums from Figure 71.

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