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Exploring the potentialities of learning through Augmented Reality Serious Games

The evolution of digital systems has shaped the way we engage with information, stimulating the proposal of new learning methodologies. Among them, thanks to the growth of the multi-media PC market, the idea of learning through entertaining digital applications (i.e., edutainment) rose to popularity through the 1990s. Then, at the turn of the century, powered by the ever-growing video-game industry, the concept of edutainment evolved into what they are now called serious games (SG), which are games designed with a purpose other than pure entertainment. Although these "serious" purposes can be varied (e.g., physical exercise and rehabilitation, and marketing), they undoubtedly include learning.

Through the years, SGs have leveraged a vast set of technological platforms such as computers, consoles, mobile devices, and, more recently, augmented reality (AR). The interest in this technology has several explanations. First, AR has shown positive evidence as an ideal tool for learning purposes. Second, the development of AR-based applications has become easier and more accessible. Third, consumer-level mobile devices can now support AR applications. Finally, both SG and AR educational applications can create motivating and engaging educational activities in which users can explore the proposed contents through an interactive and immersive digital experience that supports experiential approaches. Although the number of developed learning experiences combing AR and SGs (AR-SGs) is growing, this research field is still at an early stage and rapidly evolving as AR technology continues to improve.

Based on these premises, this Ph.D. thesis aims to advance the current state of the art in AR-SGs research exploring new potentialities, addressing possible issues, and evaluating the outcomes of combining these two tools/approaches in an educational context. More formally, this work wishes to provide empirical evidence to answer the following research questions:

RQ1: Can we establish synergies between AR and SGs in order to develop effective AR-SGs in a variety of learning contexts?

RQ2: Are AR-SGs effective?

RQ3: Usability can be an issue in AR-SGs, can it be softened?

This work adopted a case study approach through the design, development, and assessment of four AR-SGs. Each of these research "instruments" provided evidence in support of all the RQs, allowing their analysis under slightly different lenses.

To answer RQ1, I have selected a subset of learning domains in which either AR or SGs had already been primarily exploited as "individual" but not widely in combination with one another. %In the end, I identified three possible domains which met my needs. They are procedure learning, complex systems

learning, and soft-skills learning. For each context, I developed one or more applications leveraging synergies between AR and SGs, where for synergies, I mean the creation of an effective "relationship" between these two approaches/tools, where the affordances of either one would be exploited to enhance the other. Thanks to the established synergies, the proposed solutions immersed and engaged the users in the learning experience, motivated them to play (and learn), and fostered several group dynamics beneficial to the overarching learning objective. Although these outcomes have been achieved in specific topics, many of the design choices and mechanics proposed can be transferred, with similar positive results, to other topics within the same learning domain.

Through RQ2, I wished to explore the effectiveness of the proposed AR-SGs. In other words, could they achieve the purpose for which they were designed? In the context of AR-SGs, these purposes can be divided into an entertaining and educational one. The latter can then target different outcomes according to the specific learning domain addressed by the AR-SGs. These outcomes can be broad, ranging from the acquisition of concepts to the development of 21st-century skills. Finally, an essential aspect of AR-SGs (and SGs in general) is the relation that must be established (and assessed) between entertaining and educational purposes as these two elements must promote one another, i.e., the entertaining experience elicits the educational one and vice versa. To explore the effectiveness of the proposed AR-SGs I adopted an evaluation procedure that featured the collection of a comprehensive set of data, both qualitative (i.e., questionnaires) and quantitative (i.e., application logs and annotated gameplay recordings). By analyzing these data separately and by exploring possible relations, I could conclude that the proposed AR-SGs were fun and engaging, they achieved their pedagogical goal, and these two outcomes were positively interconnected as they both influenced each other. Finally, similar conclusions achieved in the design of our applications can be made for the evaluation methodologies. I believe that several experimental design choices and employed instruments could be exploited and adapted by future practitioners who aim to assess outcomes similar to those I propose.

The last research question originated from evidence in the literature reporting compromised learning outcomes caused by inadequate usability levels or poorly designed UX in AR learning applications. I approached this problem by developing the four AR-SGs through a careful process that placed users' needs at the cornerstone of my design choices. The outcomes of this process were tested through usability studies conducted for each AR-SGs. Users' evaluations were highly positive, even when targeting users with no or limited prior knowledge of AR. As an output, we propose several guidelines that future practitioners could follow when embarking on the delicate task of developing AR-SGs where usability issues do not hinder the overarching entertaining and learning experience.

Concluding, this thesis provides empirical evidence that from the combination of AR and SGs, new and unique learning experiences can be established.