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Advancing Physics Learning Through Traversing a Multi-Modal Experimentation Space

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Abstract. Translating conceptual knowledge into real world experiences presents a significant educational challenge. This position paper presents an approach that supports learners in moving seamlessly between conceptual learning and their application in the real world by bringing physical and virtual experiments into everyday settings. Learners are empowered in conducting these situated experiments in a variety of physical settings by leveraging state of the art mobile, augmented reality, and virtual reality technology. A blend of mobile-based multi-sensory physical experiments, augmented reality and enabling virtual environments can allow learners to bridge their conceptual learning with tangible experiences in a completely novel manner. This approach focuses on the learner by applying self-regulated personalised learning techniques, underpinned by innovative pedagogical approaches and adaptation techniques, to ensure that the needs and preferences of each learner are catered for individually.

Keywords. Physics learning, physics experiments, mobile devices, virtual worlds, augmented reality, self-regulated learning, personalisation

1. Introduction

Competence in science, technology, engineering, and maths (STEM) is an important pillar of today's knowledge economy. However, shortages in STEM expertise and interest in STEM careers can be identified across Europe, in particular in the field of physics and mathematics. In addition, there exists a significant gender imbalance in STEM fields, with women being historically underrepresented. As a result, STEM education – and how to make it more effective and appealing – is still an important goal of the European

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educational system. Ways of making science education and careers more attractive for young people are sought and the use of new tools and innovative pedagogical approaches in teaching STEM is promoted (e.g. [15], [12]). Different successful pedagogical models for STEM fields use teaching methods which promote hands-on, collaborative, visual, and discussion-based activities [10] [6].

In this view different approaches have accepted this challenge and have their way in science education in general and physics education in particular. The strong real-world link is a core feature especially of "context-based science education", which has a long-standing tradition and is considered to be a highly promising approach in science education [7], [3], [20], [24]. Context-based science education (CBSE) is currently broadly understood as "using concepts and process skills in real-life contexts that are relevant to students from diverse backgrounds" [9]. Making science issues relevant to students and the social group they live in (peers and relatives) counters the widespread perception of physics as being dry, impersonal, and irrelevant. In this view different CBSE classroom settings have been developed and implemented. Although this approach is promising, its effect on conceptual learning and problem solving is contradictory [19] [17].

Therefore beside the motivational aspect of translating conceptual knowledge into real world experiences a very important cognitive aspect has to be considered: It's well known that competent handling of multiple representations is supposed to be significant for learning and solving problems – especially in science education [1] [2]. Furthermore researchers have found that integrating multiple representations (especially visual ones) could afford a better conceptual learning environment for many students [6] [8] [23].

Considering these motivational and cognitive aspects, the use of smartphones and tablet PCs as experimental tool offer unique opportunities for establishing multiple links to the real world of learners and boosting their conceptual knowledge and problem solving competence. Furthermore, virtual reality environments have similar advantages, as they can offer simulations of real world experiments. We can therefore assume that this technology has positive effects on the learner's interest in both science and technology, their self-efficacy, and their learning.

This paper presents an innovative approach for physics learning that grounds on two pillars, which are (1) new developments in mobile devices, augmented reality, and virtual environments, and (2) new advancements in TEL research, including adaptive and personalised learning, mobile and ubiquitous learning. The core piece of this approach is the Smart Learning Environment that provides both a multi-modal experimentation space and a learning assistant that personally supports the learner to traverse through the experimentation space. Though this approach has not been implemented and tested yet, it still includes several components from the authors that have already been developed and tested. The goal of this paper is to outline a concept, how these components can be brought together to advance the physics education.

2. Smart Learning Environment

The core part of the conceptual approach is the Smart Learning Environment (see Figure 1) that empowers learners, students, and the general public to learn physics in new ways. This environment consists of two parts, the experimentation space and the smart assistant. The experimentation space is the technical environment that allows learners to engage with physics knowledge and experiments in different modes and on different locations. Mobile devices and their sensors are used to make various kinds of physics experiments in the real world. Augmented reality applications are used to support the understanding of the underlying physics knowledge. The same physics concepts and experiments are accessible in virtual reality settings that put a different perspective on it. Finally, existing paper-based educational material, such as books, sketches, maps or drawings, are made digitally accessible with the help of further augmented reality applications. The learners can move (traverse) between these modalities and experience learning from different perspectives.

Learning support is provided through the smart assistant that tracks the learning activities, gives personalised recommendations in terms of concepts to learn or resources to use, and personalised feedback in terms of performed activities and achieved learning progress. Furthermore, motivation is stimulated by injecting gamification elements in the experimentation space. The smart assistant also connects the modalities of the experimentation space, so that learners get support in each phase depending on their competence state, personal needs, and previous activities perfomred in the other modalities.

A major characteristic of the smart learning environment lies in its flexibility. It can be applied in both formal and informal settings, because it allows for teacher-regulated learning and self-regulated learning including motivational strategies. Learners can learm in educational institutions, at home, or outside in the real word, and alway get repective support. Details on the experimentation space and learning support are provided in the next sections.

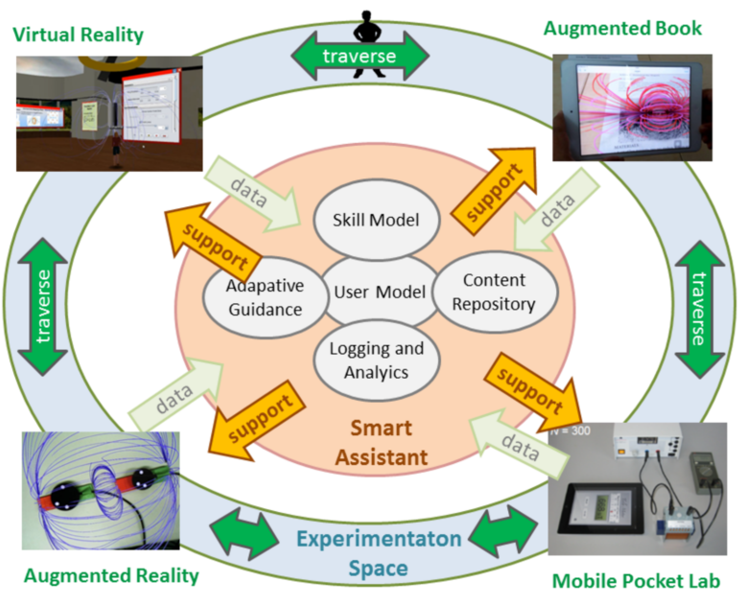

Figure 1. The Smart Learning Environment consisting of the physics experimentation space (outer circle) and the smart assistant (inner circle).

3. Physics Experimentation Space

3.1. Learning Physics Concepts with Augmented, Interactive Books

The first step in a learning process often starts with learning a theoretical concept. Traditionally printed learning material (e.g. books, graphs, exercise sheets) are used to learn concepts. The augmented book refers to the idea of using augmented reality (AR) to enrich the content of printed learning material, be it through the use of mobile devices, or directly on the paper substrate (e.g. through projecting new content). The technology works by detecting the page in view at any time and overlaying new information either over the image of the paper document (when using a mobile device) or in real life (when using projector/camera based solutions). As an example imagine the case of a learner studying magnetism and its relationship with electric current. The AR software then overlays animated examples of magnets and visualises the magnetic field and its relationship to the electric circuit (see Figure 2). The smart assistant logs this learning activity (the magnetism topic) and recommends to try out a real world experiment or other suggested activities. Once the user completes suggested activities, the book can act as the anchor point for concentrating all the new, personalised information collected by the user.

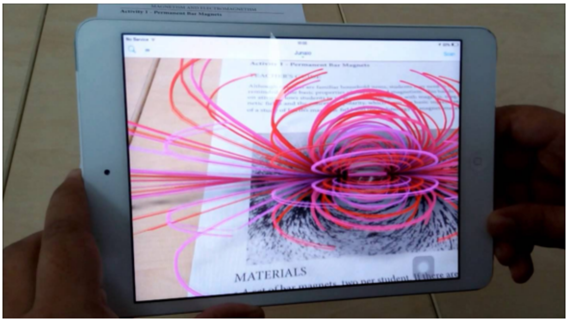

Figure 2. Learning magnetism concepts with an augmented book [Picture taken from a video of VirtuoCity Systems, http://www.virtuocity.my/].

3.2. Real world experience with the Mobile Pocket-Lab: Using Mobile Device as Experimental Tool

With internal sensors of mobile devices students could detect physical data by themselves [16] [18] . For example, to explore the relationships in the framework of magnetic fields the internal magnetic field strength sensor of smartphone/tablet PC is used. In this case, students analyse the relationship between the magnetic flux B of a coil and the electric current I, the number of coil-loops N or the distance to the coil d. Therefore, they first position the mobile device with its magnetic field sensor in front of the coil's longitudinal axis and set up the experiment as presented in Figure 3 (left side). Second, e.g., for studying the B-I-relationship, they start a relevant app (e.g. Tesla Field Meter for iOS or AndroSensor for Android), measure B successively for different I, tabulate the data, and plot the B-I-diagram with the data of the table (see Figure 3, right). In this learning space, students build up basic competences concerning cognitive as well as experimental skills and methodologies in the specific topic. The smart assistant (implemented as app on the mobile device) tracks the activity and relates it to the respective topic on the backend.

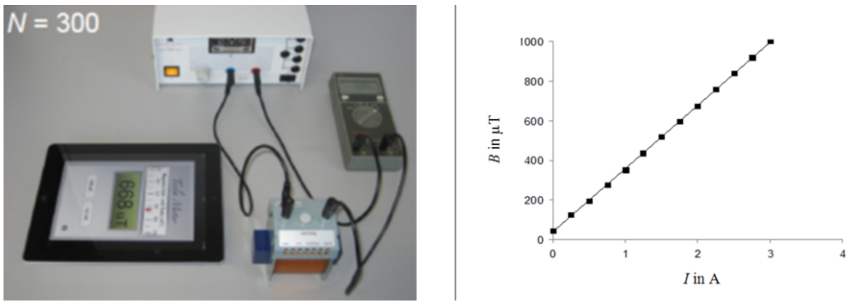

Figure 3. Magnetism experiment in real-life setting with a tablet PC.

3.3. Augmented Pocket-Lab Environment: Enrich the Real World Experiences by Conceptual Augmentation

In this learning space it becomes more important that the experimental procedure is as simple as possible for students because of their built up basic competences to allow them engaging in an explorative process in which hypotheses emerge, lead to new measurements, and observations are eventually rejected, modified, or accepted with different students following their own paths and ideas. Following the magnetism example students analyse the relationship between the magnetic flux B of a coil and the number of coil-loops N. Again the mobile device must be positioned with its magnetic field sensor in front of the coil's longitudinal axis and set up the experiment as presented in Figure 3 (left side). Second, for studying the B-N-relationship, they start a relevant app (e.g. Tesla Field Meter for iOS or AndroSensor for Android) and measure B successively for coils with different N. The data is then plotted automatically in the B-N-diagram and with the camera of the mobile device focus on the coil its magnetic flux lines (incl. vectors) are visualized by AR by object recognition. So this learning space presents learning proposals which are augmented by relevant representations to improve especially conceptual learning.

3.4. Exploring Physics Theory in the Virtual World

Virtual spaces, such as virtual worlds and immersive virtual realities, allow more advanced and interactive forms of online and digital learning and experimenting. They support interactive internet-accessible physics experiments and can be used to visualize different phenomena, which are in real life too expensive, too dangerous, or invisible. We define two major versions of virtual environments: (a) single-user environments, accessible for only one user, and (b) multi-user environments, which support the access to the virtual environment for several users in form of avatars and support communication and collaboration. Multi-user environments additionally enable collaborative remote learning scenarios. With the introduction of innovative and affordable VR devices (e.g. Oculus Rift or Google Cardboard) for the living room, also well-designed immersive

VR-experiences become more and more relevant for personal distant learning and training scenarios. Figure 4 illustrates a collaborative virtual world setup, which is designed for small student groups to learn the physics of Faraday's Law together. While they are working together on different experiments and are interacting with the three-dimensional visualizations, they can communicate synchronously with VoIP [21]. The smart assistant can be included in the virtual experiments, tracking what learners are doing.

Figure 4. Magnetism experiment and theory in the virtual reality.

4. Smart Assistant

4.1. Psycho-Pedagogical Approach

The overall psycho-pedagogical approach underpinning the smart assistant consists of a combination of different pedagogical paradigms and learning theories. This blend allows for aligning the smart learning environment with formal and informal settings. Furthermore, they provide the basis for the learning support based on technical methods.

The experience-based learning model developed by Kolb [14] is a learner-centric model that regards learning as the process where knowledge is created through the transformation of experience. This model suggests that experiments stimulate the conceptualisation and reflection of new domain knowledge and thus deeper understanding is achieved. In order to achieve a systematic approach for knowledge attainment, the psychological-mathematical framework Competence-based Knowledge Space Theory [11] is employed that provides an approach for representing skills and knowledge of both the physics subject domain and the learner. This framwork also has available methods for adaptive guidance and testing, in order to personalise the learning experience.

On a meta-level self-regulated learning describes a learner-centric approach, where the learner takes over control of the own learning process including goal setting, planning, self-monitoring, self-reflection, and self-evaluation [25]. While the experience-based learning model rather targets the acquisition of domain (physics) skills, self-regulated learning targets the application of meta-cognitive skills to control the learning process. Another way to raise the students' motivation and engagement with the learning material is to enrich learning with elements and strategies originated from game design. This process is called gamification [5] and supports the learner to interact with the system in a motivating and playful way. Different studies show the effectiveness of gamification strategies in learning contexts (e.g. [13] [22]).

4.2. Adaptive Guidance Through Smart Assistant and Gamification

The central component that manages the personal guidance is the smart assistant. This component is installed on all the mobile devices and in the virtual reality. It tracks the activities of the learner, the visited concepts, and the performed experiments in all modalities and sends the respective data to the back-end services. This data is used to derive a user profile in terms of visited resources, related competences, and potential learning problems. Based on this information, the smart assistant can provide personalised recommendations. For example, it can recommend which topic should be learned, which material or experiment should be performed, or which modality (augmented book, mobile device, virtual reality) should be used. The smart assistant should utilise a narrative-based approach [4] to ensure the concepts connect with experiences the learner has had. In this way the smart assistant connects the modalities and enables a meaningful traversing through them. Furthermore, it implements the pedagogical concepts described above. For example, it can be designed to recommend physics concepts in a meaningful sequence based on their prerequisite structure.

Gamification in our approach is used as constant companion of the learner in all the different smart learning environments and technologies. It is used as a strategy to enhance the learning experience with engaging and feedback elements. These feedback elements include for example points, progress-bars, or badges for special achievements. As a constant companion, the entire progress and the achievements are not only visible inside the current smart technology, but also in a separate cross-platform, which can be also used to share achievements with other learners for social engagement.

5. Conclusion and Future Work

This position paper presented an approach that targets the advancement of physics learning by taking into account new developments regarding mobile devices and their sensors, augmented reality, and virtual reality. Learners will be empowered to do physics experiments in real world settings and in virtual reality environments, thus applying conceptual knowledge learned with augmented reality technologies. Personalisation approaches and related services in the background support the learners by considering their individual preferences and needed amount of guidance.

The overall approach is seen as basis and direction for future research and development in these areas. It relates individual work on physics experiments with mobile devices, augmented reality, and virtual reality to a broader concept of physics learning. Thus it enables the continuous work towards the overall approach. Though the achievement of this overall goal would require a lot of efforts, the development of individual parts are more realistic for the near future. For example, doing experiments with mobile devices and using augmented reality for further help are doable in rather short time.

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