Improving Future STEM Education with Innovative Learning Management System and Technology-Enhanced Learning Materials NEWTON Project and Large Scale Pilots

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Abstract

European countries are facing potential shortage of scientific professionals in the coming years. Major reasons behind such crisis include the perception amongst students that science, technology, engineering and math (STEM) subjects are difficult, less rewarding than some other subjects and most importantly, the ineffectiveness of traditional STEM teaching paradigm in invoking students' motivation and maintaining their interests. To tackle the crisis, NEWTON¹, a large-scale initiative funded by Horizon 2020², propose to develop, integrate and disseminate innovative technologyenhanced learning (TEL) methods and tools, and build a pan-European learning network platform that supports fast dissemination of learning content to a wide audience in a ubiquitous manner. NEWTON focuses on employing novel technologies, such as serious games, AR/VR, Fab lab, virtual lab, gamification, in order to enrich learning process, enhance learner quality of experience and potentially improve learning outcomes. In this paper, a brief overview of the NEWTON project and an insight of its key components are presented. To reveal the impacts of the NEWTON offerings, three large-scale, namely, the Earth Course pilot, the Programming pilot, and the GAM-LAB pilot, are described. These pilots are deployed in four countries across the Europe, utilize the NEWTON Project Platform (the NEWTELP Platform) as well as various NEWTON technologies, and cover audience from different education levels. To effectively evaluate these pilots, a comprehensive evaluation methodology consists of surveys, knowledge tests, and interviews is employed.

Keywords

STEM, LMS, gamification, serious games, virtual lab, fablab, AR/VR, personalization, adaptation

¹ http://www.newtonproject.eu/

² http://ec.europa.eu/programmes/horizon2020/

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1. Introduction and Motivation

It is a recognized fact that most European countries are experiencing a crisis amongst their younger generations in respect of scientific vocations (CONVERT, 2005). In many European countries, declined numbers of students majored in STEM disciplines are observed. Since 2000, the proportion of graduates specialising in STEM subjects in Europe has declined from 12% to 9% (HENRIKSEN, 2016). It is not rare for students who had originally prepared for a science-based disciplines at tertiary level eventually turned down a scientific career in favour of disciplines that they believe are less difficult and more 'profitable', such as medicine, law and economics. Some other students may also select disciplines such as humanities and social sciences simply due to the higher chance of obtaining a qualification.

As attempts to reverse the aforementioned trend, the NEWTON project proposes to build an e-learning platform that corporates diverse forms of teaching/learning to service audiences from education levels ranging from primary, secondary and vocational schools to universities and further learning. In particular, NEWTON utilizes state-of-the-art technological-based contents, including virtual lab (VL) and fabrication labs (FAB LAB), adaptive multimedia/personalized mulsemedia delivery, Augmented Reality (AR)/Virtual Reality (VR) support for special learners, serious games and gamification. Moreover, innovative learning approaches such as problem-based learning, self-directed learning, and game-based learning are also incorporated.

2. Literature Review

Following the rapid growth of the information and communication technologies, elearning went through fast evolution over the past decade. Learning Management System (LMS), which acts as the hub of all online learning activities, is considered to be a key part of the e-learning system. Current LMS provide the administration of the learning process (e.g. learner registration and authorisation, course enrolment), and the facilitating of learning (e.g. course selection, course material presentation). Currently, the most popular and widely used LMS includes Moodle Moodle³, Blackboard⁴, etc.

³ https://moodle.com/

⁴ www.blackboard.com

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Meanwhile, various emerging technologies have been identified to enhance learning experience. VR enhances STEM learning by real-life imitating experience created by immersive 3D environment. VR applications have been developed for various STEM subjects, e.g., in math and geometry (Moyer-Packenham et al., 2015), and in engineering (Amirkhani & Nahvi, 2016). AR, which enhances learning experience through adding information to real objects, and VL, which provides simulation of real world and highly interactive multimedia environment (Kim, Park, Lee, Yuk, & Heeman, 2001), are also proved to be beneficial for STEM education (Enyedy, Danish, Delacruz, & Kumar, 2012) (Yoon, Anderson, Lin, & Elinich, 2017). Other TEL materials/approachs include multisensorial media (mulsemedia) (Zou, et al., 2017) (Bi, Pichon, Zou, Ghinea, & Muntean, 2018), serious games (Qian & Clark, 2016), FAB LAB (Togou, et al., 2018), and gamification (Barata, Gama, Jorge & Gonçalves, 2017).

Despite of the cheering growth of LMS, there are still challenges to be solved. First, though LMS have been extensively adopted in higher education (Kats, 2013), there is a lack of research on its application in primary/secondary school. Second, although existing LMS fulfil their roles in delivering learning contents, they merely focus on learner experience. There is no fine-grained tracking/monitoring of learner progress to offer support for personalized adaptive learning needs (S.E.N.) (NESSE, 2012). Moreover, current LMS do not provide sufficient integration of social tools to offer learners a networked learning environment. Last but not least, the ability of seamlessly accommodating various TEL content/methods is still missing in existing LMS.

Some research initiatives had already started to work on the next generation LMS which include personalization functionality such as enabling learner to receive feedback (Snodin, 2013), to assess, reflect and monitor their learning (Johannesen, 2012), and to access personalised educational content according to their profile, e.g. the Totara LMS⁵.

However, there is a lack of versatile LMS that could provide all-around comprehensive support for the aforementioned emerging technologies and advanced features to fully exploit their benefits in STEM education.

⁵ https://www.totaralms.com/

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3. Overview of the NEWTON Project

The core of the NEWTON Project includes the building of a powerful and versatile LMS (named as the NEWTELP Platform) and the development of TEL contents.

Course Management System (CMS) is the coordinator for all the functionalities of the platform and come as a bridge for different components of the platform. The CMS is assisted by several learning activity service management modules: the Search Engine; the Social Services, which includes comment on materials, content rating, forum, integration with social networks to share results, stack-overflow style Q&A system, and centralized notification/messaging system; and the Learning Actions, which provides learning access of learning materials for the student, assessment (quizzes, tests), feedbacks (surveys), and logging, by which the system records detailed information about the student progress (completed activities, start/end time, and grades).

Class Management component offers to the teachers the possibility to organize their training audience and to structure the content based on the audience profile.

Learner Model is another important module of the platfmro, which collects and maintains various information needed to enable personalised learning experiences, e.g., demographic data, physical disability, learning disability, social disability, interaction preferences, multisensorial preferences and hardware/software characteristics.

The LMS has three databases: the Content Repository, the External Content Repository, and the Learning Record Store (LRS). The Content Repository is responsible with the storage of content created and uploaded inside the platform. The External Content Repository hosts all external TEL materials such as serious games, AR/VR applications. The LRS contains all TinCan statements ("Experience API", 2018) generated by external contents, which record students' activities with external contents.

The LMS has three TEL solution components, i.e., Gamification, Adaptation, and Personalization. Through Gamification engine, teachers can configure gamification rules, such as points, badges, levels and leaderboards, for both traditional materials (pdf, tests, surveys) and TEL materials. The gamification engine cooperates with the CMS to retrieve learning records of students from the LRS database and update students' gamification achievements. The aim of the Personalization component is to offer content personalisation capabilities. It provides supports to learners in achieving the International Conference on Engaging Pedagogy (ICEP), Dublin City University, Dublin, Ireland, Dec. 14 & 15, 2018

specified learning goals by identifying learners' knowledge gaps and recommending a set of relevant contents. The Adaptation component is designed for multi/mulsemedia content. It works with the Learner Model to provide content adaptation (e.g., image quality adaptation, mulsemedia sensorial characteristics adaptation) to the learners to improve learner perceived quality, learning outcome and improve the learning process.

4. NEWOTN Large-Scale Pilots

To reveal the impacts of the NEWTON Project, three large-scale pilots were deployed in four countries across Europe, targeting audience at different education levels, ranging from primary education to third-level education. In all three pilots, courses contents and TEL materials are deployed and accessible through the NEWTELP Platform.

4.1 The Earth Course Large-Scale Pilot

Earth Course pilot is designed for primary and secondary level institutions. It focuses on four separate modules in Earth science: Astronomy, Atmosphere and Physics, Biosphere and Geosphere (Bogusevschi, Muntean, & Gorji, 2018). Each module contains TEL applications, gamification and game-based learning. Examples of the applications are shown in Figure 1. The Final Frontier application was developed by National College of Ireland (NCI) in Ireland for the Astronomy module and is focused on the Solar System, specifically on rocky astronomical objects (Mercury, Venus, Moon & Mars) and Gas planets (Jupiter, Saturn, Uranus & Neptune). Water Cycle in Nature is a VL with interactive content combined with VR, developed by SIVECO in Romania for the Atmosphere and Physics module. This application focused on precipitation formation and relevant physics concepts, such as vaporisation, condensation, evaporation and boiling. Wildlife and Sea-life are two 3D immersive VR applications for the Biosphere module developed by SIVECO. Wildlife targets educational content of terrestrial animals, specifically deer, wolf, wild boar, fox, moose, brown bear, hare and lynx. Sea-life is focused on aquatic animals, such as dolphin, jellyfish, octopus, orca, turtle, clownfish, stingray. Geography is an application employing AR and VR, developed by Slovak University of Technology in Bratislava (STUBA) in Slovakia for the Geosphere module, focusing on UK and Ireland educational content.

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This pilot is designed for 8 separate sessions and was carried out in two primary schools in Dublin, Corpus Christi Girls National School (GNS) and St. Patrick's Boys National School (BNS). Two 5th classes participated in each school, one assigned as the experimental class and one as control. In Corpus Christi GNS 30 girls were part of the experimental class and 27 girls were part of the control class. In St. Patrick's BNS both classes had 30 boys each. The experimental class students were provided the educational content employing the NEWTON approach and the control class students were provided the educational content in a classic approach manner, by their usual teacher. On a separate assessment strand, the control group was also exposed to the NEWTON approach, 4 to 10 weeks after the classic approach lessons, as a revision tool.



- (a) Final Frontier
- (b) Water Cycle in Nature

(c) Wildlife



(d) Sea-life



Figure 1 Earth Course Applications

4.2 The Programming Large-Scale Pilot

In the Programming large-scale pilot, TEL materials and innovative pedagogical approaches were introduced into Programming courses in 3 universities: Dublin City University (DCU), Ireland; NCI, Ireland; and STUBA, Slovakia. This pilot covered a 12 weeks' period, with more than 200 participants in total. Participants in the three universities were from different age groups and education backgrounds: DCU participants were first year undergraduate students from Department of Engineering, with no Programming background; NCI participants were mature students from various International Conference on Engaging Pedagogy (ICEP), Dublin City University, Dublin, Ireland, Dec. 14 & 15, 2018

previous study/work fields, with no Programming experience; and STUBA participants were second year undergraduate students from Department of Computer Science, with basic Programming experience.

Aiming at making the otherwise difficult and abstract programming concepts more appealing to students, four 2D serious games, as illustrated in Figure 2, were designed and developed for Programming courses. The Variable Game visualizes the concepts of basic data types and variable declarations in a warehouse scenario. The Loop Game conveys knowledge of basic loop, loop with continue statement, and loop with break statement through a undersea scenario. The Function Game illustrates the execution order of functions, passing arguments by values/addresses in a firework festival scenario. The Structure Game delivers the concepts of structure, how to declare variables of structures and access members of structure variables in a restaurant scenario. Moreover, adaptive multimedia (video) contents, as well as a Problem-based learning project "Morra", on the "array" topic were also used.



Figure 2 Programming Pilot serious games

4.3 The GAM-LAB Large-Scale Pilot

In this pilot, two institutes from Salerno, Italy, were involved: Giovanni Da Procida (G.D.P.) and Santa Caterina-Amendola (S.C.A.). A total of 75 students participated in the pilot, including 48 in experiment group and 27 in the control group. Among the

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participants, 7 of them have special educational needs (sensory (hearing) and intellectual (general learning disabilities) impaired learners).

This pilot consists of 8 steps, as illustrated in Error! Reference source not found.. Step 1 is theoretical/practical learning, during which students from G.D.P. interact with the Spatial Geometry VL VR application and the Ceramic VL VR application using HTC-Vive technology, while students from S.C.A. interact with the Chemistry VL web application with mulsemdia experience through exhale fan devices with memory retention selection of scents (peppermint, lavender, rosemary) and the Ceramic VL VR application. Step 2 involves graphic designing activities in G.D.P., where students learn to design complex 3D geometric shapes using the graphic design tool FreeCAD through video and text tutorials. In Step 3, students from both institutes share their ideas, suggestions, and selections of best basic geometric shapes for the design and following ceramic modelling. In Step 4, students from G.D.P. participate in FAB LAB 3D printing preparation, during which they learn about digital fabrication and FAB LAB operations through the video/text tutorials available on the NEWTELP platform and then prepare the FABLAB printing files through Ultimaker CURA software. Step 5 and 6 are FAB LAB prototyping (print out the 3D objects students designed using the 3D printer and forward the moulds back to the institutes) and ceramic modelling (laboratory production), which happen in NEWTON partner CEU San Pablo University. After students receive their 3D objects printed by the 3D printer, in Step 7, students from both institutes share and discuss together of their experience and vote for the best object/artefact produced. Finally, in Step 8, final assessment are carried out in both institutes. Along all steps, gamification points and badges are assigned.



(a) the Ceramic VL VR application

(b) the Spatial Geometry VL VR application



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5. Methodology

To effectively evaluate the impacts of the NEWTON pilots, the pedagogical assessment committee of the NEWTON Project propose a comprehensive pilot pedagogical assessment toolkit, utilizing a combination of surveys, knowledge tests, and interviews through different stages of the pilots. All three large-scale pilot described in the previous section follow the proposed methodology to enable comprehensive evaluation of individual pilot and future cross-analysis of results of all pilots.

Before the pilot starts, students are given a Demographic Questionnaire, which focuses on understand students' demographic information, such as age, gender, education background, attitude towards STEM learning, and use of technology (smartphones, computers). Then, a Learner Motivation & Affective State Pre Questionnaire is given to students, which covers questions about students' feelings towards STEM classes before interacting with NEWTON. Before students interact with each NEWTON course/technology content, a knowledge pre-test based on the learning content presented is also to be answered by them. The knowledge tests contains a few questions, which can be single choice questions, multiple choice questions and openended questions.

During students' interaction with NEWTON technologies, local NEWTON researchers and teachers are asked to note down their observation of students' reactions, along with any usability issues and barriers to learning as a result of the NEWTON technology.

After students' interaction with each NEWTON course/technology, a knowledge posttest is carried out. The knowledge pre-test and post-test together could reveal the technology's impacts on students' learning outcomes.

Upon finishing the pilot, two questionnaires are conducted: Learner Motivation & Affective State Post Questionnaire, focusing on students' affective, motivation state and attitude regarding STEM after interacting with NEWTON, and Usability Evaluation Questionnaire, covering questions regarding the usefulness of the platform, ease of use, learners' satisfaction, and learners' rating of each feature/technology.

To further expand on the data collected via the various surveys and questionnaires, focus group interviews, where 4 to 8 students selected across academic scale are interview as a group, and individual interviews are carried out after the pilot ends. The International Conference on Engaging Pedagogy (ICEP), Dublin City University, Dublin, Ireland, Dec. 14 & 15, 2018

questions of the interviews are set to reveal the nature of students' experience of NEWTON, to identify how they affected by NEWTON in terms of motivation, and to see potential ways to improve the content and the platform.

To understand teachers' experience, before and after the pilot, teachers are asked to answer a Pre-NEWTON Teacher Survey and a Post-NEWTON Teacher Survey, which covers questions related to demographics, their use of technology in the classroom, teaching practice and opinions on learner satisfaction/motivation. The pre and post surveys together reveal if changes in teachers' teaching practice after using NEWTON. Moreover, interviews and focus groups with teachers are carried out after the pilot, which reflect the nature of the student experience as observed by the teachers, whether teachers believe students have been positively or negatively affected by NEWTON in terms of their motivation to learn scientific subjects, the impacts of NEWTON on teaching practice, and the usability and potential improvements can be made.

6. Conclusions and Future Work

In this paper, the NEWTON Project, aiming at providing a versatile solution for future STEM education was described. The cores of the project include a LMS that fulfils both classic roles and advanced user experience enhancing functionalities such as personalization, adaptation, gamification, and social networking, and TEL materials in various forms. To evaluate the impacts of the project, three large-scale pilots deployed across Europe were described. A comprehensive pedagogical assessment methodology was proposed to assist the evaluation of the pilots. Future work includes analysis of each pilot's results as well as cross-analysis of all pilots results.

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