Interactive Personalised STEM Virtual Lab Based on Self-Directed Learning and Self-Efficacy

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ABSTRACT

Virtual labs enable inquiry-based learning where students can implement their own experiments using virtual objects and apparatus. Although the benefits of adaptive and personalised learning are well recognised, these were not thoroughly investigated in virtual labs. This paper presents the architecture of an interactive science virtual lab that personalises the learning journey based on the student's self-directed learning (SDL) and self-efficacy (SE) levels. The results of a pilot in two secondary schools showed that both students with low and high SDL and SE level improved their knowledge, but students with low SDL and SE had a higher number of incorrect attempts before completing the experiment.

CCS CONCEPTS

• **Human-centered computing** → *User models*; • **Applied computing** → *Interactive learning environments.*

KEYWORDS

personalisation, virtual labs, STEM education, inquiry-based learning, self-directed learning, self-efficacy

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1 INTRODUCTION

The low and decreasing engagement with STEM education is increasingly raising concerns with governments, organisations and researchers. Students often lose interest in STEM subjects during secondary education due to factors such as perceived difficulty of the subjects and students' implicit beliefs on their ability [18, 20]. Traditional STEM education makes use of physical labs that are resource intensive and costly to maintain. Virtual labs aim to overcome issues with physical labs, as well as to make practical science education available to online learners [12]. Several major projects have focused on virtual labs including the Go-Lab project that created a platform where educators can host and share virtual labs, apps and inquiry learning spaces [6], and the GridLabUPM platform that hosts virtual labs in the fields of electronics, chemistry, physics and topography [7].

Virtual labs enable inquiry-based learning which is a form of active learning that starts by posing questions, problems or scenarios. Students can create their own experiments and practice at their own pace in a safe environment. Acquiring inquiry skills during secondary education is an important step towards developing scientific literacy and pursuing further STEM education and careers [10]. Previous studies showed that personalised learning positively correlates with science performance even on country level data [17]. However, most virtual labs for STEM education lack personalisation and adaptation features [12].

This paper evaluates an interactive personalised STEM virtual lab for secondary school students. The lab teaches concepts about atoms, isotopes and molecules, and the learning journey is personalised based on students' SDL and SE levels. Self-directed learning is a process through which individuals set goals, find resources and methods, and evaluate their progress through critical reflection [4]. SDL is an important aspect in virtual labs where learners need to direct their learning experiences, pose their own questions, set goals, conduct experiments and reflect on their learning. Self-efficacy represents people's beliefs in their capabilities to accomplish specific tasks [1]. As students have different traits giving too much challenge, goal spectrum and strategies can be overwhelming for students with low SDL and SE levels.

This research work is part of the NEWTON project (http://www.newtonproject.eu) that focuses on increasing learner quality of experience [15, 16], improve the learning process and increase learning outcomes by employing innovative technologies such as AR/VR [3], virtual labs [8, 11], remote fabrication labs [19], adaptive and personalised multimedia and mulsemedia [2], interactive educational games [14], as well as innovative pedagogical approaches such as flipped classroom and problem-based learning [5].

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2 PERSONALISED VIRTUAL LAB

2.1 User Modelling and Personalisation

Atomic Structure is an interactive personalised virtual lab for secondary level students, that teaches abstract scientific concepts such as the structure of atoms, gaining and losing electrons, bonding of molecules. The lab includes various levels of personalisation: learning loop-based personalisation, feedback-based personalisation, innovative pedagogies-based personalisation (i.e., inquiry-based learning, learning in flow, SDL and SE), gamification-based personalisation, and special education needs-based personalisation (i.e., sign language translation for hearing impaired students). A detailed description of the lab is provided in [13].

Students' SDL level is determined at the beginning of each section of the lab (i.e., atoms, isotopes and molecules), by asking them to answer three questions related to self management, desire for learning, and self control dimensions of the SDL readiness scale [9]. Student's SE level is determined through one question related to their perceived ability to complete the lab [1]. All questions are answered on a 7-point Likert scale. Student's SDL and SE levels are used to personalise the feedback, the difficulty level of practice quizzes, the type of elements they are given to build, as well as the available options from which they can set own goals in the inquiry-based learning phase. Figure 1 shows an example of personalisation in terms of feedback given to students depending on their SDL and SE levels. The first picture shows low level of SDL and SE, thus the feedback aims to reduce possible anxiety, reassure the students that help will be provided and advice them to set less challenging goals. The second picture shows high level of SDL and SE, thus the feedback aims to set the students for the challenge and reassure that they can explore and self-direct through the challenge.

Figure 2 shows the interactive atom builder. The inquiry-based learning phase is offered at the end of each section of the lab, where students can set their own goals and experiment further within the atom, isotope and molecule builders respectively.

2.2 System Architecture

Figure 3 presents the architecture of the virtual lab and its integration with the NEWTELP platform developed by the NEWTON project. The lab integrates both SSO login and standalone sign-up/login in order to maximize its exploitation potential. The SSO login component enables sign-on for users that have a NEWTELP account, while the standalone sign-up/login enables access for users that do not have a NEWTELP account.

The virtual lab makes use of a user profile as input to personalise the learning journey. This can be either: (i) the user profile returned through SSO when the lab is integrated with the NEWTELP platform, or (ii) a stored user profile if the lab is used as a standalone application. The lab personalises the learning journey during which students can be given to interact with multimedia content (video, text and images), take practice quizzes, and perform inquiry-based learning experiments using the interactive builders.

The virtual lab logs the learner activities as events using the Tin Can standard. When the lab is integrated with the NEWTELP platform through SSO, the information is logged to the NEWTELP Learning Record Store (LRS). As opposed, when the lab is used as a standalone application, the information is logged using a micro-service logging module.

The virtual lab was implemented as a web-based application using HTML5, CSS and Javascript for the front-end. The back-end part of the sign-up/login and logging components make use of technologies such as AWS API Gateway, Lambda and DynamoDB. The interactive builders were developed using Unity and integrated within the web application. All the content files are stored in AWS S3 and are delivered using CloudFront.

Figure 1: SDL and SE quiz and feedback personalisation.

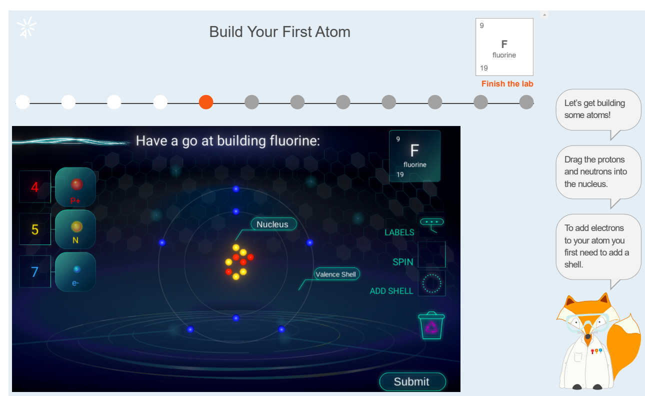

Figure 2: Interactive atom builder.

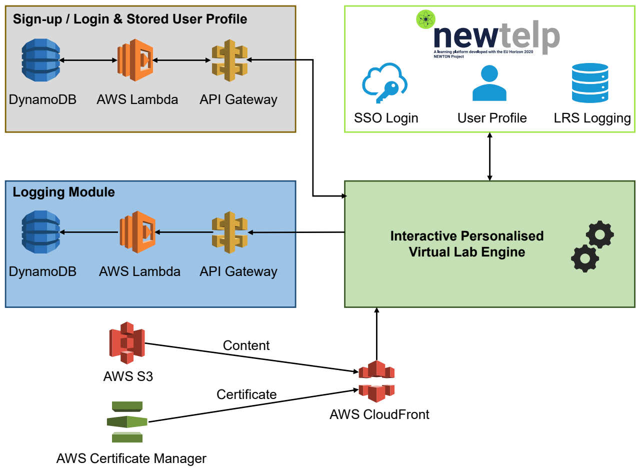

Figure 3: Architecture of the personalised virtual lab and integration with the NEWTELP platform.

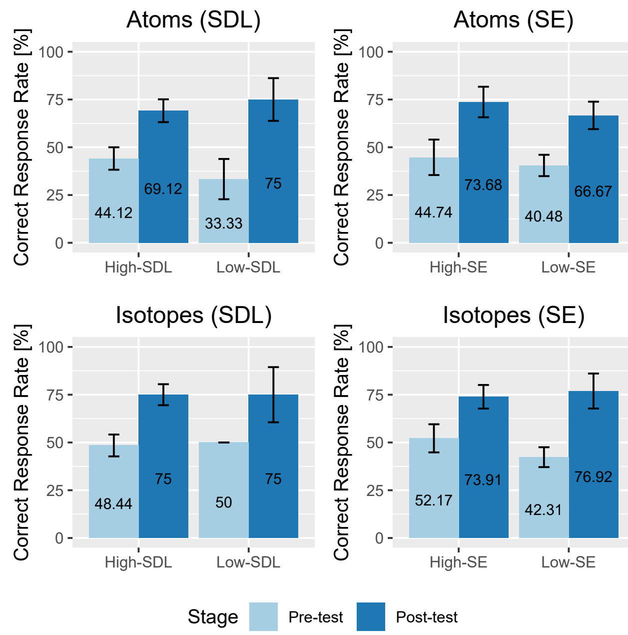

Figure 4: Pre and post knowledge test results.

3 PILOT STUDY

3.1 Methodology

A pilot study was conducted in order to evaluate the interactive personalised virtual lab across learners with different SDL and SE levels. The pilot was conducted in two secondary schools from Ireland with 42 students (26 boys, 15 girls, 1 did not tell). This consisted of a learning session using the virtual lab in the schools' PC room. Pre-pilot engagement with the teachers was aimed at informing the students about the pilot, as well as collecting consent and assent forms. The students were asked to fill a pre-test and post-test consisting of several multiple choice and short answer questions, in order to assess their knowledge on atoms and isotopes before and after interacting with the virtual lab.

3.2 Results

3.2.1 Knowledge Results. Figure 4 presents the pre and post knowledge test results in terms of mean correct response rate and corresponding standard error bars. The students were divided in two subgroups based on the responses to the SDL and SE questions they answered at the beginning of the atoms and isotopes sections of the lab (i.e., Low-SDL/SE subgroups comprise students with SDL/SE lower than 4, while High-SDL/SE subgroups comprise students with SDL/SE higher or equal to 4 on the 7-point scale). Two students did not complete the post-test, so they were excluded from all analyses. Another four students did not do the isotopes section of the virtual lab, so they were excluded from that analysis.

Figure 4 results show that all subgroups have increased their knowledge between pre-test and post-test in terms of average correct response rate for both atoms and isotopes sections of the virtual lab. The paired t-test for dependent groups was used to assess if the increases were statistically significant at $\alpha = 0.05$. The results summarized in Table 1 show that the increases were statistically significant for all subgroups in case of the atoms section. In case of the isotopes section, the results were statistically significant for High-SDL, Low-SE and High-SE subgroups but not for Low-SDL subgroup that comprised only 4 students.

Table 1: Paired t-test between pre and post knowledge tests.

VL Section	Subgroup	t-stat	df	p-value
Atoms	Low-SDL	5.00	5	0.0041
	High-SDL	3.70	33	0.0008
	Low-SE	4.69	20	0.0001
	High-SE	2.63	18	0.0172
Isotopes	Low-SDL	1.73	3	0.1820
	High-SDL	3.74	31	0.0007
	Low-SE	3.96	12	0.0019
	High-SE	2.47	22	0.0216

3.2.2 Learner Interaction Results. Two metrics were computed based on the Tin Can events for the inquiry-based learning phase. First is the number of incorrect attempts before the first correct attempt at building the atom or isotope. Second is the number of interactions with the atom/isotope builder relative to the complexity of the particular atom/isotope that the student chose to build.

Figure 5 presents the results for the different subgroups based on their SDL and SE levels. For atom builder the average number of incorrect attempts is lower for the High-SDL subgroup as compared to the Low-SDL subgroup, as well as for the High-SE subgroup as compared to the Low-SE subgroup. This indicates that students with a higher level of SDL and SE have a lower number of incorrect attempts despite doing more complex atoms. In terms of interactions, the Low-SDL and High-SDL subgroups as well as the Low-SE and High-SE subgroups show similar average numbers,

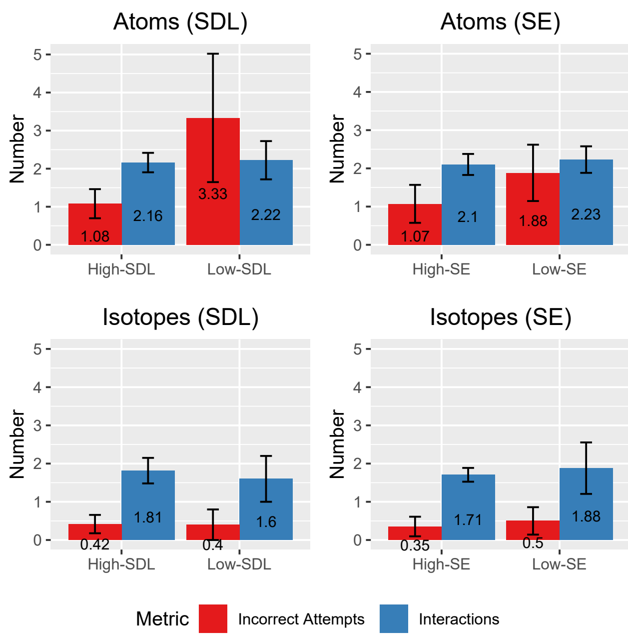

Figure 5: Incorrect attempts and interactions results.

which is expected because the numbers were computed relative to the complexity of the atoms built by different students.

For isotope builder the High-SDL subgroup presents slightly higher average number of incorrect attempts and relative number of interactions than Low-SDL subgroup. As opposed, the High-SE subgroup presents slightly lower average number of incorrect attempts and relative number of interactions than Low-SE subgroup. For isotope builder most users did not have incorrect attempts given that the average number is lower than 1.

4 CONCLUSIONS

Virtual labs present many benefits for students such as the ability to practice at anytime and at their own pace. Despite much research and development in the area, there is a lack of personalisation features in virtual labs. This paper evaluated an interactive personalised virtual lab for secondary school science where students can learn concepts and practice building atoms, isotopes and molecules. The virtual lab personalises the learning journey based on students self-directed learning and self-efficacy levels. The results from a pilot in two secondary schools showed that both students with low and high levels of SDL and SE improved their knowledge by practising with the virtual lab. However, students with low SDL and SE tend to have more incorrect attempts before competing the experiment. One limitation of the study was the small number of participants with low SDL. Future work will focus on more comprehensive evaluation of the impact of personalisation features on the learning experience. Moreover, future work will investigate automatic methods to accurately estimate student's SDL and SE level, as well as other metrics that can be extracted from the Tin Can events to improve the user modelling and personalisation.

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