Fostering Science Teachers' Design for Inquiry-Based Learning by Using a Serious Game

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Abstract— **There is wide consensus internationally amongst scientific communities that Inquiry-Based Learning can be employed to foster acquisition of clearly defined, 'certain' knowledge such as the conceptual foundations of a scientific discipline. Alternatively, it can be used to engage students with uncertainty, multiple perspectives and contestation through exploration of scientific problems. In order to enact inquiry-based learning effectively, science teachers need to be aware of how to design inquiry-based learning activities and the most effective ways of facilitating inquiry-based learning in the classroom. This paper, presents SimAULA, a serious game for helping science teachers to create engaging activities for involving students in inquiry-based quests. The paper proposes a cyclical model comprising seven inquiry steps or phases and translates these steps into practical inquiry-based activities performed in the serious game. SimAULA's overarching architecture is presented in the context of the in-game inquiry-based learning activities, which will be implemented and evaluated in a number of schools across Europe.**

Keywords: serious games; inquiry-based learning; science; teacher training

I. INTRODUCTION

Scant attention has been given in training teachers to prepare lesson plans using serious games. Although there are some instances where teachers are using digital tools for professional development, these are mainly focused on traditional content-based approaches via the use of an institutional virtual learning environment. The advent of digital games used for education and training, also known as 'serious games', may facilitate teachers in designing, and orchestrating lesson plans and managing the overall classroom environment based on pedagogically-driven strategies.

The movement towards the use of serious games as learning tools in schools has proliferated as a result of the perception that such games can help to create a memorable and engaging learning experience. Various commentators and practitioners alike argue that serious games may develop and reinforce 21st century skills such as collaboration, problem-solving and communication ([1], [2]). While in the past, teachers have been reluctant to use serious games for improving their teaching practice, there is an increasing interest, especially in science disciplines, to explore how serious games may be used to improve lesson planning and classroom management. The overarching assumption made is that serious games are built on sound learning principles encompassing teaching approaches that support the design of authentic and situated learning activities in an engaging and immersive way, although this is not always necessarily the case.

The serious game SimAULA supports the readiness of science teachers to design inquiry-based lesson plans and virtual situations. One of the benefits of using SimAULA is that experiences acquired in the virtual environment are transferrable to the real classroom and to new settings and contexts. In addition, the opportunity science teachers have to master the process of lesson planning at their own pace and time supports the development of their pedagogy as engaged producers or authors of knowledge and the generation of original intellectual or creative outcomes. In the following section, the state-of-the-art in serious games adoption is related to the design of serious games for teacher training, as well as to the design of learning activities using the inquiry-based learning approach (Section 2). This is followed by the underpinning inquiry framework developed for the game and the description of the inquiry-based activities designed for each inquiry phase (Section 3). The paper then describes the game's approach and architecture (Section 4) and concludes with a reflection on future plans for uptake and usage across schools in Europe in the forthcoming years (Section 5).

II. BACKROUND

The 2013 NMC Horizon Report [3] asserts that games are effective tools for increasing student's motivation and engagement by involving them into a memorable learning experience. A serious game can be defined as "a game in which education (in its various forms) is the primary goal, rather than entertainment" [4] p.21. Zyda [5] have suggested the element of developing game-mechanics of *competition* when the user plays against the computer in accordance to specific rules for encouraging immersion and engagement in a controlled environment. A study carried out by Ferreira et al., [6] sought to identify the possible relationships between the ability to identify mathematical patterns and the ability to play games with certain rules and victory conditions. The study showed that students were able to identify mathematical patterns more effectively by playing a game in comparison to traditional face-to-face teaching practices. Furthermore, concept scaffolding and simulation of real world experiences may be triggered effectively in order to solve problems and enhance student's performance. For example, Huang and Huang [7] surveyed 264 students playing an online educational game and found a relationship between rewards and motives. [8] have shown that games can support novel approaches to learning by scaffolding players' experiences in new worlds and learn by trying to solve ill-defined problems inside the game, bringing to the fore the notion of *'learning by doing'*, which whilst not a new concept does seem to be increasingly important in the design of effective pedagogic games.

In recent years different aspects of serious games have been widely discussed including their impact and outcomes ([9], [10]), motivating features [11] and in-game learning design [12]. This has led to an assumption that games might provide an environment where learning and teaching becomes engaging, memorable and fun [13]. Further, Hwang & Sung [14] argued that pedagogically-driven games reflect strong commitment to educational values and have great potential to drive students in achieving intended learning outcomes.

Identifying the appropriate pedagogical approach and aligning it to an intended learning outcome specified by the teacher may determine what kind of learning processes, scaffolds and activities a particular type of game will afford. However, it is also notable that focusing on scaffolding and outcomes already introduces behavioural notions of learning rather than ones from the field of critical pedagogy. Thus, training teachers to adopt pedagogical approaches based on certain learning outcomes that are supported by different types of games may enhance their educational value. From a pragmatist perspective, however, this does not mean that certain pedagogies are more cohesive than others as this always depends on the complex interplay between the learning environment, the level of students and the learning situation the teacher aims to introduce. Yet there does need to be sound match been the learning philosophy and pedagogy of the game itself.

A. Games and virtual worlds for teacher training

Research suggests that a popular method of using technology in teacher training is the use of virtual worlds ([15]; [16]). A virtual world is a useful tool in education, which provides teacher-students with opportunities to practice skills 'in world'

A taxonomy of virtual environments Duncan et al, [17] proposes that inclusion and accessibility need to be considered during development, to ensure that no minority group are excluded. The taxonomy further explains that it can be difficult for trainers to oversee educational progress of teacher-students using a virtual world, compared to in-class activities. Suggestions for an environment where trainers can observe and monitor the educational process ought to be considered in future research, to produce simulations that ensure teacher-students are not simply "playing" a game, but scaffold teachers to become engaged into in-game learning activities for extending their subject-content knowledge and projecting the curriculum.

B. Inquiry-based learning

'Inquiry' is referred to in the science education literature to designate at least three distinct but interlinked categories of activity: what scientists do (investigating scientific phenomena by using scientific methods in order to explain aspects of the physical world); how students learn (by pursuing scientific questions and engaging in scientific experiments by emulating the practices and processes used by scientists); and, a pedagogy, or teaching strategy, adopted by science teachers (designing and facilitating learning activities that allow students to observe, experiment and review what is known in light of evidence) [18]. For the purposes of the SimAULA's educational design, our focus is on inquiry as *an active learning process engaged in by students and modelled on the inquiry practices of professional scientists.*

It is important to note that while here the terms inquiry-based learning, has been adopted here, the authors recognise that this, along with forms such as 'inquiry learning [19]. This is one of many learning approaches that may be grouped under the philosophy and approach of problem-based learning. Whilst at one level this shows the value and flexibility of problem-based learning as an accommodating, adaptable and culturally relevant approach to learning, there is relatively little understanding of the impact of these different constellations on student engagement and in improving learning [20]. Inquiry-based learning was developed originally (as an instantiation of problem-based learning) in order to avoid the idea that the notion of a 'problem' is to be seen as negative or unhelpful. For example, being pregnant is not a 'problem' it is a normal process. However, it is important to recognise that other examples where the term inquiry-based learning refers to forms of learning in which learners engage with a self-determined process of inquiry. The approach is intended to foster collaborative learning and deep engagement, through enquiry, but is often little more than small group teaching. Thus the examples offered by authors using this term illustrate a clear overlap with problem-based learning but often include broader spectrum of approaches, such as project-based activities, product design projects in engineering, case-study projects using role play, and field mapping.

The US National Research Council report on *Inquiry and the National Science Education Standards* proposes a definition of inquiry teaching and learning that brings to the fore "...the abilities of inquiry, emphasizing questions, evidence and explanations within a learning context" [21] p.24. Central to this definition are the five 'essential features' of classroom inquiry. These five essential features emphasize a process of active engagement in scientific investigation, in which the focus is on students learning through and about scientific inquiry rather than on teachers presenting scientific content knowledge as portrayed in Table I.

TABLE I. FEATURES OF INQUIRY AND THEIR VARIATIONS ([20] NRC 2000, P.29)

Essential Features	More / Less	Amount of Learner Self-Direction / Amount of Direction from Teacher or Material — Variations		Less / More
Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials or other source	Learner engages in question provided by teacher, materials, or other source
Learner gives priority to evidence in responding to questions.	Learner determines what constitutes evidence and collects it.	Learner directed to collect certain data	Learner given data and asked to analyse	Learner given data and told how to analyse
Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed towards area and sources of scientific knowledge	Learner given possible connections	Learner given all connections
Learner communicates and justifies explanations	Learners forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided with broad guidelines to use to sharpen communication	Learner given steps and procedures for communication.

III. SIMAULA'S INQUIRY MODEL

The NRC features of inquiry (Table I) are essential for designing SimAULA's pedagogical model. Therefore we have adapted NRC's features of inquiry to match the distinct characteristics of a game-based learning approach encompassing the game mechanics and game play of SimAULA. The adjustments entail some structural considerations as well as the addition of 'Reflection' as a further essential feature. This is consistent with widespread recognition of the importance of student reflection activity in many recent conceptualizations. The Inquiry model is perceived as a cyclical path of the inquiry process where inquiry starts with posing questions and ends with reflection. Each step in the process leads to the next, generating new questions, constituting evidence, analyzing evidence, formulating explanations, connecting explanations, communicating findings and reflecting on the inquiry process. These overarching features of inquiry-based learning are integrated to the Simulation core of the game and when selected associated inquiry activities will be evoked based on the feature selected. For example, when an activity is associated with the 'evidence' feature then student might collect evidence through a WebQuest [22] designed by the student, guided by the teacher or fully controlled by the teacher.

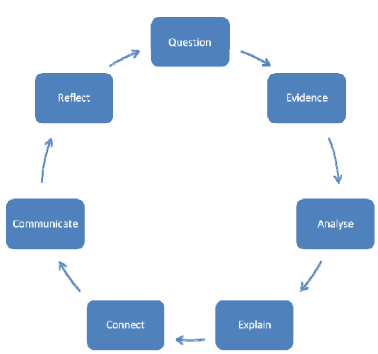

Figure 1. The SimAULA 7-step Inquiry Model

The model is mapped to SimAULA's pedagogical design in order to plan and create associated inquiry-based learning activities that place inquiry as a central feature. To achieve this, the authors mapped the essential features of inquiry (Table I) to the SimAULA Inquiry Model (Figure 1) for describing inquiry-based activities that are performed in the game (Table II). For example, activities that focus on posing *Questions* include certain processes that involve students, in creating their own scientifically-oriented questions under the guidance and support of the teacher who clarifies, refines questions by using the in-game options. During the *Evidence* phase, students create their own scientific hypothesis by using the in-game scientific tools (e.g. microscope) for data collection. The teacher provides guidelines and clarification through the in-game prompts. In the *Analysis* phase, students undertake data analysis by using research methods and processes suggested by the teacher. In *Explain & Connect,* students compare and connect data to prior evidence. The teacher suggests through the top-down in-game option additional educational content such as books, journals and resources from the Web. During the *Communicate* phase, students communicate findings through logical arguments in conjunction with the teacher's suggestions and prompts that are selected by the user when appropriate. Finally, in the *Reflect* phase, students reflect on the scientific investigation and on the inquiry process based on the assistance and support provided by the teacher and selected via the dialogical menu in the game. For orchestrating the inquiry activities there is no specified sequence, therefore the activities could be repeated based on the number of times that is necessary to complete a learning outcome.

TABLE II. DESCRIPTION OF INQUIRY ACTIVITIES IN SIMAULA

Inquiry Features from NRC	Inquiry Features in simAULA	Description of Inquiry Activities in simAULA including student & teacher roles
Learner engages in scientifically oriented questions	Questions	Students (avatars) are provided with a scientific topic which are presented as an embedded video in the simulation. Students are jotting down their questions and they are starting to pose them to the rest of the classroom. The teacher(user) provide guidelines on how questions should be formulated and also clarifies, refines the questions posed by students through the in-game top-down menu.
Learner gives priority to evidence	Evidence	Students (controlled by the simulation) are starting to create hypothesis for a scientific phenomenon by using the in-game scientific tools (e.g. scientific microscope, or virtual experiment) for data collection. The teacher elaborates/refines the steps for hypothesis generation, testing and evaluation through the in-game prompts.
Learner formulates explanations from evidence	Analyse	Students proceed to analysing data collected based on processes of analysis suggested by the teacher within the simulation and available to the student via the GUI. The teacher suggests a number of data analysis methods and guides the whole process of analysis.
Learner connects explanations to scientific knowledge	Explain & Connect	After conducting the analysis, students are explaining, comparing and connecting data with prior evidence. Teacher suggests through the top-down in-game option how to start the process and also recommends resources such as books, journals, Web that include relevant studies for students to explore.
Learner communicates and justifies explanations	Communicate	Student forms logical arguments to communicate findings in a way that it can be understood from the wider scientific community. The teacher monitors the process and gives guidelines and clarifies/corrects arguments when appropriate through the in-game dialogue options.
	Reflect	Student reflect on the scientific investigation and on the inquiry process based on guidelines provided by teacher through the in-game top-down menu.

IV. SIMAULA DESCRIPTION AND ARCHITECTURE

SimAULA places a virtual practicum in the form of a three-dimensional world adapted in the context of teaching and learning in schools. Both in-service and pre-service teachers interact with students' avatars and develop lesson plans in the virtual classroom. The teacher adopts the role of a science teacher in a biology classroom as an avatar and develops a number of lesson plans for the students. Students are expected to respond in different ways as they would do in a traditional classroom. The teacher evaluates skills and competencies for managing class and enhancing learning. The objective is to accompany the student through the lesson creation as well as making appropriate decisions to reach the learning aims. A real teacher controls the teacher avatar while the computer controls the student avatar. The main way of communication and interaction is by selecting the options offered by the system. Students are likely to respond according to the selections the teacher makes, as the objective is to develop and manage the classroom during the lesson and resolve and possible conflicts that may appear.

The design consists of three key sub-components: the Student Model, the Classroom Model and the Pedagogical Model. Inquiry-based learning is applied in different types of classrooms, with different ICT and resource availability, and with a different range of learning activities.

The system is divided into two parts. The first part contains the GUI core - the graphical interface which is based on Unity3D, and the second part contains the Simulation Core - hosting the inquiry model. This module is also responsible for driving the simulation. The communication between the two different parts/modules of the system is made through a webservice. The Simulation Core and the GUI core are comuncating via the phases shown in Figure 2. In order to increase interactivity of the game, a number of additional interactive elements are implemented into the game, these include:

- Whiteboard - Users can write on the whiteboard and also watch video footage of various school lessons.
- Computer - The user can use the computers mouse to select icons on the screen.
- Microscope - A microscope slide is shown out of focus, the user must focus the microscope correctly.

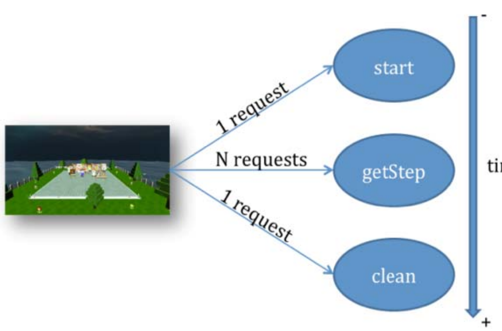

Figure 2. Communication between GUI and Simulation Cores

The teacher is able to configure the desk arrangement in order for students to enact individual, group-based and whole classroom inquiry activities while the teacher retains the role of the arbiter of legitimate biological activity (see Figure, 3).

Figure 3. Desk arangement based on individual, group and whole classroom inquiry activities.

The primary purpose of SimAULA is to help science teachers to develop an awareness of implementing inquiry-based learning in their classroom. The central aspect therefore is to develop and extend understanding of the different phases and activities teachers need to consider in designing an inquiry-based lesson plan. The focus of attention is inquiry-based learning and not the technological tools used to support the inquiry process. This is highlighted in the game by always starting in terms of describing the purpose of the activity as well as identifying the intended learning outcomes (Figure 4). This is essential for the teacher in order to be able to choose the right inquiry-based phases and activities and align them to intended learning outcomes. Aligning inquiry strategies with inquiry activities and inquiry assessment is our primary goal, as it would help to provide an intuitive model for teachers to rationalize and practice.

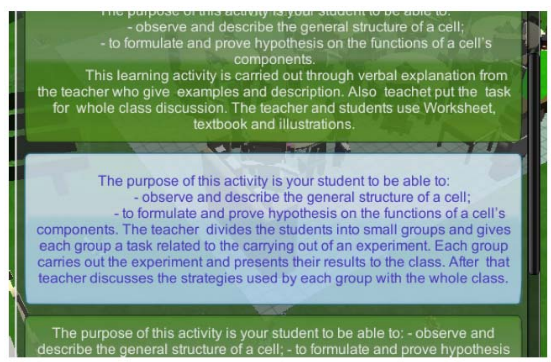

Figure 4. GUI displays the intented learning outcomes, description of teacher and student roles and inquiry activity type.

It would make sense therefore to include descriptions of inquiry-oriented learning goals and then provide the necessary options for the teacher to decide the inquiry-phase and associated activities necessary to match with the intended learning outcome.

V. CONCLUSION AND FUTURE WORK

This paper presented the overarching inquiry-based model used to inform the pedagogical design of SimAULA, the in-game inquiry-process, the associated inquiry activities and student response along with the core game system architecture. Drawing on the wider evidence base, we have identified seven (7) essential inquiry features. These are vital elements for effective practice in triggering students' attention, provoking wonder and engagement in scientific activities including asking questions, planning an conducting investigations, drawing conclusions, revising theories, communicating results and reflection.

We are working further on the inquiry-based model to improve and develop the associated inquiry activities presented in Table II for each of the different phases. The team is also delineating the various inquiry types and their connection to learning approaches and phases of inquiry in the context of the game. More dialogical and prompting options for the teacher to choose from are currently being considered for improving teacher-student interactions that are taking place in the inquiry phases within the game. The inclusion of a tutorial at the beginning of the game is perceived as a useful approach for assisting users to learn the various options and gameplay of the game. Furthermore, the authors are investigating the association of acquired inquiry-based skills to standard teacher's competency frameworks for increasing the extent to which SimAULA is used by science teachers by incorporating inquiry-based as well as technical skills into the school science curriculum. This may also increase teacher's ability to innovate by introducing inquiry-led innovation that can be shared and re-used from other science teachers. The basic limitation of SimAULA is the lack of a game analytics mechanism for tracking data on what players are doing in the game as means of providing meaningful feedback for facilitating further improvement on adopting inquiry-based learning.

In terms of future research SimAULA will be implemented and evaluated on a large scale in Europe in the context of a European project. In congruence with the project objectives, SimAULA will be tested in 5,000 schools using a variety of research instruments including surveys, statistical analysis, interviews and observations. This will enable the team to evaluate the uptake and efficacy in training science teachers to understand inquiry-based lesson planning across Europe, through a game-based intervention, realised over the next 2 years. The findings of the evaluation will be published to high-impact research journals. Testing the proposed inquiry-based model and aligning it to learning approaches and assessment is being undertaken through the iterative and participatory design processes within the project.

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