Training Science Teachers to Design Inquiry-Based Lesson Plans through a Serious Game

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Abstract— **A significant challenge for science teachers' training is to understand how to enact teaching strategies that would encourage students to perceive learning as a memorable experience instantiated through an activity; and thereby getting involved in a process of meaning-making. This paper describes SimAULA, a serious game that aims to integrate inquiry learning into game dynamics for scaffolding science teachers' efforts to design their lesson plans. To this line, the paper proposes a 7-step process of orchestrating inquiry features that enable science teachers to think about inquiry in the context of creating activities based on real-world situations that map closely on to students' understandings rather than those with naturally occurring complex patterns. SimAULA's overarching architecture is presented in the context of the 7-stage inquiry process to be implemented and evaluated in a number of schools across Europe.**

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

I. INTRODUCTION

Scant attention has been given in training teachers to prepare lesson plans using a serious game. 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 on 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 is proliferated by the perceived ability of such games 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]. While in the past, teachers have been reluctant in using serious games for improving their teaching practice, there is an increasing interest, especially in science disciplines, to explore how serious games could be used to improve lesson planning and classroom management [2]. 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.

Developing serious games based on student-centred pedagogies that enable students to engage actively with questions and problems associated with their subject or discipline is an empowering approach with benefits for subject learning as well as for developing a wide range of important high-order intellectual attributes including the notion of *'transferability*. Inquiry-based learning is perceived as an emerging learning approach for transferring learning in real-worlds situations. It can be seen as a variant of active learning in which students carry-out research like activities to explore and master an existing knowledge-base - and as a tool for developing relevant discipline-based and other transferable capabilities and understandings.

The serious game SimAULA supports the readiness of science teachers to design inquiry-based lesson plans as well as to manage the classroom while engaging in 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 confidence into the realms of genuine scholarship, positioning them as engaged producers or authors of knowledge with potential to generate original intellectual or creative outcomes. In the following section, the state-of-the-art in serious games design is related to the design of serious games for teacher training, the design of learning activities using the inquiry-based learning approach, and inquiry-based serious games for science education (Section 2) followed by the underpinning inquiry framework developed for the game (Section 3). Then, the paper 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. BACKGROUND

The 2013 NMC Horizon Report [3] asserts the perspective 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. [5] added the element of a *contest* played with a computer in accordance to specific rules. [6] carried out a study 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, [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'*.

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] led to an assumption that games might provide an environment where learning and teaching becomes engaging, memorable and fun [13]. [14] argued that pedagogically-driven games reflect strong commitment to educational values and have great potential to drive students in achieving intended learning outcomes.

In contrast to the commonly used term *game-based learning,* which predominantly focuses on student motivation, game-design features, learning achievements, learning attitudes and in-game assessment, *game-based teaching* refers to the teacher practices involved in designing, selecting, facilitating and validating the use of games for educational and training purposes [15]. There are a number of inter-related aspects in game-based teaching surrounding teachers' conceptions of, and approaches to, serious games [16]; teacher's role in facilitating learning in the game [17] and the relationship between teacher's approaches of teaching and the learning models applied in games. 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. Thus, training teachers to adopt pedagogical approaches based on certain learning outcomes that are supported by different types of games will potentially 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.

A.   Games and virtual worlds for teacher training

Using technology, as a training tool is predominant as technology becomes integral in modern workplaces, yet some teachers have shown an unwillingness to adapt their teaching style as many of these teachers are overwhelmed with the plethora of the teaching approaches that could be adopted to support the specific modalities of a digital tool. Current research finds that a popular method of using technology in teacher training is the use of virtual worlds ([18], [19]). A virtual world is a useful tool in education, which provides teacher-students with "lived experiences".

A taxonomy of virtual environments from [20] propose 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.

TABLE I.   INQUIRY TYPES (ADAPTED FROM [25] NRC 2000)

A. Structured	Strongly teacher-directed. Students follow their teacher's direction in pursuing a scientific investigation to produce some form of prescribed product, e.g. they investigate a question provided by the teacher through procedures that the teacher determines, and receive detailed step-by step instructions for each stage of their investigation.
B. Guided	More loosely scaffolded. Students take some responsibility for establishing the direction and methods of their inquiry. The teacher helps students to develop investigations, for example offering a pool of possible inquiry questions from which students select, and proposing guidelines on methods.
C. Open	Strongly student-directed. Students take the lead in establishing the inquiry question and methods, while benefiting from teacher support. For example, students initiate the inquiry process by generating scientific questions and take their own decisions about the design and conduct of the inquiry and the communication of results.
D. Coupled	A combination of two types of inquiry, for example a guided inquiry phase followed by an open inquiry phase.

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) [21]. 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.*

Inquiry learning science activities encompass a broad spectrum ranging from strongly teacher-directed to strongly student-directed [22]. Since science teachers need to adopt different strategies according to different intended learning outcomes, the needs of students, and the specific circumstances of their own (diverse) science classrooms, understanding different types of inquiry learning and teaching will help them to create learning activities that are appropriate in context. A continuum of types of science inquiry, which we refer to as 'structured', 'guided', and 'open', based on usage in the literature, is often described (e.g., [23]) and is reflected, although not systematically, in the Examples of Teaching and Assessment provided by [24] and illustrated in Table I.

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" [25] p.24. At the centre of its definition are 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 II.

TABLE II. FEATURES OF INQUIRY AND THEIR VARIATIONS ([25] NRC 2000, P.29)

Essential Features	More ← Less	Amount of Learner Self-Direction		Less → More
	Less ←	Amount of Direction from Teacher or Material		→ More
		Variations		
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.

NRC [25] created these inquiry-based categories and their variations to map the entire spectrum of using inquiry-based learning according to the needs and level of a particular classroom. For example, when the teacher wishes to have control over the inquiry activity, then inquiry design

is focused on teacher direction and support. If the teacher decides to allow students to direct the inquiry, then inquiry design becomes more open and student-directed.

C. *Inquiry-based Serious Games for Science*

Designing effective inquiry-based learning activities in serious games have not been evidenced in many serious games. However, there some examples of inquiry-based serious games that have been used particularly in science. For example the North Carolina State University developed the serious game *Crystal Island* that targets science education for eight grade students. The game adopts inquiry-based learning to explore concepts related to microbiology. The learning environment (see Figure 1) is set on a volcanic island where a research centre has been established to study the flora and fauna. The player is free to explore the world, to constitute evidence and collect it, as well as interacting with other characters. As some members of the research team fall ill, the player needs to identify the cause of their illness. The user can perform various scientific investigations including experiments in the laboratory, interacting with other characters, reading virtual books on diseases and collecting data about what poisoned the members of the research team.

Figure 1.   The Crystal Island game environment.

Another example of an inquiry-based serious game for science is the *RiggleFish* developed by the UL Lafayette's centre for Innovative Learning and Assessment Technologies. In the game the players take the role of a geneticist tasked to discover a fish species. Players work on a research laboratory to breed a type of RiggleFish that produces Omega X. To accomplish the task, students must determine through scientific investigation and observation the phenotypes and genotypes of fish collected and then breed the fish to obtain the RiggleFish (Figure 2).
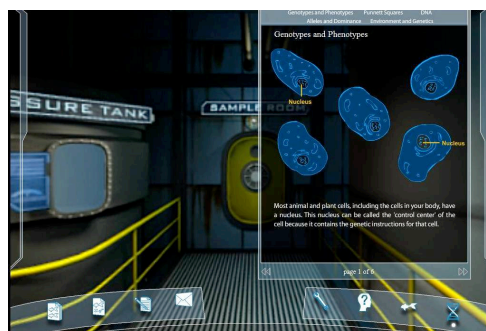

Figure 2.   RiggleFish instruments and information resources

Based on a similar game pattern, the *Crazy Plant Shop* serious game help students learn about genes and inheritance. Special order requests from mysterious customers require students to understand dominant and recessive traits and how genetic traits get passed from one generation to the next (Figure 3). The game is designed for science classrooms and being used by students that adopt inquiry learning for investigating how cells grow and their transfer from the parent cells to the offspring.

Figure 3.   A mysterious customer enquiring for a mysterioufifs plant

Bringing the pervasiveness and interaction of a Massively Multiplayer Online Game (MMOG) to classroom teaching, MIT developed *The Radix Endeavor* for Science, Technology, Engineering and Math (STEM) in high schools. The game covers topics in biology, statistics, geometry, algebra and probability. The story unfolds on an island with many unknown species and plants waiting to be discovered using inquiry and scientific investigations. The type of game structure has affordances based on inquiry-learning and scientific ways of approaching a phenomenon. Within the game a player can collaborate with other online players for comparing ideas and solve problems, as well as for conducting their own experiments to develop hypothesis while being immersed by the social and contextual elements of the MMO's distinct game-play, mechanics and goals (Figure 4).

Figure 4.   The MMO game environment

MMOs seem to be used frequently for promoting social learning and participatory processes between dispersed players around the world. The aim is for different players wih disctinct skills to collaborate together for achieving a common goal.

III.   SIMAULA'S INQUIRY MODEL

The NRC features of inquiry (Table II) are essential for driving 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 asking 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 process. (Figure 5). These overarching features of inquiry 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 the student might collect evidence through a WebQuest [26] designed by the teacher or student, guided by peers or teacher or fully controlled by the teacher.
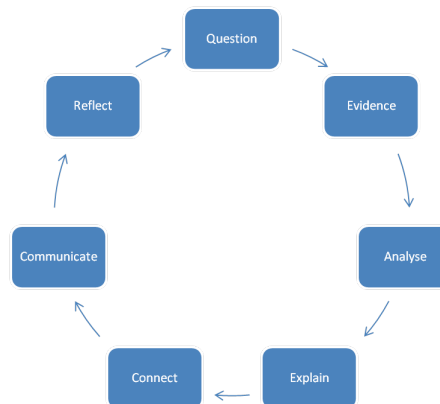

Figure 5.   The SimAULA 7-step Inquiry Model

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 student's avatars and develop lesson plans in the virtual classroom. The teacher develops 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 react in different ways as they would do in a traditional classroom. The teacher tests skills and competencies for managing class and enhancing learning. The objective is to accompany the student through the lesson making 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 reacting 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 learning will be 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 comunicating via the phases shown in Figure 6. 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.

vary. But the final goal of the simulation is not to represent in a realistic way the complex interaction taking place in a school classroom. The main learning objective is to foster student teacher's reflection on his/her inquiry choices and to play with different alternatives in a protected virtual environment. Once the user launches the simulation, the simulation requests from the user to select the type of activity from the 7 inquiry features presented in Figure 5. Then, the sequence of activities is provided for a student to decide about how the student will go with the activity (open, structured, and guided) (Figure 8).

Figure 8.   The sequence of SimAULA inquiry process and acitivities taking place in the game

The system is available for PC and MAC and we are currently working on making it available online via Unity Web Player. The system displays the intended learning outcomes related to a specific inquiry activity, it describes the teacher's and student's role (individual and group-based), the tools (e.g. textbook, worksheet, etc) used to implement the activity and type of activity (individual, group-based, whole classroom) (Figure 9).
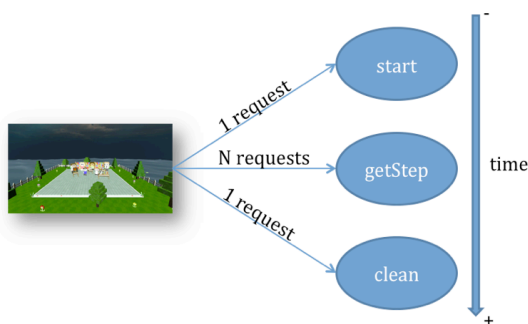

Figure 6.   Communication between GUI and Simulation Cores

The teacher is able to configure the desk arrangement in order for students to enact individual, group-based inquiry and whole classroom inquiry activities (see Figure 7).
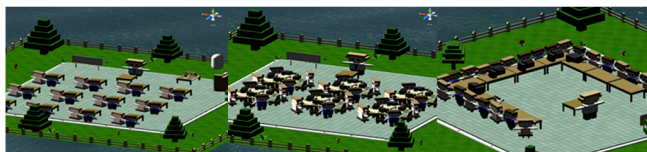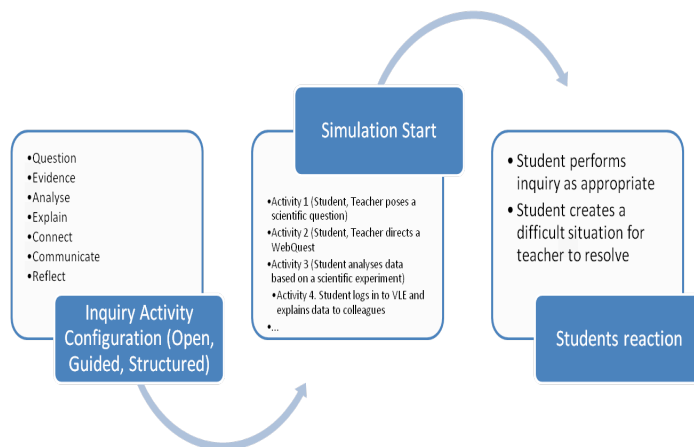

Figure 7.   Desk arangement based on individual, group and whole classroom inquiry activities.

The rationale of the simulation is to allow the teacher to vary some attributes and experience how behaviours can
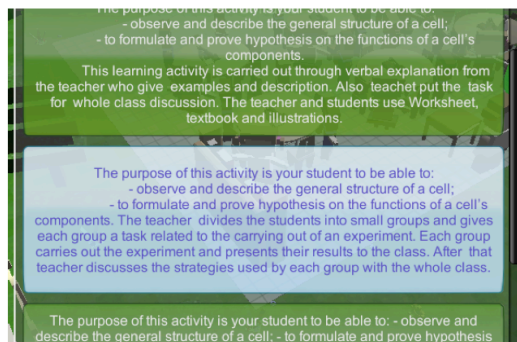

Figure 9.   GUI displays the intended learning outcomes, description of teacher and student roles and inquiry activity type.

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 encompassing 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 as elements of effective practice for triggering student's attention, provoke 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 better reflect the associated inquiry activities for each of the different phases. We are also working on highlighting the various inquiry types and their connection to intended learning outcomes and phases of inquiry in the context of the game.

In terms of future research, SimAULA is going to be implemented and evaluated at large scale in Europe in the context of a European project. In congruence with the project objectives, SimAULA is going to be tested in 5,000 schools using a variety of tools for collecting data including surveys, interviews and observations, as means 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. Testing the proposed inquiry model and aligning it to learning outcomes and assessment is being undertaken through the iterative and participatory design processes within the project.

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