Lameras et al. Smart Learning Environments (2021) 8:7
https://doi.org/10.1186/s40561-021-00152-z

Smart Learning Environments

RESEARCH Open Access

Science teachers' experiences of inquiry-based learning through a serious game: a phenomenographic perspective

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Abstract

This study employed a phenomenographic approach to investigate science teachers' conceptions of inquiry-based learning through a serious game. Simaula is a prototype game designed and used as a virtual practicum for eliciting understandings on how in-game inquiry was appeared to, or experienced by, the participating teachers. Group interviews with 20 secondary education science teachers revealed four qualitatively different ways of experiencing inquiry-based learning through Simaula: (a) as uncovering insights about student's learning needs, interests and emotions; (b) as generating ideas and concepts for meaningful inquiry; (c) as a set of operations for designing and carrying out scientific research; and (d) as authentic inquiry for enabling knowledge building processes. Seven dimensions of variation have been identified viewed as contextual influences on conceptions of in-game inquiry constituting discernment of: epistemic inquiry-based learning modes; role of teacher; role of student; game-play focus; core mechanics focus; feedback and progress mechanics and game uncertainty. The results illuminated a partial in-game inquiry approach with distinct epistemic modes from developing empathy and meaning making to knowledge construction and knowledge building. The findings also indicated that game design elements played central role in shaping conceptions of in-game inquiry from focusing on rules and logic as means to completing the game's level to understanding the complexity of core mechanics for developing and transferring in-game inquiry to the real classroom. This insinuates that distinct game design properties may be considered in terms of extending intrinsic in-game inquiry experiences to actual in-class inquiry practice.

Keywords: Serious games, Inquiry-based learning, Science teachers, Phenomenography

Introduction

This study is grounded in two inter-related areas of research. The first draws on teachers' experiences of Inquiry-based Learning (IBL) in school science education and the second contemplates on the use of Serious Games (SGs) as means to experience in-game IBL for teaching science. IBL is often used as an umbrella term that embraces an array of pedagogical approaches supporting views of learning that encourage problem-solving, posing questions, knowledge construction and conducting research (e.g. Kang, Orgill, & Crippen, 2008; Marshall, Horton, & Smart, 2009). Although the use of SGs in science school education has been evidenced during the early 1980's (e.g. Magnussen, 2014), there is recently a surge of interest to investigate how SGs are experienced and employed by science teachers as means to enhance teaching and learning (e.g. Ucus, 2015; Dickey, 2015).

Cheng, Chen, Chu, and Chen (2015) conducted a systematic review on the use of SGs in science education and identified that teachers are keen on adopting SGs to convey complex and ill-defined scientific concepts in more context-specific and authentic ways. Vlachopoulos and Makri (2017) articulated on the tenets of SGs for science mainly because of their scenario orientated design inspiring students to collaborate, critically think and prioritise on certain tasks and activities. Rutten, van Joolingen, and van der Veen (2012) highlighted that a common instructional design preference entrenched in SGs was IBL propagating a design trend for science games to embrace IBL over other strategies. This implicit connection between IBL and science games may be related with coupling the immersive potential and context-awareness of games with IBL principles related to discovery learning, hands-on activities and authentic problems. (e.g. Cheng et al., 2015; Hwang & Chen, 2017; Sabourin, Rowe, Mott, & Lester, 2012). Li and Tsai (2013) carried out a review on game-based learning in science education and showed that there was a substantive use of games for transferring scientific knowledge and less use for facilitating students' inquiry and problem-solving skills. This echoed the views of Wouters, van Nimwegen, van Oostendorp, and van der Spek (2013) in terms of proliferating the use of SGs predominantly for information transmission and knowledge retention and with moderate emphasis on critical thinking, collaboration, reflection and social and emotional skills. Teacher's role seems to be important in shifting the foci from perceiving games as tools for knowledge retention and passive learning to experiencing them as mediums for encouraging inquiry and active learning. In light of this, Rutten et al. (2012) resonated on the need of a framework to delimit the role of the teacher in orchestrating teaching using games.

The effectiveness of SGs on science learning in schools has been studied extensively across an array of learning outcomes (e.g. Hussein, Ow, Cheong, Thong, & Ale Ebrahim, 2019; Krinks, Johnson, & Clark, 2018; Rowe et al., 2017). Rastegarpour & Marashi, (2012) sought to investigate the effects of SGs on chemistry learning and highlighted the instrumental role of play and the active engagement of students with gameplay as opposed to a more passive learning activity observed in the classroom. Lester et al. (2014) integrated a game into a science classroom and the results of the pilot study indicated that the game positively impacted content knowledge on science topics and problem-solving skills emancipating a rationale for emerging deliberations on wider adoption of games into science education.

Despite diverse evidence on researching the effectiveness of SGs in school science education, there is little, if any, empirical research on science teachers' experiences of IBL through SGs. This is not to negate the value of investigating the effectiveness and trends of SGs in school science education, but to argue that developing a conceptual understanding of how teachers' experience IBL with the aid of a serious game may have a relationship to students' learning. Currently, there is no systematic knowledge on science teachers' understandings of IBL, as an instructional strategy, using SGs, with a pertaining focus on how game design considerations may influence conceptions of in-game IBL.

This study investigated school science teachers' conceptions of IBL through a serious game. Phenomenography was adopted as an interpretive research methodology for developing, following a data-driven approach, a hierarchically structured and related set of categories of description (e.g. Marton, 1988), which represented teachers' different ways of experiencing in-game IBL.

Simaula is a SG prototype developed as part of a large-scale inquiry-based research project and it was used in this study to elicit teachers' experiences of in-game IBL. Simaula simulates a science classroom where players are sought to experience in-game IBL. To set the stage for our findings and discussion, and before elucidating on aims, research questions and methodology, we present a brief review on experiences of IBL in school science education, which informed our findings and the pedagogical design of the game. A description of the game's design in terms of linking IBL research to game mechanics is also articulated.

Variation in experiences of IBL in science education

An important contribution in shaping IBL for science education in schools was the publication of the *National Science Education Standards* (NRC (National Research Council), 1996) in the US. The *Standards* identified five conceptions of classroom inquiry: (1) engaging in scientifically oriented questions; (2) giving priority to evidence (3) formulating explanations from evidence; (4) evaluating explanations in light of connecting findings with scientific theory and (5) communicating and justifying proposed explanations. NRC (National Research Council) (2000) proposed a distinction between *full* inquiry when all five-inquiry features are endorsed and *partial* if one or more inquiry elements are omitted, but others are present (e.g. Hofstein, 2004). Although there is consensus that inquiry is an integral aspect of students' science learning there are certain barriers such as insufficient professional development or teacher's increased workload that may deter teachers to enact inquiry in the science classroom. Disciplinary differences seem to also influence conceptions and enactment of inquiry. In particular, Breslyn and McGinnis (2011) conducted empirical research on how secondary science teachers' discipline may influence conceptions of inquiry-based teaching and learning. The study revealed that teachers' conceptions of inquiry are different depending on the discipline in which inquiry teaching was enacted. Key factors such as the structure and context of the discipline influenced the 'use of inquiry' demonstrating the situated nature of their conceptions. An interesting aspect to investigate is the developmental nature and logical inclusivity of the conceptions when the structure of the discipline is changing.

There is an assertion that by making available explicit representations of teachers' conceptions of inquiry an inherent link will be most likely created between teachers' thoughts and actions (e.g. Hewson, Kerby, & Cook, 1995). Such actions may be represented as 'structured', 'guided', and 'open' which may serve as the basis for conveying the level of student involvement in the inquiry process and the degree of teacher intervention in student's learning (e.g. Sadeh & Zion, 2009). In structured inquiry the teacher is asking questions, students follow teacher's direction and receive detailed step-by-step instructions for each stage of the investigation (e.g. Salim & Tiawa, 2015). In the next level of complexity, guided inquiry, students select from a range of questions provided by the teacher, take more responsibility in accessing and retrieving content and establish methods and directions of inquiry (e.g. Chatterjee, Williamson, McCann, & Peck, 2009; Ucar, Trundle, & Krissek, 2011). In open inquiry, students initiate the inquiry process by making decisions about the scientific methods, employment and communication of scientific findings (e.g. Berg, Bergendahl, & Lundberg, 2003; Krystyniak & Heikkinen, 2007).

Aims and research questions

The aim of this study was to investigate the qualitatively different ways school science teachers' experience IBL through using the serious game Simaula. Despite increasing interest in investigating conceptions of teaching and learning using SGs (e.g., Bourgonjon et al., 2013; Huizenga, ten Dam, Voogt, & Admiraal, 2017) there is no empirical evidence that explores in-game IBL from a relational stance discerning variation in developing ways of understanding IBL through SGs. Current research focus is on how SGs may optimise teaching and learning with emphasis on student's learning. In particular, the research stimulus is on correlating student's in-game acquired content-knowledge and skills with attainment of learning outcomes demonstrated by students during classroom teaching (e.g., Giannakos, 2013; Kiili & Ketamo, 2017; Kiili, Moeller, & Ninaus, 2018). There is no phenomenographic empirical evidence, however, on how teachers develop their understandings of teaching using IBL with the aid of a serious game, and how game design elements may influence the way IBL is conceived and practiced during gameplay. Teachers' experiences of in-game IBL will aid the development of a structured and rigid framework that delineates qualitatively different in-game conceptions of IBL that may inspire teachers to contemplate and demarcate on the different ways IBL may be enacted in the classroom. Such framework may also help game designers to design games that are based on formal pedagogical structures that enable deep and meaningful learning. To this end, the research questions that this study sought to address are:

(1) What are school science teachers' conceptions of IBL with the aid of a serious game?
(2) How game design elements may influence conceptions of in-game inquiry-based learning?

Mapping IBL to game mechanics

Simaula's design paradigm was driven by SGs research on mapping learning to game mechanics (e.g. Lameras et al., 2017; Bedwell, Pavlas, Heyne, Lazzara, & Salas, 2012) as an informed attempt to understand how IBL may be experienced and developed through game-play. We employed the term Serious Game Mechanic (SGM) (Arnab et al., 2015) to denote design decisions for linking learning situations, represented through *learning mechanics*, *to game mechanics* that are directly associated with player's actions and the outcomes of these actions.

IBL framework and alignment with content model

The player adopts the role of a science teacher, teaching science topics, in a virtual classroom, such as the CO2 emission, the electromagnetic spectrum and the Foucault pendulum selected to situate in-game inquiry into topics that would allow for an extensive understanding and exploration of different inquiry practices. We have adapted NRC's five conceptions of inquiry (Fig. 1) to align with Simaula's content, feedback and learning outcomes models acting as the underpinning framework that informs the way the core SGM (i.e. non-linear dialogue system) discerns IBL representations during game-play.

Simaula's content model is related with the IBL framework in a sense that it creates a structure for aligning a feature of the IBL experience with a scientific topic. For example, CO2 increasingly emphasises the importance of orienting and asking questions; the electromagnetic spectrum is associated with carrying out research and the Foucault pendulum emphasises the process of communication and sharing.

The non-linear in-game dialogue system

Simaula's core SGM is a dialogue-based system that alters the sequence of the dialogues based on the choices made by the player (Fig. 2). The non-sequential dialogue trees are intentionally designed to underline that there was not any single-path to experience IBL and that the player was given options to make decisions mostly related to their own views of IBL. It was also the instrument that dynamically affected the student

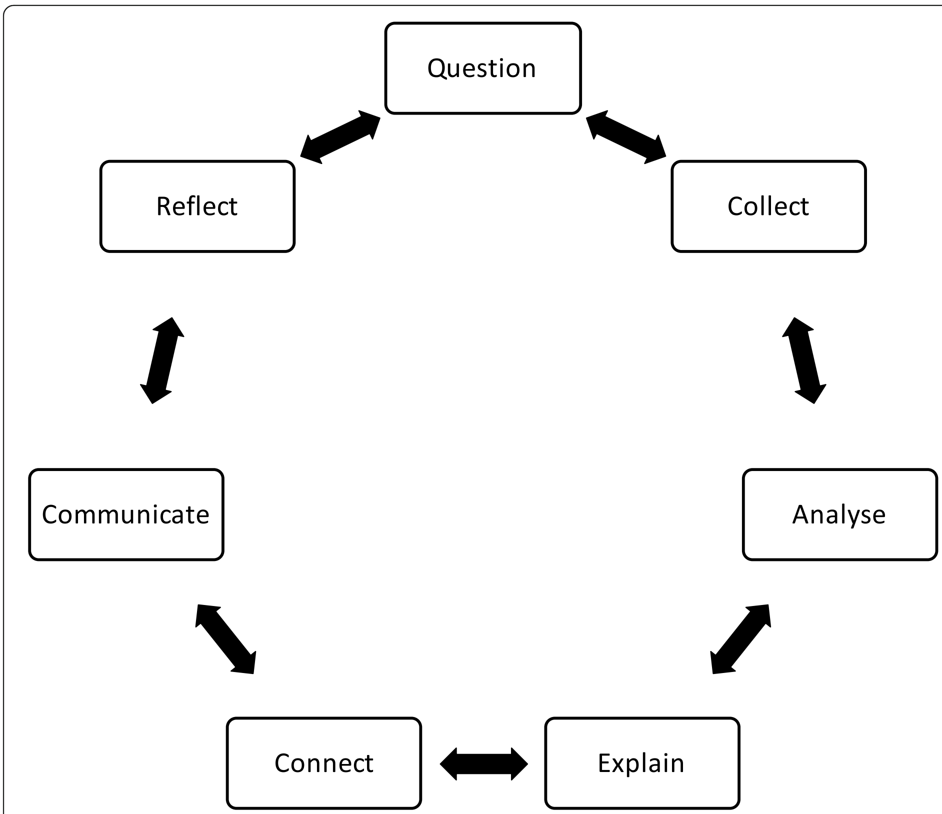

Fig. 1 Simaula's inquiry framework as the overarching in-game IBL structure

Fig. 2 The non-linear dialogue mechanic with different inquiry options

Non-Player Character (NPC) engagement meters values - attention and comprehension - hence it determined player's performance tied to the narrative.

There were three or four different types of choices players could choose from: (1) statements – the teacher instructs the student to explain a topic without any guidance or background information, rated as a 'poor' choice (2) closed questions – the teacher explains content and then asks students to summarise explanations rated as 'OK' (3) open questions – the teacher encourages students to formulate their own questions and self-directed lines of inquiry, rated as 'Best' and (4) research questions – the teacher encourages students to engage in scientific research, rated also as 'Best'. Interaction with the student NPCs was based on the particular inquiry choice selected by the player. Student NPCs responses were affected by player's choices and in turn determined the value of the NPC attention and comprehension meters. For example, if an 'open' choice was selected (e.g. let's discuss the effects of CO_2 in our atmosphere), then a student NPC might feel interested hence an increase of the meter value would be triggered. If a 'statement' question was chosen (e.g. show students different CO_2 effects and instruct them to memorise them) then a student might feel 'bored' or 'disruptive' and a decrease of the meter values would be triggered. When the player asked a question to a selected student NPC, then the NPC responded with a scripted answer. The answer reflected the level of attention and comprehension meters of the student NPC. By clicking the 'respond button' the game encouraged the player to engage in a short dialogical process with the student NPC by selecting choices that would motivate the student and thereby regain attention. Attention was regained through selecting choices that would engage students into group discussions as an inquiry activity or through conducting an experiment. Similarly, comprehension could be regained by choosing questions that set students in inquiry activities for carrying out a visual experiment, showing, for example, how the light is retracted to different colours followed by in-game choices that encouraged students to explain their observations. Such dialogue choices could trigger a group experiment for collecting data on circular motion conservation and analysing the physical properties of the Foucault Pendulum.

The types of choices served as an implicit rating system for measuring players' in-game progress and it would not necessarily constitute a particular conception of in-game IBL. Players selected a choice for responding to an IBL in-game question and then they reflected on their choices during the group discussion by articulating on how in-game inquiry appeared to them. The categories of description, dimensions of variation and outcome space have been constituted from the players' descriptions on, and reflections of, 'why' a particular type of choice was selected in conjunction to players' broader gameplay strategies.

Feedback and progress indicators

Simaula's grading system indicates in a summative way the overall player's progress for a particular game level. Grades emulate the grading system used in conventional classrooms and provide spontaneous, linear and cumulative feedback on overall performance. It can be used directly for improving performance by repeating the level and at the same time may be perceived as a performance indicator for the player to compare and improve over previous grades gained. The grades are based on time spent to complete the level and overall student comprehension and attention meters. An average grade is then calculated based on three metrics (Fig. 3: top left chart). If the player gets an average A-C grade the next level is unlocked and the player may start playing (Fig. 3: bottom-right chart). If not, then the level needs to be restarted. Next level adds more complexity in game-play by increasing the number of NPC students (from 3 to 5), and fusing scientific experiments with more complex and ill-defined dialogues between the player and NPC students.

To stimulate deeper understanding on developing in-game IBL, Simaula visualises textual feedback for reflection on previous inquiry choices. When the player selects an

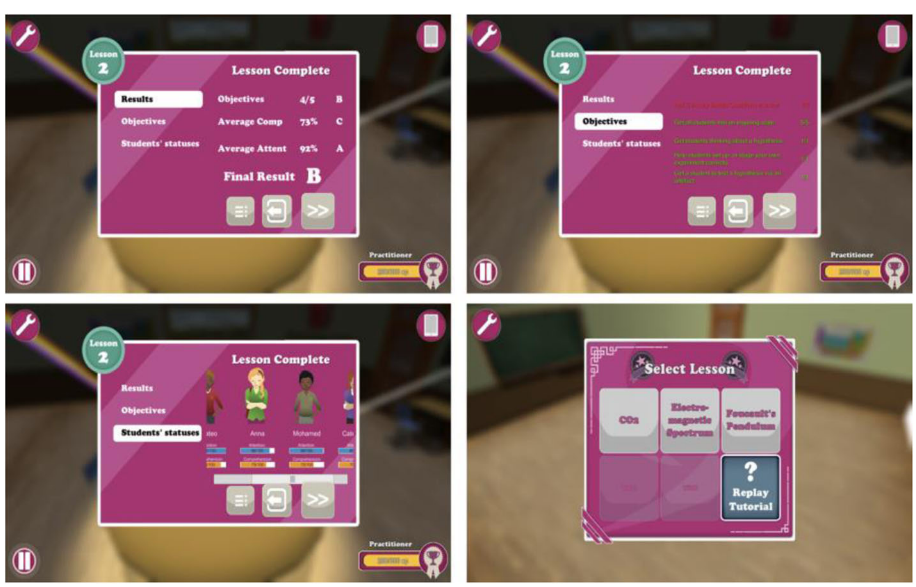

Fig. 3 Top-left chart: objectives, comprehension and attention metrics for calculating final grade. Top-right chart: level objectives accomplished. Bottom-left chart: Student's comprehension and attention levels. Bottom-right chart: Unlocking all three levels adding increased level difficulty

inquiry option then the virtual avatar provides formative feedback on the choice made. If the choice is rated as optimal (e.g. getting a 'best' rating), the avatar praises the player to continue at this pace (Fig. 4: top left chart). If the choice is rated as not poor but also as not optimal (e.g. getting an 'OK' rating), a hint is given for refining the selected IBL (Fig. 4: top right chart). If the question is not rated as optimal (e.g. a 'poor' rating) then the avatar triggers a prompt for helping the player to understand optimal ways of experiencing IBL. (Fig. 4: bottom left chart).

The activity log system (Fig. 4: bottom right chart) may be used during game-play to access previous inquiry choices and adapt strategy for next choices or after game play for reflection on how in-game IBL may be transferred to other contexts.

Uncertainty as an informed in-game design decision

Uncertainty is a key element in playing Simaula as it poses to the player the challenge to complete the level objectives by making a series of IBL choices through the non-linear narrative mechanic. A degree of uncertainty is desirable and needs to be an informed design decision for the game being in some sense 'hard to play', or at least, 'non-trivial' to win. The outcome of Simaula is merely a binary 'win' or 'loss' state expressed numerically but has deeper instantiations in terms of players' efforts to understand the rules, to become acquainted with the game's inner logic twinned with endeavours to adjust their performance for making the necessary inquiry decisions. In order to exert a feeling of purpose to the player, Simaula expresses uncertainty related to the inquiry choices in a sense that the player is not aware exactly the outcome of the IBL choice.

There is an intrinsic connection between uncertainty and IBL in-game learning. It empowers the player by adding a sense of choice in terms of the inquiry strategy mostly relevant to them and creates a feeling of influencing the outcome based on the

Fig. 4 Top-left chart: avatar provides feedback to a 'best' choice. Top-right chart: avatar provides feedback to an 'OK' choice. Bottom-left chart: avatar provides feedback to a 'poor' choice. Bottom-right chart: activity log stores choices for reflection

decisions made during game-play. Simaula exploits different sources of uncertainty (e.g. Costikyan, 2013) across the unpredictable combination of inquiry options the players needs to make for completing the level's objectives. In conjunction to this, uncertainty as an inherent design element in Simaula may impact conceptions of in-game IBL. It is therefore interesting to understand how different sources of uncertainty, as an inherent game design consideration, may influence experiences of in-game IBL.

Methodology

The study followed a phenomenographic approach to investigate the qualitatively different ways in which teachers experience IBL with the aid of Simaula. The study is premised on the principle that experiences of IBL are strongly influenced by teachers' actions, and that the context in which the experiences are embedded (in this case within a games environment), in turn, influence the experience (Prosser, Trigwell, & Taylor, 1994). A logical set of 'categories of description' and the 'outcome space' are perceived as the *outcomes* of phenomenographic research (Marton & Booth, 1997).

The composition of the sample was established from 22 initial responses to an email invitation sent to a network of teachers who would be interested in taking part to the study. Of the 22 email responses, and consistent with recommended sample sizes between 15 and 20 participants (e.g. Trigwell, 2000), 20 school teachers teaching science in secondary education (grade 9 through grade 12) from five schools in the greater area of Boston, Massachusetts, US fully participated in this study. To achieve variation in experience, purposive sampling was adopted in terms of both recruiting the participants and assigning them to each focus group with varied characteristics and backgrounds in: (1) teaching, (2) teaching using IBL, (3) teaching and learning using digital SGs, (4) playing Digital Games (DGs) and (5) taught science subjects with identifiers of subject area (PH = Physics; CH = Chemistry; BI = Biology) and (6) gender (Table 1).

Reflecting on the gender bias towards women science teachers and women game-players, 11 of the participants were females and 9 were males. In presenting the phenomenographic data below, participant identifiers (P1-P20) are supplemented with a pseudonym for indicating gender.

We endeavoured to carry out focus group interviews because both individual and collective responses could be discerned which is a key aspect of phenomenographic research. For example, within a focus group discussion, a comment may lead to a more developed idea provided by another participant constituting high levels of synergy, spontaneity and snowballing. As a result, variation may be delimited in more nuanced and inclusive ways through group dynamics tapping into the multiple realities of the interviewees. We therefore conducted four focus group interview sessions with five participants each, lasting 90–100 min in total per session (45–50 min Simaula play-testing followed by 45–50 min focus group interview), where interviewees had the chance to respond on their experiences of in-game IBL after playing Simaula. We certainly acknowledge that IBL is often viewed as a challenging and complex approach to teaching hence its practice within a classroom environment may be sporadic (e.g. Lotter, Harwood, & Bonner, 2007). However, the purpose of this study was to reveal conceptions of in-game inquiry as influenced by game design elements rather than attempting to change conceptions of IBL. In this sense, the rich-data set that was collected constituted the desired variation on the phenomenon in question and thereby the scheduled

Table 1 Characteristics of the sample

Teaching	IBL teaching	Teaching via SGs	Playing DGs	Science subjects	Gender
20 years	5 years	6 years	None	PH	Female
20 years	5 years	5 years	4 years	CH	Male
20 years	2 years	4 years	4 years	BI	Male
15 years	3 years	None	5 years	PH	Male
13 years	4 years	3 years	6 years	PH & BI	Female
13 years	3 years	2 years	None	BI	Female
12 years	1 year	None	3 years	PH	Female
12 years	6 months	3 years	2 years	BI	Male
12 years	4 years	None	3 months	CH	Male
11 years	6 years	2 years	2 years	PH	Male
11 years	6 months	6 months	None	BI	Male
11 years	2 years	None	3 months	PH	Female
10 years	5 years	3 months	10 years	CH	Female
8 years	3 years	None	3 years	BI	Male
8 years	2 years	None	1 year	PH	Male
6 years	4 years	2 years	None	PH	Female
6 years	5 years	3 years	2 years	PH	Female
5 years	1 year	None	4 years	BI	Female
3 years	1 year	None	1 year	PH	Female
3 years	6 months	6 months	5 years	BI	Female

exposure to the game supplemented by the group-interviews was ample for delineating how in-game IBL was experienced by the participating teachers. We designed the focus group interviews, based on a praxis-reflection process (e.g. Jarvis, 1999) starting firstly by playing Simaula as a practical approach to developing experiences of IBL and observing players' in-game IBL decisions, complemented by focus group interviews for engaging participants in a process of analysing, expressing and exchanging descriptions of their developed conceptions of in-game IBL.

Focus-group interviews were flexible, responsive and loosely structured based on semi-structured questions as to aid participants to explain their understanding more completely. After completing the game's tutorial, participants started playing the game by attempting to select a preferable inquiry choice from the different options, which would constitute their experiences of in-game IBL.

When play testing concluded, the focus group discussion started with key lines of questioning stemmed from three primary questions: (1) 'How do you understand IBL through playing Simaula?' (2) 'What are you trying to achieve by selecting a particular in-game IBL choice?' (3) 'What was the value of Simaula in developing your in-game IBL experiences?' Follow-up questions and probes were employed related to specific in-game inquiry features (e.g. 'What do you mean by inquiry-learning based on selecting a particular inquiry option?', 'Why would you choose a different option?') and questions related to game design influences in developing IBL (e.g. 'What do you see as the value of in-game feedback?', 'Could you please say more about how this relates with your in-game IBL experience?', 'How Simaula's features influenced your conceptions of IBL?'). Other themes emerged as prominent to the interviewees' interests in relation to perceived roles and level of engagement were probed as: 'How did you relate student's engagement with your chosen inquiry response?' 'What do you think is your role as a teacher in delivering IBL?' 'What do you think is student's role in inquiry?' Prompts to stimulate in depth views and clarification around the design of game and learning mechanics linked to IBL experiences frequently included 'What do you see as the value of the in-game IBL non-linear dialogue system as a mechanism for depicting different ways of practicing inquiry?' 'Why do you see as important in understanding Simaula's rules, and objectives?' 'What do you see as the value of Simaula's visual rating system in understanding your progress in developing IBL?' 'Why is that important?' 'How the experience of in-game uncertainty influenced your conceptions of IBL?' Picking up on analogies such as 'you said you felt like a student getting a bad grade when you lost, can you explain why you felt this way?' facilitated the process of describing conceptions in a mode, which is relational, experiential, content-oriented and qualitative.

Frequently during the discussion some of the interviewees were referring back to Simaula's activity log system to reflect on their selected inquiry choices and articulate further on why particular choices have been selected over others while contemplating on alterative choices that would most likely evidence development on conceptions of in-game IBL. To comply with ethical research procedures, all participants signed an information sheet and a consent form making explicit what is expected from them, the right to withdraw and our obligations towards them and towards the data we collected about them in terms of treating data confidentially, their voluntary participating nature and their right to withdraw at any time. We also described to participants our overall research design strategy underpinning the research objectives and questions having been validated externally to ensure that the questions asked would address the research's objectives.

The focus group interviews were tape-recorded and then transcribed verbatim allowing to search for qualitative variation in the conception and to focus attention on the phenomenon. We used qualitative data analysis software (Dedoose) for supporting data management, coding and monitoring the stages of the analysis to enhance the quality and rigour of the process.

Considerations of quality and rigour at the group-interview stage were made to assure joint exploration of how in-game IBL was experienced (Marton, 1988) and to minimise interviewer influence by giving attention to expressions highlighted by interviewees and clarifying intended meanings by asking follow-up questions. The interviewer avoided introducing new terms into the discussion and provided the time and space to the interviewee to reflect and express views and experiences. Researcher bias was also mitigated by posing questions about how do interviewees experience in-game IBL in different ways for encouraging variation and richer data.

We followed a four-phase analysis procedure (e.g. Alsop & Tompsett, 2006; Marton & Booth, 1997) in an iterative manner for delineating relationships between meaning and structure. The analysis embarked with becoming familiar with the data gathered hence we started to analyse the first 10 transcripts produced in line with recommendations of other phenomenographic studies that 10–12 transcripts form the ideal to maximum number that can be analysed at any one time (e.g. Åkerlind, 2008). Coding lists then started to emerge based on similarity of general 'themes' of described experiences of in-game IBL. The remaining transcripts, if similar, were mapped against existing codes. Transcripts that added a different aspect of the described experience led to the development of new codes, to the reconstitution of the categories and to the revision of the relationships between them. A set of logically inclusive categories of description was developed when all transcripts were grouped into associated code lists.

We then structured the experiences through formulating the different aspects of the conception represented in the dimensions of variation. Codes that represented contextual aspects of the phenomenon (e.g. game design elements that influence how in-game IBL was conceived) were arranged in each theme to delimit variation within and across the categories of description. Each category was linked with a set of dimensions of variation which seemed to influence the experience of in-game IBL.

The final step of the process looked for describing the meaning of the experience as well as the structure of the experience for constituting the outcome space. We reinterpreted the codes from the categories of description and the codes from the dimensions of variation with focus on comprising distinct groupings that stipulated structure, whilst deconstructing the critical aspects of the way of experiencing in-game IBL.

The data analysis was carried out principally by the lead researcher in extensive discussions, revisions and reflections of the data with other two researchers. The role of the researchers was to develop a shared perspective by comparing and contrasting code lists generated by the lead researcher and checking for reliability. For example, the lead researcher discussed preliminary codes with the team for attempting to map them across the transcripts. Codes that were perceived as unjustifiable by two or more researchers were discarded. If all researchers would be able to justify and resonate with coding and code lists as consistent then this would denote an agreed interpretation to retain the coding. As such, inter-coder reliability was achieved when agreement between the researchers on the consistency of coding perpetuated evidence of the reliability and rigour of the analysis. The frequency of interactions between the team-members was an iterative cycle of individual analysis (e.g. preliminary coding) followed by team analysis and meaningful discussions (e.g. compare codes, identify gaps, inform further sampling) prompting to individual synthesis (e.g. developing categories, dimensions of variation and outcome space). During team meetings the focus was on codes that required extensive refinements or developments to inform the next round of sampling. Meanings and interpretations were hence validly derived from the data as a collective and dialogical experience of the team informing the actions of each member. This process of analysis adhered to recommendations that phenomenographic analysis should be carried collaboratively and through meaningful dialogical processes between the researchers for mitigating idiosyncratic interpretations (Marton & Booth, 1997).

Results

Four categories of description and seven dimensions of variation were constituted to describe meaning and structure of teachers' conceptions of IBL through Simaula. Drawing on these findings, we articulate on understandings of in-game IBL and on game design aspects more likely to influence in-game IBL conceptions and practice.

Categories of description

Simaula was conceived as a medium for developing experiences of IBL as:

(A) uncovering insights about students' learning needs, interests and emotions
(B) generating ideas and concepts for meaningful inquiry
(C) a set of operations for designing and carrying out scientific research
(D) authentic inquiry for enabling knowledge building processes

Table 2 presents illustrative quotations for each of the four categories and the sections that follow discuss each category in detail. Individual respondents are identified as P (participant) 1–20 followed by a pseudonym to denote their gender.

Category a: uncovering insights about student's learning needs, interests and emotions

In this category, Simaula is seen as a medium for experiencing IBL in terms of understanding student's ways of learning, needs and dispositions. Collecting information through posing questions on identifying student's prior knowledge, ways of learning, feelings and emotions was in the foreground of the experience. This was evidenced from teachers' in-game IBL choices and from interpretations of the visual icons visualising students' feelings. Developing empathy or personal interest towards students' needs is in focal awareness and it is evidenced through closed-type inquiry choices that would frame student's prior knowledge and would allow access to subject-content interests and topic misconceptions to tailoring inquiry to student's requirements.

Category B: generating ideas and concepts for meaningful inquiry

In this category, Simaula is seen as a medium for experiencing in-game IBL for helping students to generate, brainstorm and clarify ideas and concepts. The focus was to guide students in developing ideas and meaning-making processes through exploring a wide solution space. Posing questions and communication still remain in the focal awareness of the experience, as in Category A, but now it shifts from empathy-building and

Table 2 Categories of description on experiences of IBL through Simaula

Category	Description	Representative quotations
A	IBL through Simaula as uncovering insights about students' learning needs, interests and emotions	I have selected choices to learn more about them (P13, Jacob). I chose options for exchanging content about CO2 (P17, Alex). This IBL choice shows what they feel via the visual engagement icons and meters (P3, Nick).
B	IBL through Simaula as generating ideas and concepts for meaningful inquiry	I picked choices to sketch (P11, Sara). I saw this 'thinking' icon something meaningful came up. (P5, George). Asked about CO2, they responded and I probed again. (P12, Rory). I perceived that an increase of the comprehension meter partly showed me that the student is thinking so trying to make meaning out of something; I was trying to find choices that made students to tell me what they think (P1, Bianca).
C	IBL through Simaula as a set of operations for designing and carrying out scientific research	I observed students starting to collect information, observing the lights, (P6, Jane). It depicts the basics of research (P18, Luka). I chose for NPCs to start analysing, see what to measure, and taking the lead (P19, Sheena).
D	IBL through Simaula as authentic inquiry for enabling knowledge building processes	Just wanted to do science (P10, Amanda). One NPC described it very accurately as being an actual scientist (P15, Linda). This is what inquiry is, thinking and reflecting as a scientist (P15, Linda).

identification of students' needs to helping students representing, visualising, discovering and communicating ideas and concepts for creative thinking and meaningful learning. The in-game inquiry choice types selected were both closed and open signifying teachers' intentions to guide students in participating to discussions for developing, externalising and expressing their views and opinions.

Category C: a set of operations for designing and carrying out scientific research

In this category, Simaula is seen as a medium for experiencing IBL through a set of processes for designing and doing research. Knowledge construction is the outcome from engaging with research. Explanations on what constitutes research and what are the necessary steps to designing research are viewed as broad guidelines for students to be introduced into the complex process of scientific investigations. Simaula was experienced as broadly introducing students to research in terms of: how to design research questions, particularly related to a student-identified scientific problem, collecting and analysing data, searching, retrieving and accessing prior research evidence. The category includes aspects from Category A such as questioning and developing empathy, and aspects from Category B such as encouraging students to generate, clarify and communicate ideas for meaning-making. There is a shift however in Category C from meaning making to knowledge construction through learning how to formulate research questions and hypothesis, observing and gathering evidence and conducting analysis as foundational principles of scientific research.

Category D: authentic inquiry for enabling knowledge building processes

In this category, Simaula is seen as a medium for experiencing IBL as mediating knowledge-building processes through emulating what scientists do for conducting research-based inquiry. There is a transition from empathising (Category A), meaning making (Category B), knowledge construction (Category C) to knowledge building (Category D). As in Category C conducting research and scientific investigations is in the focal awareness of the experience but now is viewed not as merely introducing students to research but as a knowledge building epistemic fluency that produces a tangible outcome of interest by using the scientific vocabulary, methods, processes and strategies adopted by real scientists when conducting scientific investigations.

Dimensions of variation

We sought to identify seven dimensions of variation that are logically developed from one category to another as evidenced in the data. Table 3 highlights differentiation of each dimension of variation and illuminates the inclusive relationship delineated between the categories. Table 4 shows illustrative quotations from participants for each dimension. We discuss each dimension of variation in turn.

Focus on epistemic IBL modes

Category A strongly reflects an epistemic mode of initiating inquiry through understanding student's prior knowledge, needs and emotions: 'Firstly I need to get closer to them, to know what they know, what they like, how they learn … ' (P17, Alex). Category B epistemic mode shifts towards meaning-making through helping students to

Table 3 Dimensions of variation

	A	B	C	D
Focus on epistemic IBL modes	Empathy	Meaning	Knowledge construction	Knowledge building
Role of teacher	Diagnose needs and interests	Motivator and guide	Collaborator	Modeller
Role of student	Externalising prior knowledge, needs and feelings	Ideating, brainstorming and negotiating ideas	Understanding scientific research	Practicing authentic scientific inquiry
Focus on game-play	Play of pleasure	Play of experience	Play of meaning	Play of reflectivity
Focus on core SGMs	tutorial for instructions on 'how to play'	Understanding structure of IBL dialogue system	IBL dialogue for impulsive thinking	IBL dialogue for deeper thinking
Feedback and progress mechanics	Familiarising with visual rating system and engagement metrics	Grading system for adjusting performance	Virtual trainer feedback for making improved IBL choices	Activity-log for reflection on transferring in-game IBL to real classroom
Game uncertainty	Rules uncertainty	Performative uncertainty	Player unpredictability	Semiotic uncertainty

create ideas, externalise, communicate and negotiate with peers. Negotiation and sharing were also evident by choices that guided students to discuss, share and becoming more autonomous in creating their own meaning of the scientific content: 'The 'drawing' choice followed by an open discussion helped me to understand that inquiry is

Table 4 Dimensions of variation with representative quotations for each category

Dimension	Representative quotations
Focus on epistemic IBL modes	A: Learning what NPCs know, how they learn, how they feel about what they learn (P1, Bianca). B: Choosing to create meaning through visualising an idea (P3, Nick). C: Observing, collecting and analysing evidence (P16, Jonas). D: Investigating CO2 hypothesis this is what research is about (P17, Alex).
Role of teacher	A: It was a way to see what they feel and need. (P20, Anna). B: Having them sketch something, externalise it […] (P12, Rory). C: I was acting as their partner from the way my selected options were expressed. (P4, John). Helping NPCs to experience what real science is […] (P18, Luka).
Role of student	A: Finding more information about gamma rays (P5, George). B: Picking to draw an idea and then they started being more responsive (P3, Nick). C: Game-students suggested how to tackle experiments (P10, Amanda). D: Students in-game role was how to experiment with science (P15, Linda).
Focus on game-play	A: It is like playing a game, just need to win (P17, Alex). B: Difficult to grasp the association between the choices (P7, Lina). C: Trying to improve the way I understand inquiry (P20, Anna) D: Getting my NPCs to collect data, can do this in class (P15, Linda).
Focus on core SGMs	A: Playing the tutorial first (P13, Jacob). B: Wondering how the dialogues are connected (P16, Jonas). C: Quick answers and fast responses (P5, George). D: I took the time to think over my choice. (P10, Amanda).
Feedback and progress mechanics	A: I see a connection between XPs, meters and dialogue ratings. (P1, Bianca). B: Got a C grade, need to try harder (P12, Rory). C: The avatar made me re-think my strategy (P17, Alex). D: I searched the activity log to find a previous dialogue, which I could adopt to my teaching (P14, Alice).
Game uncertainty	A: Not sure what the rules are (P19, Sheena). B: I will not finish this level today (P10, Amanda). C: I randomly tried different choices to resonate how inquiry unfolded (P11, Sara). D1: I can't match what inquiry represents in the game with the purpose it brings to my classroom (P7, Lina). D2: Inquiry requires time, resources and institutional support for doing it properly (P3, Nick).

about firstly visualising and understanding an idea and then sharing it with others to build a stronger understanding of it' (P5, George).

In Category C, the epistemic mode is knowledge construction through introducing students to research. There is a closer integration of learning, teaching and research, and in the focal awareness resides the aspect of introducing scientific research and what it means to be a researcher. Open inquiry is perceived as important for introducing students into scientific research for supporting the knowledge construction process and promoting a critical approach to inquiry. In Category D, the focus is on research as in Category C, but now the epistemic mode is the making of scientific outcomes through using methods, processes and practices employed by real scientists, and also considering the potential of a research-teaching connection in the schooling system: 'While choosing a research-directed dialogue activity, I pondered how important is for schools to invest and build on their research capacity' (P15, Linda). Tangible scientific outcomes were perceived as the product of scientific research: 'Science research is about applying knowledge for making something' (P10, Amanda).

Role of the teacher during in-game IBL

In Category A, the role of the teacher is perceived as setting the frame for inquiry by attempting to diagnose interests, needs and ways of learning predominantly via transferring content initiated through a question with a pre-defined answer: 'first I need to diagnose what they know about CO2' (P2, Jasmine). In Category B teacher's role to diagnose prior knowledge is extended as having the role of building support and guidance in developing ideas for meaningful learning. Teachers perceived their role as guiding and re-directing the inquiry process when engagement decreased: 'I normally picked choices that suggested how to start ideate and ways of expressing and then clicking for a group discussion to further expand on their ideations and lift up a bit a [student's] attention bar' (P4, John).

In Category C, teachers perceived their role as collaborators in terms of not only introducing research processes but also being a research partner: 'I felt like doing the experiment with them, like being a colleague' (P18, Luka). In Category D, the role as collaborator is extended to modelling the attributes and attitudes of what scientists do when carrying out research resembling processes and practices enacted by real scientists as an emancipatory practice to research.

Role of the student during in-game IBL

In Category A, student's role is structured and directed by the teacher: 'I was making choices to help my NPCs [students] recall knowledge by giving them some hints and direct them to fossil fuel material' (P13 Jacob). In Category B views on student's roles shifted from passive recipient of knowledge to more active roles as starting to become more self-directed in developing and making ideas explicit through negotiations, argumentation and group discussions guided by the teacher: 'Students need to start thinking about how their own ideas are related to gamma rays for making their own meaning' (P4, John).

In Category C, the role of the student is shifted to getting introduced to research as means to develop broad understandings of the processes, strategies and tools employed for conducting scientific research: ‘NPC responses seemed to be more self-directed, it was like they were determined to do their measurements or to start reflecting on what worked well for them’ (P1, Bianca). In Category D, student’s role in enacting IBL is seen as expanding in terms of sensing the spirit of science: ‘NPCs [students] may now see the essence of how science works via the light travel experiment and the wave range data collection […]’ (P11, Sara).

Focus on game-play

In Category A, teachers experienced game-play in terms of attempting to learn Simaula’s basic rules, input controls and overall game logic: ‘Firstly, I had to understand the game’s rules, this is what I do when playing games’ (P13, Jacob). Game-play was perceived as a ‘play of pleasure’ triggering a natural enjoyment increasingly prevalent in entertainment games. In Category B, the view of game-play as an entertainment game still exists in focal awareness, but at the fore is the view of increasing the experience of understanding the internal structure and logic of the IBL dialogue system as means to completing the level and unlocking the next one thereby perceiving game-play as a ‘play of experience’: ‘I felt good when I completed the CO2 level just like playing an arcade, you feel like the mission is completed and you move on to the next one’ (P20, Anna).

In Category C, there is a shift from experiencing game-play as playing an entertainment game to playing a game for learning. It was perceived that by understanding the meaning of an IBL choice would help on deciding on a series of choices that would in turn lead to more cohesive understandings of IBL and thereby experiencing game-play as ‘a play of meaning’: ‘Lots of thinking was required to retain this exploratory inquiry mode while doing the experiment’ (P12, Rory). In Category D, game-play is focused on considerations of, and reflections on, perceived in-game IBL practices with the potential to be transferred in the classroom characterising the experience of game-play as ‘play of reflectivity’. ‘I’ve had some serious thinking about how some of these IBL examples could be used in my actual teaching and if all these choices made sense’ (P19, Sheena).

Focus on core SGMs

In Category A the primary SGM focus is on playing the tutorial for comprehending rules and what determines or limits choices, actions and outcomes as means to shaping game-play strategy: ‘Learning the essentials and getting ready to play the game’ (P3, Nick). In Category B, the focal aspect is on understanding the IBL non-linear dialogue system and the inner-logic to choosing a dialogue: ‘I was trying to make sense what are the hidden connections between different dialogues and what makes them to be better or worse than others’ (P5, George).

In Category C, the primary focus shifts from using SGMs for understanding rules, logic and structure to focusing on using the IBL non-linear dialogue mechanic for attaching meaning to an IBL choice. The primary focus is on using the IBL dialogue mechanic for making instantaneous or impulsive responses to IBL through a swift conceptual tempo hence emphasis is on ‘doing’ and less on ‘reflecting’ when choosing a dialogue. ‘I just hit the response button. The first option that came to mind […] why should I overanalyse it?’ (P12, Rory). In Category D, the use of the IBL dialogue mechanic is perceived as an opportunity to think deeper and consider alternative choices, problematising and evaluating previous responses as anchors to further develop the in-game IBL experience by reflecting on a specific inquiry choice. 'I tend to go one-by-one all four options and visualise in my head possible outcomes before clicking my final choice' (P14, Alice).

Feedback and progress mechanics

In Category A, the focus is on getting to know the visual rating system especially in terms of understanding what makes a 'Best', 'OK' and 'poor' rating and how these ratings are associated with an increase or decrease of an NPC student's attention and comprehension meters. 'Trying to grasp why this 'poor' rating keeps my student's attention bar low all the time' (P11, Sara). In Category B, attention shifts from becoming familiar with the visual rating feedback system to increasingly more active forms of understanding progress and performance through scoring as explicit and binding in terms of determining a certain amount of knowledge to be acquired and to indicate the correct option: 'I need to have some quantifiable indicators that tells me how I did' (P14, Alice).

In Category C, the emphasis is on feedback provided by the virtual trainer as means to help on making informed inquiry choices leading to enhanced or more developed conceptualisations of IBL: 'The virtual trainer encouraged me to think what I needed to do for improving my inquiry choice' (P10, Amanda), characterising reception of feedback as an internal process evoked from evidence and the intention to use it for further improving in-game inquiry. In Category D, the emphasis is again on internal feedback processing but now the purpose is for self-assessment and reflection. The primary view is that the activity-log mechanic would facilitate efforts in thinking about ways of translating in-game experiences of IBL into real teaching practice: 'The activity log was quite handy for me to review my inquiry choices and thinking how these can be practiced in a real classroom' (P18, Luka).

In-game uncertainty

In Category A, views on in-game uncertainty are associated with difficulties in understanding the rules and logic of the game. It was perceived that during the early stages of playing Simaula, there was uncertainty in terms of teachers' confidence to learn the basic rules: 'I am feeling a bit out of my comfort zone, don't know how to start playing' (P14 Alice). In Category B, views of in-game uncertainty are shifted towards performative uncertainty in terms of selecting the correct inquiry choice that would enable to address the level's objectives, gain XPs and getting an 'A-C' average grade for completing the level: 'I was not sure, if I will get the necessary grade for going on to the level' (P8, Vily).

In Category C, views of uncertainty are in line with player's unpredictability as part of their effort to create meaning of the in-game IBL choices made: 'I did choose NPCs to form a group for doing the electromagnetic experiment rather than choosing an individual activity which could make more sense and see how it would pan out (P19, Sheena). In Category D, in-game uncertainty is experienced as semiotic uncertainty challenging the view that in-game IBL as practiced may have analogous impact on student's learning and engagement while enacting it in the classroom. This semiotic instantiation of uncertainty attempts to transfer in-game inquiry to actual teaching practice. 'I am not sure what would be the effect of practicing inquiry as in the game to my classroom' (P7, Lina). This leads to two inter-related sub-views of semiotic uncertainty: The first is *'self-referentiality'*, referring to own inquiry practice in the game and questioning the emerging meaning when applied in the classroom. The second is *'uncertainty of perception'* associated with the difficulty of perceiving inquiry as being transferable to different teaching contexts, parsing the view that IBL experiences as developed in the game or other simulated contexts require strenuous efforts to practice in realistic teaching conditions. 'Inquiry is so unpredictable, you never know how is it going to work out in the real classroom' (P14, Alice).

Discussion

Outcome space on science teachers' conceptions of in-game IBL

Science teachers experienced in-game IBL in four qualitatively different ways. The outcome space in Table 5 illustrates the referential and structural aspects, which encapsulate the totality of the experience. The *Standards* (NRC (National Research Council), 1996) highlighted the importance of prior conceptions of IBL in shaping approaches to IBL. From the phenomenographic perspective that this study is grounded, we sought to perpetuate the premise that particular in-game conceptions of IBL delimited by teachers is a function of both the teacher and the context (e.g. Marton, 1988; Marton & Booth, 1997). We perceived therefore that the way teachers experienced IBL before playing the game may be different from their conceptions of in-game IBL hence this study did not aim to investigate how prior conceptions of inquiry influenced experiences of in-game inquiry.

While this study confirms some of NRC's features of inquiry emphasising questions, evidence, explanations, evaluation via connecting with scientific theory and communication as core properties, it also identifies some distinctive aspects stemmed from the categories of description and dimensions of variation that constituted science teachers' conceptions of in-game IBL. In particular, in Category A the empathy aspect reveals a new key dimension of inquiry linked to the need of establishing a relationship with the student and as part of introducing IBL (e.g. Goodyear & Zenios, 2007). This may illuminate a 'gathering student requirements' stage of inquiry, increasingly exerting a more

Table 5 Outcome space

	Referential ('what' of the conceptions)	Structural ('how' of the conceptions)		
		Structured inquiry	Guided inquiry	Open inquiry
A	Uncovering insights about students' learning needs, interests and emotions	A		
B	As in (A) and for generating ideas and concepts for meaningful inquiry		B	
C	As in (B) and as a set of operations for designing and carrying out scientific research			C
D	As in (C) and as authentic inquiry for enabling knowledge building processes			D

personalised approach to designing inquiry driven by students' learning needs, feelings and prior knowledge.

In our categories of description there were certain features of inquiry that were more prevalent than others. In Categories A and B the *'question' and 'communication'* features were in the focal awareness of the experience perceived as teacher-directed thereby formulated and provided by the teacher. The *'evidence'* and *'analysis'* features were prominent in Categories C and D with a more student-directed orientation and an emphasis on the process in a sense that the focus was on learning the process of designing and doing research. The *'connect'* feature was not made explicit in teachers' conceptions in a way that it has not been inferred as a feature in relation to the in-game IBL choices made. This suggests that a 'partial inquiry' approach (e.g. Asay & Orgill, 2010; Kang et al., 2008) with four out of five features was revealed in science teachers' conceptions of in-game IBL. *'Reflection'* as an extended inquiry type has been discerned which may complement the existing IBL features provided by NRC.

The aspect of ideating for meaningful inquiry, in Category B, brings to the fore creative and design-like subjects closely reflecting a view of inquiry as applying design principles for creatively gathering ideas, needs and requirements for exploring a wide solution space. Another distinct feature as it was represented in Category C, was on introducing students to research for strengthening the nexus between teaching and research in schools. The rationale of inquiry as a research is widely discussed in studies for learning and teaching (e.g. Levy & Petrulis, 2012; Spronken-Smith & Walker, 2010) alluding to the premise that creating an awareness of how research is being carried out may progress the experience of transitioning from secondary to higher education.

The explicit connection between inquiry and research is extended in Category D constituting a view of research-based inquiry as encouraging students to impersonate a scientist, engage and emulate research methods from diverse perspectives, an aspect identified from NRC (National Research Council) (1996) as a step beyond 'inquiry as a process' and Buxton's (2006) conceptions of authentic science education. The underlying assumption was that by incorporating visual representations of in-game experiments that required NPCs to think of and act like a scientist would likely constitute a more cohesive perception of research-based authentic inquiry.

Game design influences and implications for in-game IBL practice and transfer

Our study draws attention to different perspectives on SGs design, pertaining the focus on SGMs for the purpose of introducing rules, scope and understanding core mechanics and then gradually extending the focus on SGMs for developing meaning and also for entering a state of reflection. Arguably, this developmental progression is further reflected in the core SGMs dimension. From playing the tutorial as means to shaping game-play strategy and understanding the inner-logic of an IBL dialogue as reflected in Categories A and B to using the IBL dialogue mechanic for impulsive or reflective IBL responses as experienced in Categories C and D. The notion of designing SGMs that facilitate different ways of processing in-game knowledge has not been researched extensively, but our study suggests that two aspects may be considered to situate SG design with different forms of in-game knowledge acquisition: For impulsive in-game practice, SGMs that focus on 'instant action' and on 'doing' through a timer-mechanic to gauge 'choosing the first option that will come to mind'. For reflective thinking, SGMs that place more emphasis on reflection by reviewing previous choices or allowing the player to take the time (e.g. no timer-mechanic or a slow-motion timer gauge) as means to reflect on the action of making a choice and continue to reflect after it.

The intrinsic view of a game as *autotelic* (e.g. Salen & Zimmerman, 2004) highlighting the self-contained purposes and goals only relevant within the game's context and separated from lived experiences may not be a pertinent design consideration for SGs. There may be a genuine expectation to experience the essence of practicing in-game inquiry in real everyday school settings. Our study did not reveal any explicit design considerations pointing to SGMs that would enable a distinct transfer of in-game inquiry to real classrooms but there were certain views that reflected an inherent need for SGs that would support external functions by extending in-game artificial experiences to actual teaching and learning practices.

Conclusions and limitations

The results of this study revealed an inclusive set of categories of description on science teachers' conceptions of IBL through using a serious game that could help teachers to discern and delimit the different ways IBL can be enacted. There was broad consistency between NRC's features of inquiry in science education, however our study illuminated a partial inquiry approach to in-game IBL as the *'connect'* feature was not in the focal awareness of participants' conceptions of in-game IBL. *'Reflection'* has been identified as an extended or supplementary feature of inquiry placing emphasis on the process of reflecting on the inquiry-learning journey rather than merely engaging in content exchange. Aspects of inquiry discerned from this study, which are distinctive from other studies as epistemic modes is the emphasis on creating empathy for student's needs, ideating ideas and concepts for meaningful inquiry, through the process of introducing research for knowledge construction and as part of commencing a teaching-research nexus in schools, to highlighting the importance of inquiry in terms of emulating research methods and empirical investigations as authentic knowledge building processes adopted by real scientists.

Game-design elements appeared to play an important role in shaping conceptions of in-game IBL. It was evident from the dimensions of variation that teachers' focus was on design principles mostly seen in the design of entertainment games especially prevalent in less-developed categories where the focal awareness was on SGMs that helped getting to know the internal structure of the game with a broad goal to complete the level extended to using SGMs for understanding the structure of the non-linear IBL mechanic as means to progress to the next level, through more developed categories with focus on using the core SGM for developing complex and dynamic IBL meanings to using SGMs that would support reflection on ways of practicing IBL in the real classroom. There is a logical progression on views of the nature of SGMs from introducing rules and setting the physical and temporal boundaries closely reflecting the design of an entertainment game to focusing on SGMs with particular attention on how IBL is discerned, visualised and represented. The results of the study revealed central aspects of designing SGMs for enabling the representation of impulsive thinking for rapid knowledge processing and SGMs for enabling reflective thinking, allowing time to reflect on the in-game action and continue to reflect after it.

While our study provides useful insights on conceptions of IBL using a serious game and on delimiting game design elements that may be perceived as the outer boundaries influencing teachers' understandings, it is important to highlight some of the study's limitations.

First, our sample consisted of science teachers from different scientific disciplines delimiting varied conceptions of IBL using a serious game. Subject-related influences have not been considered in terms of how the nature of a science subject might influence experiences of in-game IBL. Since IBL may be experienced in more than one way across scientific subjects, it would be interesting for future studies to investigate subject-specific experiences of in-game IBL.

Second, certain features of inquiry have been discerned with associated scale of openness as reflected in the study's outcome space. The categories of description reflected a partial inquiry mode as not all NRC's five essential features were discerned from teachers' chosen dimensions, as in phenomenography the overarching purpose is to allow for participants to choose the dimensions of their answers. It would be interesting for future studies to investigate variations of full inquiry interpretations and delineate inferences between inquiry features and levels of openness.

Third, Simaula was designed with specific subject content, design goals, SGM priorities including the IBL framework, the non-linear IBL core mechanic, the engagement metrics and feedback mechanics that would possibly impede or hinder some dimensions of in-game IBL that have not been captured in the outcome space. It is important for future studies to design serious games with balanced and purposeful SGMs, and in-game content aligned to real subject content taught by the participating teachers that would help them to choose dimensions closely reflecting real practice and thereby facilitating endeavours in making the transition from in-game IBL to practice in the real classroom.

Finally, due to the purposive sampling process adopted in this study with guidelines to involving participants with certain profiles and subject backgrounds and due to the implicit design considerations to map IBL with game mechanics, results may not be generalisable to other studies carried out in different contexts.

We are cautious about drawing strong inferences between the notion of a game as *autotelic* and the underlying intrinsic purposes and goals to be extended in a lived experience therefore no explicit design considerations were made in relation to how SGMs would possibly support the transition of in-game IBL to the real classroom. However, in that it revealed that teachers would increasingly consider practicing in-game inquiry into the classroom, our study points to a distinctive design difference between SGs and entertainment games in relation to developing game architectures that would support in-game IBL transfer to real classrooms. The results of the study could act as a catalyst for developing frameworks on how science teachers experience IBL and also for designing SGs that are informed by rich-mediated pedagogical designs. Situated studies on science teachers' experiences of IBL with the aid of SGs would help to contemplate the notion of transferring in-game IBL artificial experiences to lived teaching and learning practices.

Acknowledgements
We are grateful to the teachers that participated in the study and formed our sample for collecting and analysing the data. We would also like to thank the Massachusetts Institute of Technology (MIT), STEP lab for providing support and guidance during the data collection stage.

Authors' contributions

All five authors contributed to the game's design, literature review, methodology, data analysis and reliability. Data collection was conducted by the first author who has also led the data analysis procedure and the preparation of the manuscript. Discussions and comments in terms of improving the manuscript were made from all authors, on subsequent iterations, until the final submitted version. The submitted manuscript is approved by all authors.

Funding

The design and development of Simaula was fulfilled as part of the Inspiring Science Education (ISE) project funded by the European Commission (CIP-ICT-PSP-2012-325123) and the research has been funded by Coventry University, School of Computing, Electronics and Mathematics.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on request.

Declarations

Ethics approval and consent to participate

All participants in the study signed an information sheet and an institutional consent form making explicit what was expected from them, the right to withdraw. and our obligations towards them and towards the data we collected about them in terms of treating data confidentially, their voluntary participating nature and the right to withdraw at any time. The study has been approved by Coventry University ethics committee with reference number P45040.

Consent for publication

An institutional consent form was used that all participants signed as part of providing consent for publication.

Competing interests

The authors declare that they have no competing interests.

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Received: 16 December 2020 Accepted: 22 April 2021
Published online: 12 May 2021

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