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Review

Phases of inquiry-based learning: Definitions and the inquiry cycle

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ABSTRACT

Inquiry-based learning is gaining popularity in science curricula, international research and development projects as well as teaching. One of the underlying reasons is that its success can be significantly improved due to the recent technical developments that allow the inquiry process to be supported by electronic learning environments. Inquiry-based learning is often organized into inquiry phases that together form an inquiry cycle. However, different variations on what is called the inquiry cycle can be found throughout the literature. The current article focuses on identifying and summarizing the core features of inquiry-based learning by means of a systematic literature review and develops a synthesized inquiry cycle that combines the strengths of existing inquiry-based learning frameworks. The review was conducted using the EBSCO host Library; a total of 32 articles describing inquiry phases or whole inquiry cycles were selected based on specific search criteria. An analysis of the articles resulted in the identification of five distinct general inquiry phases: Orientation, Conceptualization, Investigation, Conclusion, and Discussion. Some of these phases are divided into sub-phases. In particular, the Conceptualization phase is divided into two (alternative) sub-phases, Questioning and Hypothesis Generation; the Investigation phase is divided into three sub-phases, Exploration or Experimentation leading to Data Interpretation; and the Discussion phase is divided into two sub-phases, Reflection and Communication. No framework bringing together all of these phases and sub-phases was found in the literature. Thus, a synthesized framework was developed to describe an inquiry cycle in which all of these phases and sub-phases would be present. In this framework, inquiry-based learning begins with Orientation and flows through Conceptualization to Investigation, where several cycles are possible. Inquiry-based learning usually ends with the Conclusion phase. The Discussion phase (which includes Communication and Reflection) is potentially present at every point during inquiry-based learning and connects to all the other phases, because it can occur at any time during (discussion in-action) or after inquiry-based learning when looking back (discussion on-action).

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Contents

1. Introduction

Inquiry-based learning is an educational strategy in which students follow methods and practices similar to those of professional scientists in order to construct knowledge (Keselman, 2003). It can be defined as a process of discovering new causal relations, with the learner formulating hypotheses and testing them by conducting experiments and/or making observations (Pedaste, Mäeots, Leijen, & Sarapuu, 2012). Often it is viewed as an approach to solving problems and involves the application of several problem solving skills (Pedaste & Sarapuu, 2006). Inquiry-based learning emphasizes active participation and learner's responsibility for discovering knowledge that is new to the learner (de Jong & van Joolingen, 1998). In this process, students often carry out a self-directed, partly inductive and partly deductive learning process by doing experiments to investigate the relations for at least one set of dependent and independent variables (Wilhelm & Beishuizen, 2003). It should be added that in the context of this study we are focusing on learners: what is new knowledge to them is not, in most cases, new knowledge to the world, even if the approach can be flexibly used by scientists in making their discoveries of new knowledge. In addition, it should be noted that an investigation does not always involve empirical testing.

Several quantitative studies support the effectiveness of inquiry-based learning as an instructional approach. Alfieri, Brooks, Aldrich, and Tenenbaum (2011), for example, performed a meta-analysis comparing inquiry to other forms of instruction, such as direct instruction or unassisted discovery, and found that inquiry teaching resulted in better learning (mean effect size of $d = 0.30$). A meta-analysis by Furtak, Seidel, Iverson, and Briggs (2012) incorporated studies using a broad range of terms to describe inquiry-based learning (e.g., mastery learning, constructivist teaching); they reported an overall mean effect size of 0.50 in favor of the inquiry approach over traditional instruction. A positive trend supporting inquiry-based science instruction over traditional teaching methods was found in a research synthesis by Minner, Levy, and Century (2010). In addition, it has been demonstrated that web-based guided inquiry-based learning can improve different inquiry skills, such as identifying problems, formulating questions and hypotheses, planning and carrying out experiments, collecting and analyzing data, presenting the results, and drawing conclusions (Mäeots, Pedaste, & Sarapuu, 2008). Recent technological advancements increase the success of applying inquiry-based learning even more (de Jong, Sotiriou, & Gillet, 2014). Educational policy bodies worldwide regard inquiry-based learning as a vital component in building a scientifically literate community (European Commission, 2007; National Research Council, 2000). Therefore, it is valuable to examine inquiry-based learning further in more detail and identify its core elements. In this article we present such a search for the key elements of inquiry-based learning. In doing so, we have taken an approach where we have focused only on inquiry-based learning described under this term. Several related areas have been excluded, such as discovery learning, project-based learning, game-based learning, and problem-based learning, as including these concepts would make our study too broad and the outcomes might not be easily applicable in the practical context in developing inquiry activities by teachers or educational designers.

Inquiry-based learning aspires to engage students in an authentic scientific discovery process. From a pedagogical perspective, the complex scientific process is divided into smaller, logically connected units that guide students and draw attention to important features of scientific thinking. These individual units are called inquiry phases, and their set of connections forms an inquiry cycle. The educational literature describes a variety of inquiry phases and cycles. For example, the 5E learning cycle model (Bybee et al., 2006) lists five inquiry phases: Engagement, Exploration, Explanation, Elaboration, and Evaluation. An inquiry cycle proposed by White and Frederiksen (1998) also identifies five inquiry phases, but labels them as Question, Predict, Experiment, Model, and Apply. An apparent distinction between these examples is that the initial phases of the 5E cycle (Engagement and Exploration) suggest starting with an inductive (empirical/data-driven) approach, whereas the first two phases of the White and Frederiksen inquiry cycle (Question and Predict) suggest a deductive (theory/hypothesis-driven) approach. However, both induction and deduction can coexist in an inquiry cycle. In fact, Klahr and Dunbar (1988) characterized the scientific reasoning process as a dual search in two spaces, which they call experiment space and hypothesis space. How researchers choose to balance inductive and deductive approaches in an inquiry cycle can influence the selection and/or arrangement of inquiry phases.

Inquiry cycles follow from a historical progression of instructional models and therefore represent a contemporary view that is built upon a solid historical foundation. Bybee et al. (2006) discussed the origins of the 5E instructional model and show that early frameworks began with defining a list of fundamental conceptual phases. For example, Dewey (1933) outlined several important aspects of inquiry-based learning, such as defining a problem, formulating a hypothesis, and conducting tests. Later frameworks elaborated on the interaction between phases, the sequencing of phases, modifications in terminology, and the necessity of particular phases. Bybee et al. emphasized that prior instructional models served as a foundation to build newer models. Therefore, many contemporary inquiry cycles implicitly reflect aspects of earlier frameworks such as the empirical cycle by de Groot (1969).

The way an inquiry cycle is presented usually suggests an ordered sequence of phases. However, researchers are also usually careful to add a disclaimer that inquiry-based learning is not a prescribed, uniform linear process. Connections between the phases may vary depending on the context. In an inquiry cycle proposed by Justice et al. (2002), a single inquiry phase (Self-reflection/Self-evaluation) directly connects to all other phases. The authors argued that this particular inquiry phase, which encourages learner self-awareness, is needed at all inquiry phases. How inquiry phases are arranged in an inquiry cycle can depend on the nature of the phase. de Jong and Njoo (1992), for example, made a distinction between inquiry processes that directly generate or transform information (transformative processes) and processes that manage the learning process (regulative processes). As seen with the various terms applied for different inquiry phases, certain diversity also appears in understanding the relations and sequencing of the inquiry phases within inquiry cycles, for example, whether regulative processes are related to the whole, overarching inquiry-based learning or to each specific phase. Clarification would help avoid confusion among teachers and instructional designers who work with inquiry-based learning approaches.

Based on our initial analysis of several articles (Bybee et al., 2006; Justice et al., 2002; White & Frederiksen, 1998) we found that different descriptions of inquiry cycles in the research literature originating from different researchers use various terminologies to label phases that are essentially the same. A preference for one term over another is not consequential as long as the terminology has been clearly defined and understood. But what is important is to find out how many inquiry phases are actually unique and conceptually independent. Another assumption we make is that the diversity of inquiry cycles can be simplified according to the framework by Klahr and Dunbar (1988) in which inquiry reasoning processes are divided into two parts. The two parts relate to the inductive/deductive dichotomy in scientific reasoning, and in the case of diverse inquiry cycles it may be that different researchers have constructed different cycles based on placing more emphasis on one approach over the other. It is important to examine how inquiry phases relate to the path along which an inquiry reasoning process proceeds.

Therefore, we feel there is a need for an analysis of the terms used for describing inquiry phases in order to provide a comprehensive inquiry cycle that is aligned with the most common understandings about inquiry-based learning. A rigorous and systematic review that identifies and extracts the core components of inquiry-based learning is then able to provide a broad framework to organize the many specific implementations of inquiry cycles described by various researchers. It should offer a contemporary and concise summary of how inquiry-based learning is structured. It is also worth mentioning that most previous instructional models only focused on transformative learning processes and did not include regulative processes as independent inquiry phases. The interaction between transformative and regulative processes is now viewed as a key element in inquiry-based learning (de Jong & van Joolingen, 1998).

Although the literature on inquiry cycles and phases presents a variety of terms for phases and connections between phases, the successful application of inquiry cycles in situations ranging from in-classroom activities (Meyerson & Secules, 2001) to computer-based environments (de Jong et al., 2010; Mäeots, Pedaste, & Sarapuu, 2011) suggests an underlying commonality that is at the core of inquiry-based learning.

The goal of this article is to identify and summarize the core features of inquiry cycles from the viewpoint of the learning process by systematically reviewing the literature on inquiry phases and cycles. The outcome of this review is a synthesized inquiry cycle that combines the strengths of existing inquiry-based learning frameworks.

In the current article the following research questions were addressed:

(1) Which inquiry phases are necessary for complete inquiry-based learning?
(2) How should the inquiry phases be arranged to inquiry cycles and an inquiry-based learning framework?

2. Method

A systematic literature review was conducted in order to identify the core phases of inquiry-based learning and how the different phases are involved in the learning process. The EBSCO host Library (www.ebscohost.com) database was used to search for articles using the search terms: *inquiry phases*, *inquiry stages*, *inquiry cycle*, *inquiry models*, *inquiry learning processes*, *inquiry-based learning*. The search was limited to the term 'inquiry' in different contexts since it was important to focus on how this particular and widely used term had been used in several policy documents (European Commission, 2007, 2011; National Research Council, 2000, 2006; Rocard et al., 2007) or in national curricula. The EBSCO host Library was selected because this database has meta-data of more than 64,000 journals, 6 million books, and 400,000 conference proceedings. This exceeds the numbers in Scopus or ISI Web of Knowledge. In the following sections, an overview of the search and data-analysis processes is presented.

2.1. Search procedure

The first step in the search procedure (Fig. 1) was the selection of the educational databases referenced in EBSCO host Library. The following databases were included: *Academic Search Complete*, *Central & Eastern European Academic Source*, *E-Journals*, *ERIC*, *PsycARTICLES*, *PsycINFO*, and *Teacher Reference Centre*. To specify the search to retrieve a high number of academically relevant research articles, the following search criteria were set in EBSCO: (1) related words applied; (2) search within the full text of the articles; (3) full text available; (4) published since 1972 (the earliest year available); and (5) academic journals as a source type. The search was carried out on 1 December 2012 and resulted in 535 matches for the term “inquiry phases”; 920 matches for the term “inquiry stages”; 294 matches for the term “inquiry cycle”; 528 matches for the term “inquiry models”; 51 matches for the term “inquiry learning processes”; and 2000 matches for the term “inquiry-based learning”. Most of the articles retrieved in this initial step did not focus on educational issues (e.g., ‘inquiry cycle’ is a software engineering term used for improving a set of requirements, ‘inquiry models’ can refer to professional ethics in the medical field, ‘inquiry phase’ is sometimes a synonym for discovery phase in legal terminology). Eliminating these non-relevant search matches therefore narrowed down the results to 60 articles that addressed inquiry in an educational context as an approach for learning.

2.2. Data analysis

The systematic review process for the 60 selected articles consisted of three steps. First, each article was categorized into one of two groups depending on the information it contained: (1) descriptions of general inquiry phases only; (2) descriptions of inquiry phases along with possible inquiry cycles (see Appendix A). All articles that did not include at least one of these types of information were excluded from the following analysis, which reduced the number of selected articles to 32. Second, the terms describing inquiry phases were extracted from each article. Third, available descriptions of the reported inquiry phases were collected from the articles selected for the analysis and sources outside the articles, if necessary, in order to clarify their content and relations with other phases.

Comparative analysis of the data extracted from the 32 articles involved compiling definitions of the inquiry phases, determining their position in the inquiry cycle, and eliminating redundancy between phases. If a specific term was not defined by the authors, then the meaning of the term in the context of the article was analyzed in order to classify the term within the framework of the authors’ other terms. Next, the terms of the inquiry activities were sequenced, and the inquiry phases described by different authors with different terms were compared. This helped to build a system of terms that served the study as a database for finding the most common inquiry phases and for merging multiple sub-processes to form bigger modules.

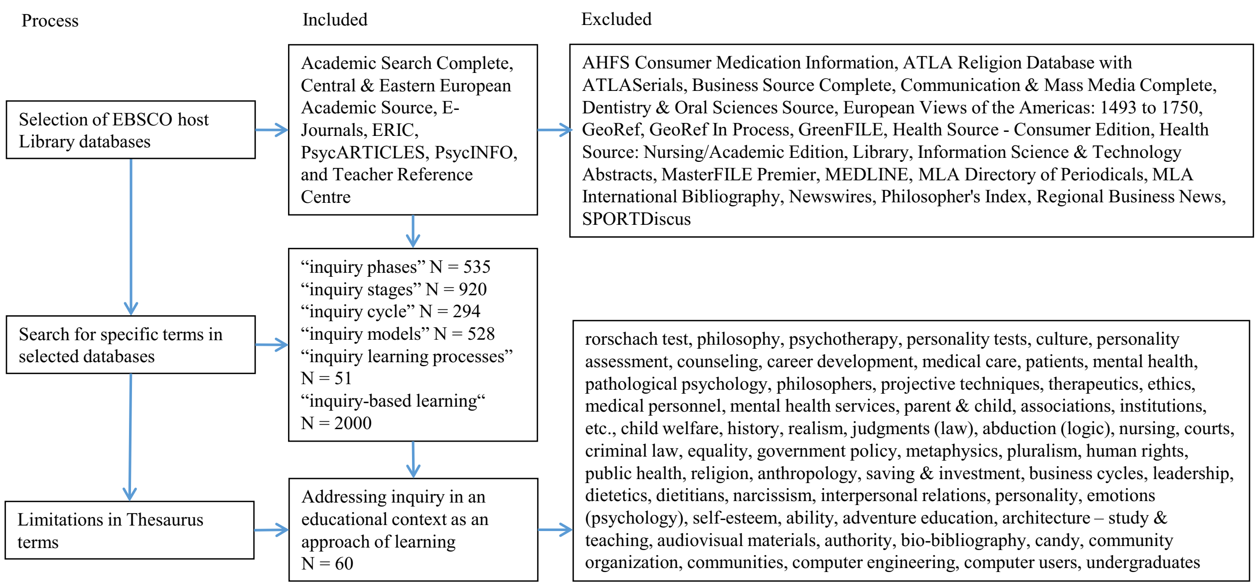

Fig. 1. Flowchart of the literature search procedure.

3. Findings and discussion

The review of the 32 articles allowed us to generate an initial overview of the common phases across the articles and was the basis for proposing a comprehensive inquiry-based learning framework. It was decided that this synthesis would be limited to the articles found by the systematic search in order to avoid unsystematic collection of articles that would decrease the reliability of the study. First, we describe how we merged the variety of terms that were used to describe inquiry phases in the articles analyzed in this study. Next, the common inquiry phases are introduced, and finally, these are synthesized in a new framework that captures the core of the inquiry cycles presented in the 32 articles selected in this literature search.

3.1. Variety of inquiry phases

The review process resulted in a list of 109 different terms for inquiry phases (see Appendix A). These terms showed considerable overlap, which became evident when comparing the descriptions of the phases. Therefore, in the first round of analysis, the meaning of the terms used by different authors was analyzed, and the terms were grouped according to similar criteria, creating a list of 34 slightly different inquiry activities. The reduction from 109 to 34 terms occurred through a process of comparing definitions of different terms and eliminating redundancies. Next, in the second round these 34 processes were sequenced and re-organized into 11 prospective phases; in the third round of analysis these 11 were finally merged into five general inquiry phases along with a few sub-phases (see Fig. 2). We took into account that a cycle that would present too many phases could adversely affect student learning in an environment for inquiry-based learning, and, therefore, discussions also focused on merging terms to reach an optimal number of phases. The details of this process as well as the reasons for merging the processes into phases will follow.

Six out of the 32 articles initiated the inquiry cycle with ‘orientation’, ‘introducing a topic’ or ‘theory’ (group 1 in Fig. 2), followed up by ‘learning challenge’, ‘anchor’, ‘find my topic’, ‘engage’, ‘learner investigates scientifically oriented questions’

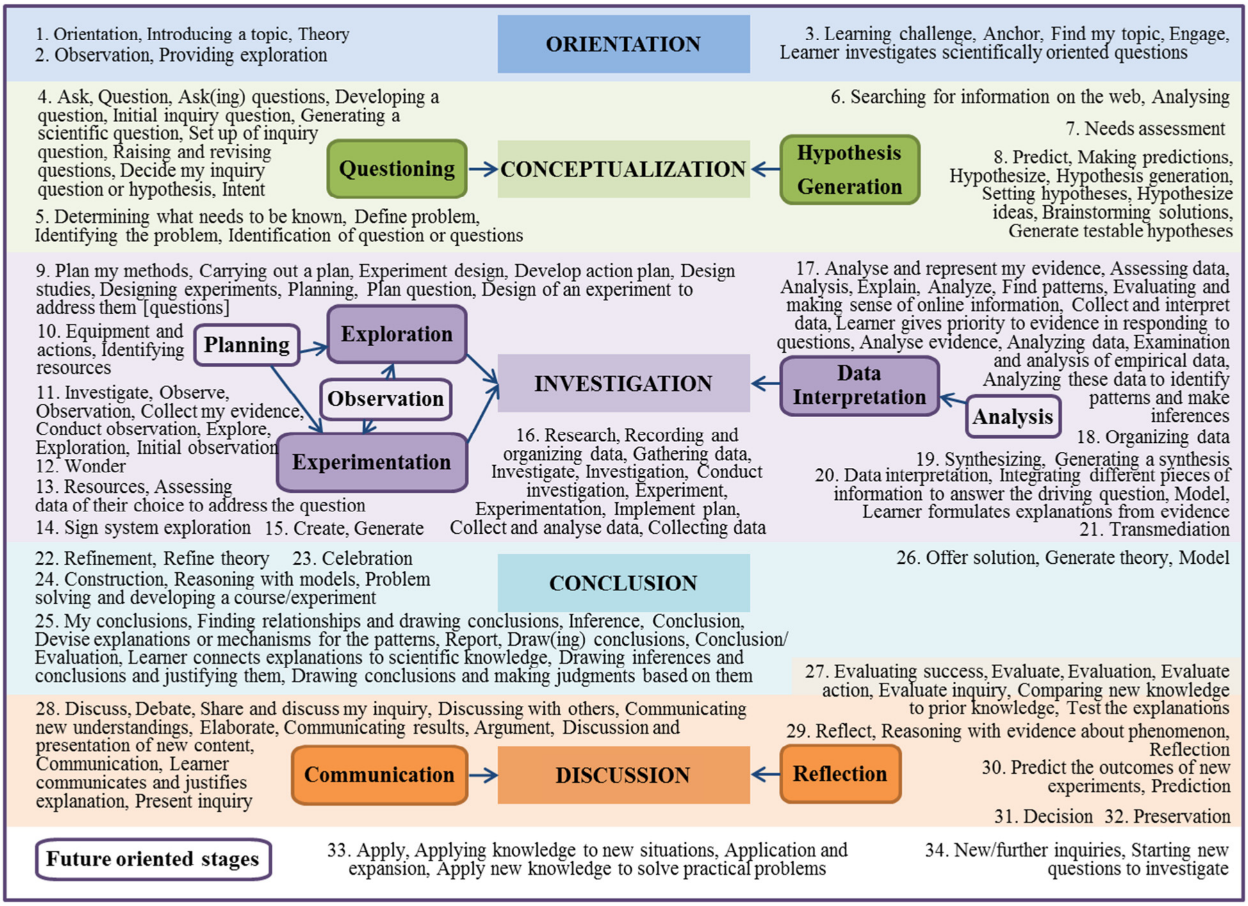

Fig. 2. Visualization of the process by which the initial 34 groups of inquiry activities were merged into bigger groups and finally into five general inquiry phases.

(group 3). Some articles also described an intermediate process, simple ‘observation’ or ‘exploration’ of the behavior (group 2). Overall, all of these activities fall under the term ‘orientation’, since their aim is to get the learner started with a new topic for investigation. One has to explore or observe a phenomenon in order to get interested in it, to read some theory in order to know the scientifically oriented questions related to this particular phenomenon, and to engage him or herself with the issue through a challenging anchor point. In addition, it was found that ‘orientation’ was the most frequently used term in talking about these three initial processes: the term ‘orientation’ was used in four of the articles, whereas all other terms were used only once or twice. Thus, it was decided that the first inquiry phase in the compiled inquiry cycle should be Orientation.

The inquiry cycle continued (or in some articles began) with asking more specific scientific questions that might be specific research questions or more open questions about a particular domain. This process was a very common one in the literature review; 14 out of the 32 articles described it using the following terms: ‘ask’, ‘question’, ‘ask questions’, ‘developing a question’, ‘initial inquiry question’, ‘generating a scientific question’, ‘set up of inquiry question’, ‘raising and revising questions’, ‘decide my inquiry question or hypothesis’, ‘intent’ (group 4). This set of terms suggested that the second inquiry phase in our provisional inquiry cycle should be Questioning, because it covers the meaning behind all of the terms used in the 14 articles.

Hypothesis Generation was introduced in the provisional inquiry cycle as the third stage, because it was very common in the reviewed research articles. Eleven out of the 32 articles introduced it through the following terms: ‘predict’, ‘making predictions’, ‘hypothesize’, ‘hypothesis generation’, ‘setting hypotheses’, ‘hypothesize ideas’, ‘brainstorming solutions’, ‘generate testable hypotheses’ (group 8). Despite the differences in terms used by the authors, these all indicated a need to have a hypothesis or prediction before the learner can start with planning an exploration or investigation. Three slightly different intermediate processes that help move from questioning toward hypothesis generation were also identified. The first of these (group 5) was described through phrases such as ‘determining what needs to be known’, ‘define problem’, ‘identifying the problem’, ‘identification of a question or questions’. These processes can be related to the previous phase of Questioning. Similarly, the other two processes (groups 6 and 7) can be related to the process of Hypothesis Generation, since these describe processes that are needed to collect information for formulating hypotheses. These processes were described by different authors through the following phrases: ‘searching for information on the web’, ‘analysing’, or ‘needs assessment’. These processes guide learners toward hypothesis generation. Overall, however, it was clear that there was an overlap between the processes for generating hypotheses and questioning. Therefore, it was decided for the final inquiry cycle to position Questioning and Hypothesis Generation as sub-phases that together form a more general inquiry phase termed Conceptualization.

The Hypothesis Generation sub-phase or general Conceptualization phase was followed by a distinct planning process that was characterized in 10 articles as ‘plan my methods’, ‘carrying out a plan’, ‘experiment design’, ‘develop action plan’, ‘design studies’, ‘planning’, ‘plan question’, ‘designing experiments’, or ‘design of an investigation to address them [questions]’ (group 9). A slightly different process was introduced by two other authors: ‘equipment and actions [planning what is needed according to methods]’ and ‘identifying resources’ (group 10). In our initial analysis, all of these activities were combined in an inquiry activity called Planning. In the subsequent analysis, Planning is considered as a sub-process within the Investigation phase, which is the third general inquiry phase after Orientation and Conceptualization in the compiled inquiry cycle.

The Investigation phase was characterized in 11 articles through the following terms: ‘investigate’, ‘observe’, ‘observation’, ‘collect my evidence’, ‘conduct observation’, ‘explore’, ‘exploration’, ‘initial observation’ (group 11). ‘Investigate’ was a term used by three authors, ‘observation’ by five authors and ‘exploration’ by three authors. It was understood that investigation is somewhat more systematic and based on a plan, while observation and exploration may have more flexibility. Two types of investigation processes were distinguished: Exploration and Experimentation. Exploration is seen as a sub-phase of Investigation and more related to a simple observation process. In this process, students make discoveries related to their questions without clear hypotheses in mind. Experimentation is a sub-phase where students collect evidence concerning a hypothesis; it is derived from the ideas introduced in the articles that differentiated an investigation process. Both Exploration and Experimentation involve Planning.

Processes in groups 12–15 were uncommon and were left out of the general inquiry-based learning framework but can still be considered as activities within the Investigation phase: ‘wonder’, ‘resources’, ‘accessing data of their choice to address the question’, ‘sign system exploration’, ‘create’, ‘generate’.

Another process involved in the planning processes in both the Exploration and Experimentation sub-phase is data collection (group 16). The data collection process was indicated by the following terms: ‘research’, ‘recording and organizing data’, ‘gathering data’, ‘investigate’, ‘investigation’, ‘experiment’, ‘experimentation’, ‘implement plan’, ‘collect and analyse data’, ‘collecting data’.

Next (groups 18–21), processes conducted after the simple data analysis were described through several terms that indicate follow-up activities to help in drawing conclusions: ‘organizing data’, ‘synthesizing’, ‘generating a synthesis’, ‘data interpretation, ‘integrating different pieces of information to answer the driving question’, ‘model’, ‘learner formulates explanations from evidence’, ‘transmediation’. No specific phase was created for these activities in the current synthesis. These activities concerning more advanced data analysis are part of the sub-phase Data Interpretation, which thus consists of both simple and advanced data analysis. In the final version of the inquiry cycle, Data Interpretation is seen as one sub-phase of the Investigation phase, together with the Exploration and Experimentation sub-phases. These processes form a coherent set where a learner could move backwards and forwards several times if Data Interpretation leads to revising an Experimentation plan or stimulates additional Exploration.

The next process could be characterized as (Data) Analysis. The process of data analysis was the one most frequent one in the articles analyzed in the review (explicitly present in this narrow meaning in 16 articles). The terms used included 'analyse and represent my evidence', 'assessing data', 'analysis', 'explain', 'analyse', 'find patterns', 'evaluating and making sense of online information', 'collect and interpret data', 'learner gives priority to evidence in responding to questions', 'analyse evidence', 'analysing data', 'examination and analysis of empirical data', 'analysing these data to identify patterns and make inferences'.

Finally, 14 articles included a conclusion process (group 25), and the same number of articles had a discussion process (group 28). In some cases, several additional processes that support arriving at conclusions were introduced: 'refinement', 'refine theory', celebration', 'construction', 'reasoning with models', and 'problem solving and developing course/ experiment' (groups 22–24). The conclusion and discussion processes occasionally overlapped. Sometimes conclusions followed discussion or communication (a term that was often used in descriptions of discussion), but most frequently, conclusions were based on investigation and analysis and later communicated to others. Therefore, it was still possible to emphasize these two as separate phases of inquiry-based learning. The Conclusion phase was characterized using the following terms: 'my conclusions', 'finding relationships and drawing conclusions', 'inference', 'conclusion', 'devise explanations or mechanisms for the patterns', 'report', 'draw(ing) conclusions', 'conclusion/evaluation', 'learner connects explanations to scientific knowledge', 'drawing inferences and conclusions and justifying them', 'drawing conclusions and making judgments based on them' (group 25). Within these descriptions, 'conclusion' was a recurring term, and it was used in the inquiry-based learning framework synthesized in the current study.

The Discussion phase was elaborated through the following terms: 'discuss', 'debate', 'share and discuss my inquiry', 'discussing with others', 'communicating new understanding', 'elaborate', 'communicating results', 'argument', 'discussion and presentation of new content', 'communication', 'learner communicates and justifies explanations', 'present inquiry' (group 28). Discussion and communication were both very common in the list of terms used to describe this process. However, communication sometimes indicated only a unidirectional process where a student communicates his/her conclusions to others, but discussion was always seen as a wider bidirectional process. Therefore, we decided to use the term 'Discussion' to describe the fifth general phase of the inquiry cycle.

While some authors saw the potential for either Conclusion or Discussion to be the final phase of the inquiry cycle, several other authors indicated that conclusions should be verified and/or generalized through discussion and other specific activities. Therefore, Discussion can be seen as a separate final phase of the inquiry cycle. However, it could also be seen as a phase that is conducted in parallel with Conclusion or all other phases where the information gathered in a phase needs discussion. Discussion among students throughout an inquiry enactment becomes more apparent when the inquiry activities at task require collaboration. Our analysis revealed four articles that distinguished a phase for generating generalizations based on the conclusions: 'offer solutions', 'generate theory', and 'model' (group 26); however, these overlapped with the phase of conclusion. In eight studies, emphasis was placed on evaluating inquiry-based learning, using the terms 'evaluating success', 'evaluate', 'evaluation', 'evaluate action', 'evaluate inquiry', 'comparing new knowledge to prior knowledge', 'test the explanations' (group 27). Evaluation can be considered to be a process relating to conclusion or reflection (Leijen, Valtna, Leijen, & Pedaste, 2012). Therefore, evaluation of inquiry-based learning is positioned as a process falling between the Conclusion and Discussion phases (in particular, between the Conclusion phase and the Reflection sub-phase). In addition, based on five of the articles analyzed in the current study, Reflection can be distinguished as a separate inquiry sub-phase, captured by terms such as 'reflect', 'reasoning with evidence about phenomenon', and 'reflection' (group 29). One of the distinctions between Communication and Reflection as sub-phases of Discussion concerns the object that is being communicated or discussed. Communication will probably be more related to experimentation or exploration outcomes, whereas reflection will more often concern the processes involved. However, reflection-related activities sometimes also included 'predict the outcomes of new experiments', 'prediction', 'decision', 'preservation' (groups 30–32). Thus, it was reasonable to introduce Reflection as one of the sub-phases of the Discussion phase of the general inquiry cycle. In this case, Communication is a discussion process between a learner and his/her peers or teacher and Reflection is regarded as an inner discussion of the learner.

The articles analyzed in the current study supported the distinction of two more future-oriented stages (groups 33 and 34) which, however, were not directly related to inquiry-based learning and were therefore not included as inquiry cycle processes synthesized in the current work. These processes were labeled as 'apply', 'applying knowledge to new situations', 'application and expansion', 'apply new knowledge to solve practical problems' or 'new/future inquiries', and 'starting new questions to investigate'.

In conclusion, based on the initial analysis, eleven common and most frequently seen (based on the number of articles in which particular terms were used) phases were identified, in the following order based on the sequence of the inquiry cycle: Orientation, Questioning, Hypothesis Generation, Planning, Observation, Investigation, Analysis, Conclusion, Discussion, Communication, and Reflection. However, it was not practical to retain 11 phases, because inquiry-based learning is often referred as a complex and difficult learning process for the learners (de Jong & van Joolingen, 1998; Veermans, van Joolingen, & de Jong, 2006) and therefore, a smaller number of phases helps to better present the whole inquiry-based learning. The initial list of 11 inquiry phases was reduced, not by eliminating any particular phase, but by doing an in-depth analysis as described earlier to organize similar phases into groups (e.g., Planning, Observation, and Analysis were re-grouped under

Exploration, Experimentation, and Data Interpretation and all three of these sub-phases were grouped under Investigation, as described earlier).

3.2. Descriptions of general inquiry phases

The analysis of the descriptions and the definitions of inquiry phases presented in the articles reviewed led to a new inquiry-based learning framework that includes five general inquiry phases (see Table 1 for definitions): Orientation, Conceptualization, Investigation, Conclusion, and Discussion. In general, this cycle is similar to several others; however, it uses terms that have been extracted as core terms from the articles found in this review, and it covers the processes behind most of the inquiry phases described in these articles. Further, it can be expected that this cycle also covers many inquiry-based learning frameworks that were not found in the current search and might therefore be compatible with teachers' current understanding of inquiry-based learning and help to structure their teaching according to this framework of learners' processes. For example, de Jong (2006b) also provided an inquiry cycle that consists of five general phases and a few sub-phases. In his work, the general phases were Orientation, Hypothesis Generation, Experimentation, Drawing a Conclusion, and Making an Evaluation. Experimentation had sub-phases of experiment design, prediction, and data interpretation. In our new cycle, Conceptualization is broader than Hypothesis Generation as it also involves an additional sub-phase, Questioning. Investigation is broader and involves Exploration in addition to Experimentation and Data Interpretation. Discussion is broader than Making an Evaluation, including both Reflection (which contains description, critique, evaluation, and discussion in a narrow context of reflection, see Leijen et al., 2012) and Communication about findings. Other inquiry-based learning frameworks can similarly be seen as falling within the framework proposed in the current study. In order to enable that type of comparison, this section elaborates on the descriptions of phases and sub-phases of the new inquiry-based learning framework.

Orientation focuses on stimulating interest and curiosity in relation to the problem at hand. During this phase the learning topic is introduced by the environment or given by the teacher or defined by the learner (Scanlon, Anastopoulou, Kerawalla, & Mulholland, 2011). The main variables of the domain are identified during the Orientation phase, and its outcome is a problem statement.

Conceptualization is a process of understanding a concept or concepts belonging to the stated problem. It is divided into two sub-phases, Questioning and Hypothesis Generation. These sub-phases yield similar yet distinguishable outcomes: Questioning arrives at a research question or more open questions about a domain, while Hypothesis Generation arrives at a testable hypothesis. Both of these are based on theoretical justification and contain independent and dependent variables, but have one key difference – the hypothesized direction of the relation between variables given in the hypothesis is not present in the case of a research question (Mäeots et al., 2008). In general, hypothesizing is a formulation of a statement or a set of statements (de Jong, 2006a), while questioning is a formulation of investigable questions (White & Frederiksen, 1998). Thus, the outcomes of the Conceptualization phase are research questions or hypotheses to be investigated or both if first research questions are formulated and then hypotheses are generated based on these.

Investigation is the phase where curiosity is turned into action in order to respond to the stated research questions or hypotheses (Scanlon et al., 2011). The sub-phases of Investigation are Exploration, Experimentation, and Data

Table 1
Phases and sub-phases of the synthesized inquiry-based learning framework.

General phases	Definition	Sub-phases	Definition
Orientation	The process of stimulating curiosity about a topic and addressing a learning challenge through a problem statement		
Conceptualization	The process of stating theory-based questions and/or hypotheses.	*Questioning*	The process of generating research questions based on the stated problem.
		Hypothesis Generation	The process of generating hypotheses regarding the stated problem.
Investigation	The process of planning exploration or experimentation, collecting and analysing data based on the experimental design or exploration.	*Exploration*	The process of systematic and planned data generation on the basis of a research question.
		Experimentation	The process of designing and conducting an experiment in order to test a hypothesis.
		Data Interpretation	The process of making meaning out of collected data and synthesizing new knowledge.
Conclusion	The process of drawing conclusions from the data. Comparing inferences made based on data with hypotheses or research questions.		
Discussion	The process of presenting findings of particular phases or the whole inquiry cycle by communicating with others and/or controlling the whole learning process or its phases by engaging in reflective activities.	*Communication*	The process of presenting outcomes of an inquiry phase or of the whole inquiry cycle to others (peers, teachers) and collecting feedback from them. Discussion with others.
		Reflection	The process of describing, critiquing, evaluating and discussing the whole inquiry cycle or a specific phase. Inner discussion.

Interpretation. Students explore/observe, design different experiments by changing variable values, make predictions, and interpret outcomes (de Jong, 2006a; Lim, 2004; White & Frederiksen, 2005). In general, exploration is a systematic way of carrying out an investigation with the intention of finding a relation among the variables involved (Lim, 2004). In this case there is no need for stating a hypothesis, but careful planning is still needed in order to save resources (e.g., time, materials, money). However, experimentation concentrates on making and applying a strategic plan for the experiment with a specific timeline, and it naturally follows from the Hypothesis Generation phase. In this case evidence for testing a hypothesis will be collected and in planning the experiment the variables that should be kept constant or varied in conducting an experiment should be defined. Both Exploration and Experimentation involve the design and implementation of the investigative activities, and an intermediate outcome is the design or plan of the exploration or experiment. For example, if the domain requires specific equipment or materials to be used, the choice of the materials and equipment is part of the design developed during the Exploration or Experimentation phase. During Exploration and Experimentation data will be collected. The Data Interpretation sub-phase is focused on making meaning out of collected data and synthesis of new knowledge (Bruce & Casey, 2012; Justice et al., 2002; Lim, 2004; White & Frederiksen, 1998; Wilhelm & Walters, 2006). The final outcome of the Investigation phase is an interpretation of the data (a formulation of the relations between variables) that will permit returning to the original research question or hypothesis and drawing a conclusion regarding what was asked or hypothesized.

Conclusion is the phase in which the basic conclusions of a study are stated (de Jong, 2006a). In this phase learners address their original research questions or hypotheses and consider whether these are answered or supported by the results of the study (Scanlon et al., 2011; White, Shimoda, & Frederiksen, 1999). It may lead to new theoretical insights. The outcome of the Conclusion phase is a final conclusion about the findings of inquiry-based learning, responding to the research questions or hypotheses.

Discussion contains the sub-phases of Communication and Reflection. Communication can be seen as an external process where students present and communicate their findings and conclusions to others, and receive feedback and comments from others (see Scanlon et al., 2011) and sometimes listen to others and articulate one's own understandings (Bruce & Casey, 2012). Reflection is defined as the process of reflecting on anything in the learner's mind, e.g., on the success of the inquiry process or cycle while proposing new problems for a new inquiry cycle and suggesting how the inquiry-based learning process could be improved (Lim, 2004; White & Frederiksen, 1998). It is mainly viewed as an internal process (What did I do? Why did I do so? Did I do well? What are the other options in a similar situation?). Within this process, several activities, such as role-play, writing a diary or narrative, and guiding questions, can be distinguished as support for this (Runnel, Pedaste, & Leijen, 2013), and these can help students' reflections to reach specific levels of quality: description, justification, critique, and discussion (Leijen et al., 2012). Thus, reflection is often more focused on the inquiry-based learning process and communication on domain-related outcomes of this process. Both Discussion sub-phases can be seen as occurring at two possible levels: (1) communicating or reflecting on the whole process at the end of the inquiry-based learning or (2) in relation to a single phase in the cycle.

3.3. *Inquiry-based learning framework*

Based on the overview of the proposed inquiry phases and sub-phases and their definitions, an inquiry-based learning framework was developed (see Fig. 3). The arrows in Fig. 3 demonstrate different pathways through the framework. Although the cycle often (in 13 articles out of 32 reviewed in our study) starts with Orientation, it displays flexibility in the pathways that can be followed. Three possible inquiry cycles can be traced by following the arrows: (a) Orientation–Questioning–Exploration–Data Interpretation (possibility in the cycle to go back to Questioning)–Conclusion; (b) Orientation–Hypothesis Generation–Experimentation–Data Interpretation (possibility in the cycle to go back to Hypothesis Generation)–Conclusion; and (c) Orientation–Questioning–Hypothesis Generation–Experimentation–Data Interpretation (possibility in the cycle to go back to Questioning or Hypothesis Generation)–Conclusion. Even more flexibility can be created by linking the framework with design-based research (Barab & Squire, 2004). In this case the research could start in the Conceptualization phase and have several short cycles between the Conceptualization phase and the Investigation phase. However, for design-based research the investigation phase should not test a model or theory under development but different features of the naturalistic environment where the theory/model should work. After collecting 'background information' the learner (or researcher) could turn back to the Conceptualization phase to test the model/theory in mind. If, after several loops, the 'notional test' is successful, then the theory or model itself could be tested.

The Discussion phase can be seen as a set of processes that are "optional" for the inquiry cycle, because for an individual learner, inquiry-based learning outcomes can often be arrived at without any Communication or Reflection. However, the quality of the whole inquiry-based learning and its related learning gains can depend on the discussions during each inquiry phase and/or after completing all of the other phases. Several authors have included Discussion as a culminating inquiry phase (Bruce & Casey, 2012; Conole, Scanlon, Littleton, Kerawalla, & Mulholland, 2010; Valanides & Angeli, 2008), while others consider Conclusion as the final stage of an inquiry cycle (de Jong & van Joolingen, 2008; National Research Council, 1996; Tatar, 2012).

Based on our framework we recommend starting the inquiry-based learning process with Orientation, where students not only get an idea about the topic to be investigated but are also introduced to the problem to be solved. If students' curiosity is already raised from previous studies or interests, this phase is often not needed (which is especially the case with

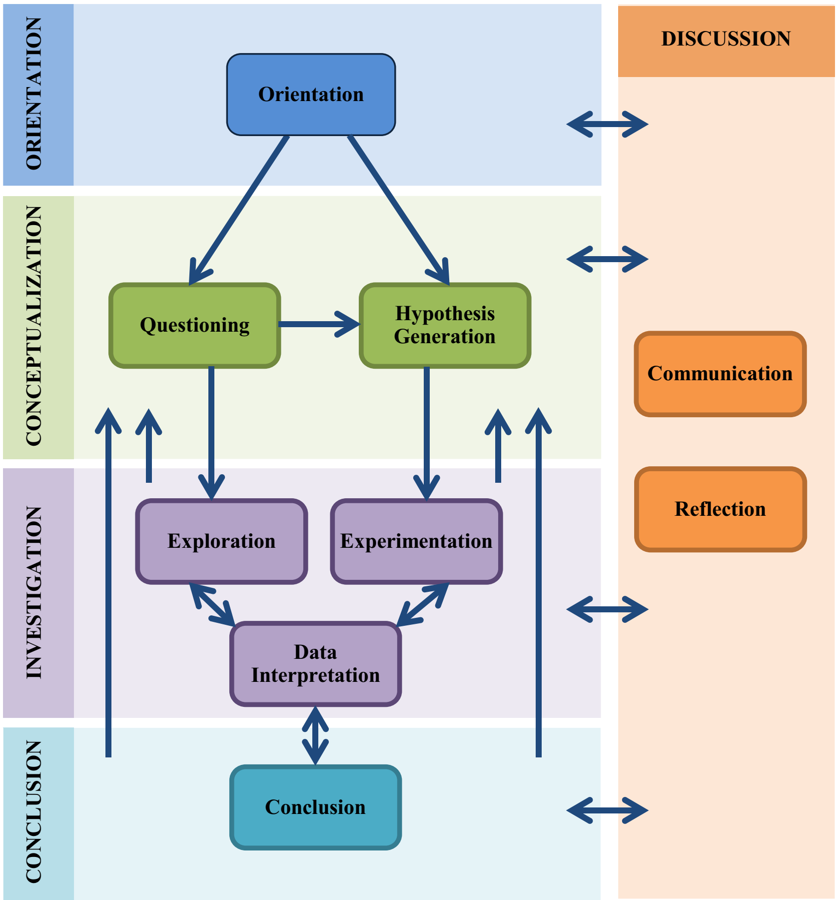

Fig. 3. Inquiry-based learning framework (general phases, sub-phases, and their relations).

researchers doing research). In the following step, students have different possibilities for forming the key concept to be studied in the inquiry-based learning process: hypothesis-driven approach or question-driven approach. If the students have no specific idea and only a general plan of what to explore, they should start from more open question(s) that guide them to the exploration of a phenomenon (data-driven approach, pathway 'a'). In this case, it is expected that students will return to the Conceptualization phase if they have specified, revised or derived new ideas from the Exploration phase or data gathered, but they can also move directly from Exploration to Data Interpretation and Conclusion. If the students have a more specific, often theory-based idea about what to investigate, then a hypothesis-driven approach is suitable ('b'). A slight deviation from the latter could be the question-driven approach, where students have a question and their next goal is to collect background information for stating a specific hypothesis as a possible answer to the question ('c'). In conclusion, the three suggested but not the only possible pathways are the following:

(a) Orientation–Questioning–Exploration–Questioning–Exploration–Data Interpretation–Conclusion (the loop between Questioning and Exploration can be repeated several times, but it is also possible to move directly from the first Exploration to Data Interpretation; Communication and Reflection can be added to every phase);
(b) Orientation–Hypothesis Generation–Experimentation–Data Interpretation–Hypothesis Generation–Experimentation–Data Interpretation–Conclusion (the loop between Hypothesis Generation–Experimentation–Data Interpretation can be repeated several times, but it is also possible to move directly from the first Data Interpretation to Conclusion; Communication and Reflection can be added to every phase);
(c) Orientation–Questioning–Hypothesis Generation–Experimentation–Data Interpretation–(Questioning) Hypothesis Generation–Experimentation–Data Interpretation–Conclusion (the loop between Hypothesis Generation–Experimentation–Data Interpretation can be repeated several times, but it is also possible to move directly from the first Data Interpretation to Conclusion; after Data Interpretation it might be necessary to revise Questions, but more often only Hypotheses are revised; Communication and Reflection can be added to every phase).

The pathway in the Investigation phase depends primarily on the actions taken during the Conceptualization phase. The Questioning sub-phase can precede the Hypothesis Generation and/or the Exploration sub-phases. In both Exploration and

Experimentation, planning is an important activity to avoid inappropriate use of resources, such as time, materials, and money. Data Interpretation is the next step after either the Exploration or Experimentation sub-phases where data are collected. Here students analyze data according to a specific strategy and method planned in the Exploration or Experimentation sub-phases and make their first interpretations of the data. From Data Interpretation, it is possible to move forward to the Conclusion phase or go back to the Conceptualization phase to revise existing or define new questions or hypotheses, which makes inquiry-based learning a cyclical process. If some issues have been discovered in Exploration or Experimentation, it might be a good idea to turn back to change the plan or experiment design made in a particular sub-phase without changing research questions or hypotheses. If a student collected enough data for confirming his or her hypothesis or for answering the stated question(s), then he or she may proceed to the next phase for stating final conclusions. These are stated in the Conclusion phase, where the outcomes of the Investigation phase are compared with the output of the Conceptualization phase. In case the data-collection was not as successful as planned (according to the findings in the Data Interpretation sub-phase), the student can go back to the Conceptualization phase to re-state a question or hypothesis, which serves as new input for the Investigation phase. In this case, the results of Data Interpretation serve the student as new theoretical knowledge for him/her to formulate questions or hypotheses. However, going back to the Conceptualization phase is not only a consequence of insufficient or disconfirming data. Moving back may also be in response to new ideas that arise out of the collected data during interpretation. Thus, inquiry-based learning can be seen as cyclical on multiple levels, and it is evident how the pathways described in this synthesis can form different inquiry cycles. In addition, the starting point of the cycle can be flexibly varied. For example, one might start from Exploration of a phenomenon and later move to Conceptualization to formulate meaningful hypotheses.

In all phases from Orientation to Conclusion, the processes of the Discussion phase are also possible. The Discussion phase is here defined from learners' perspective in the inquiry-based learning context. Both Communication and Reflection can be seen as on-going processes, which help students receive feedback about their learning process by sharing their domain-related outcomes and process-related ideas with others. This means direct communication among peer students, teacher, etc. However, it could also involve guided monitoring of students' learning process by using reflection activities. In this context, discussion can be seen as a process supporting meta-cognition or regulative processes of inquiry learning as proposed by de Jong and Njoo (1992). Two types of reflection can be distinguished (Schön, 1987): (a) *reflection-in-action*, where the students evaluate their study process while conducting the activities of a specific phase and collect particular information for this while planning and monitoring learning activities or (b) *reflection-on-action*, where the students evaluate their study process after completing the whole inquiry cycle. In both cases, students use the results of their reflection to revise the activities engaged in during specific phases (e.g., re-stating their research question) or as an input for a new inquiry cycle. Therefore, it follows that the effect of one's reflection on the success of inquiry phases or the improvement of inquiry skills is strongly related to the quality of the reflection. Similarly, Communication can be viewed as 'in-action' communication or 'on-action' communication, i.e. it is either part of an inquiry phase or performed as a separate activity at the end of the inquiry cycle.

The new inquiry-based learning framework presented in Fig. 3 broadly reflects a contemporary view of inquiry-based learning. It is derived from a systematic review of inquiry-based learning frameworks found in the educational research literature and is an attempt to cover many different implementations of inquiry-based learning. Early frameworks of inquiry-based learning may have neglected meta-cognitive processes, which in Fig. 3 are found in the Discussion phase and are also in connection with the four transformative general inquiry phases. The possibility that inquiry-based learning may primarily follow an inductive or deductive reasoning approach, as Klahr and Dunbar (1988) discuss, is captured in Fig. 3 through the use of various sub-phases within the Conceptualization and Investigation phases. However, the framework is not limited to either one approach since the pathways connecting phases in Fig. 3 allow for iterations and cyclical movement, thereby increasing the range of possible inquiry process implementations. Overall, the framework brings together core elements of inquiry-based learning and connects them in such a way as to show that multiple implementations of inquiry cycles can develop out of a single framework.

4. Conclusions

The main goal of the current study was to provide instructional designers and teachers with a synthesized inquiry-based learning framework from learners' perspective that can be used to ensure an effective inquiry-based learning process. In a number of other studies in the past, many alternative inquiry cycles have been introduced containing an unreasonably high number of different terms to describe the various inquiry activities. This made it hard for novice designers and teachers to understand which are the core phases and processes of inquiry-based learning. Without this information, their first attempts to achieve generally effective inquiry-based learning for students could lead to failure. Therefore, in the current study a systematic literature review was conducted in order to identify and summarize the core features of the inquiry-based learning process and to synthesize a framework that combines the strengths of existing inquiry-based learning frameworks. It is expected that the use of the new framework extracted from the literature review can be the key to success in implementing inquiry-based learning effectively.

The inquiry-based learning framework proposed in the current study on the basis of the analysis of the literature consists of five general phases and nine sub-phases for inquiry-based learning. These inquiry phases and related processes can be organized in different pathways that could be followed when designing specific learning situations. The basic version starts from the Conceptualization phase, where students have the option to move on to the Investigation phase through generating either questions or hypotheses. A set of questions is needed to make a plan and begin with exploration, while a hypothesis-driven approach guides students to more structured experimentation in the Investigation phase. In addition, a particular inquiry cycle can be adapted by placing different emphases on the Discussion phase. In the simplest case, students could just present their inquiry-based conclusions to others, while in a more sophisticated process communication and reflection could be important processes that are invoked in every general inquiry phase as well as at the end of a learning cycle. For example, students, by themselves or in a group of peers, can discuss their learning process and outcomes of the Conceptualization phase before moving on to Investigation.

The value of this synthesized framework lies in the possibility that it could form the basis for a general structure of inquiry-based learning environments (such as Go-Lab, http://www.golabz.eu/, SCY-Lab, http://scy-net.eu/ or Ark of Inquiry, http://arkofinquiry.eu/), which provides teachers and students with structured and scaffolded inquiry activities. The synthesized framework takes into account the strengths of the reviewed studies and avoids rare variations. The framework supports structuring the complex inquiry-based learning process and, eventually, designing guidance that is necessary in order to enhance the efficiency of the learning process. Thus, it can be argued that this framework could be applied widely in designing inquiry cycles in the context of both virtual and real-world environments. In this context it can also be a guide for teachers. For example, the phases identified in the framework can be seen as different stages in the learning process that are characterized by their input, actions, and output. In this way, the inquiry-based learning framework supports teachers and designers in analyzing what is needed as input by the learners in each stage and what is the expected output. In a structured learning environment there are two options for the designers. One is to provide all input information, guidance for actions, and information about expected outcomes to the learners when they "enter" a particular phase. Another option is to leave more freedom to the learners while guiding them toward a productive learning process based on the specific issues that have been detected during the learning process. In the first case, the framework could be applied for designing the main structure of the learning environment, while in the second case, it is important to take into account students' needs that should frame the design and content principles of supportive elements of a learning environment.

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Appendix A. Articles used in the analysis of inquiry phases and inquiry cycles

Reference	Level of information presented	Domain of the study	List of inquiry phases (reference included if cycle derived from another source)
Banerjee (2010)	Phases	Inquiry framework	Learner investigates scientifically oriented questions, Learner gives priority to evidence in responding to questions, Learner formulates explanations from evidence, Learner connects explanations to scientific knowledge, Learner communicates and justifies explanations
Bell, Urhahne, Schanze, & Ploetzner (2010)	Phases + Cycle	Collaborative inquiry learning; Inquiry framework	Orientation/question, Hypothesis generation, Planning, Investigation, Analysis/interpretation, Model, Conclusion/evaluation, Communication, Prediction
Bevevino, Dengel, & Adams (1999)	Phases	Constructivist theory in the classroom	Exploration, Discussion and presentation of new content, Application and expansion
Bruce & Casey (2012)	Phases	Digital literacy	Ask, Investigate, Create, Discuss, Reflect (Bruce & Bishop, 2002; Community of Informatics Initiative (CII, 2009)
Conole et al. (2010)	Phases	Healthy eating	Find my topic, Decide my inquiry question or hypothesis, Plan my methods, equipment and actions, Collect my evidence, Analyse and represent my evidence, My conclusions, Share and discuss my inquiry (Anastopoulou et al., 2009)
Çorlu & Çorlu (2012)	Phases	Physics teachers	Identifying the problem, Analysing, Setting hypotheses, Generating a synthesis, Problem solving and developing a course/experiment
Etkina et al. (2010)	Phases	Physics	Observe, Find patterns, Devise explanations or mechanisms for the patterns, Test the explanations, Predict the outcomes of new experiments, Apply new knowledge to solve practical problems (Etkina & van Heuvelen, 2007)
Friedman et al. (2010)	Phases + Cycle	Higher education	Ask, Investigate, Create, Discuss, Reflect (Community of Informatics Initiative (CII, 2009)
Gilbert (2009)	Phases + Cycle	Early childhood	5E Inquiry Cycle: Engage, Explore, Explain, Elaborate, Evaluate (Llewellyn, 2002)

Appendix A. (Continued)

Reference	Level of information presented	Domain of the study	List of inquiry phases (reference included if cycle derived from another source)
Gunawardena et al. (2006)	Phases	Instructional design model	Learning challenge (i.e., a case, problem, or an issue), Initial exploration, Resources, Reflection, Preservation
Gutwill & Allen (2012)	Phases	Science learning in museums	Asking questions, Making predictions, Designing experiments, Analysing data, Reasoning with models, Drawing conclusions, Communicating results (e.g., Minstrell & van Zee, 2000; White & Frederiksen, 1998)
Kuhn & Dean (2008)	Phases	Educationally disadvantaged, low-achieving middle-school students	Intent (identifying the question to be asked), Analysis (designing an investigation, and interpreting data), Inference (drawing conclusions), Argument (entering claims into scientific discourse) (Kuhn, 2001, 2002, 2005)
Kuhn & Pease (2008)	Phases	Middle-school students	Identification of a question or questions, Design of an investigation to address them, Examination and analysis of empirical data, Drawing inferences and conclusions and justifying them (Klahr, 2000; National Research Council, 1996), Identifying a question, Accessing data of their choice to address the question, Analysing these data to identify patterns and make inferences, Drawing conclusions and making judgments based on them
Larotta (2007)	Phases	Inquiry in the adult classroom	Observe, Wonder, Explain, Generate Theory
Lim (2004)	Phases + Cycle	Designing inquiries on the web	Ask, Plan, Explore, Construct, Reflect
Meyerson & Secules (2001)	Phases	Social studies	Anchor, Generate, Research, Debate, Offer solution
Palincsar, Collins, Marano, & Magnusson (2000)	Phases	Learning disabilities	Engage, Investigate, Explain, Report
Popov & Tevel (2007)	Phases	Physics	Question, Predict, Experiment, Model, Apply (White & Frederiksen, 2000)
Li, Moorman, & Dyjur (2010)	Phases + Cycle	Mathematics	Ask, Investigate, Create, Discuss, Reflect (Community of Informatics Initiative (CII, 2009)
Scanlon et al. (2011)	Phases	Technology	Orientation, Set up inquiry question, Plan question, Conduct investigation, Analyse evidence, Draw conclusions, Present inquiry, Evaluate inquiry (e.g. White et al., 1999)
Smyrnaiou, Foteini, & Kynigos (2012)	Phases	Physics	Orientation, Hypothesis generation, Experimentation, Conclusion (de Jong & van Joolingen, 2008)
Spronken-Smith & Kingham (2009)	Phases	Geography	Developing a question, Determining what needs to be known, Identifying resources, Gathering data, Assessing data, Synthesizing, Communicating new understandings, Evaluating success (Justice et al., 2002)
Steinke & Fitch (2011)	Phases	Higher education	Theory, Generate testable hypotheses, Collect and analyze data, Refine theory (Kantowitz, Roediger, & Elmes, 2009)
Tatar (2012)	Phases	Science laboratories	Ask questions, Design studies, Collect and interpret data, Draw conclusions (National Research Council, 1996)
Valanides & Angeli (2008)	Phases	Science	Conducting observation, Recording and organizing data, Discussing with others, Drawing conclusions, Reasoning with evidence about a phenomenon
van Joolingen, de Jong, & Dimitrakopoulou (2007)	Phases	Science	Orientation, Hypothesis generation, Experimentation, Conclusion, Evaluation (de Jong, 2006a)
Wall, Higgins, Glasner, Mahmout, & Gormally (2009)	Phases + Cycle	Learning to learn	Cycle1: Define problem, Assess needs, Hypothesise ideas, Develop action plan, Implement plan, Evaluate action, Decisions (Reflect, Explain, Understand action) Cycle 2: Redefine problem, Assess needs, Develop new hypothesis, Revise action plan, Implement revised plan, Evaluate action, Decisions (Reflect, Explain, Understand action) (adapted from Kemmis & McTaggart, 1988)
Wecker, Kohnle, & Fischer (2007)	Phases	Computer literacy	Hypothesis generation, Experiment design, Data interpretation (de Jong & van Joolingen, 1998; Schwartz, Lin, Brophy, & Bransford, 1999; van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005)
White & Frederiksen (2005)	Phases + Cycle	Mathematics	Question, Hypothesize, Investigate, Analyse, Model, Evaluate (White & Frederiksen, 1998)
Wilhelm & Walters (2006)	Phases + Cycle	Mathematics Science	Llewelyn's Inquiry Model: Introducing a topic, Assessing prior knowledge, Providing exploration, Raising and revising questions, Brainstorming solutions, Carrying out a plan, Collecting data, Organizing data, Finding relationships and drawing conclusions, Communicating results, Comparing new knowledge to prior knowledge, Applying knowledge to new situations, Stating a new question to investigate (Llewellyn, 2002)
Youngquist & Pataray-Ching (2004)	Phases	Early childhood classroom	Observation, Initial inquiry question, Sign system exploration, Analysis, Transmediation, Refinement, Celebration, New/further inquiries (adapted from Short, Harste, & Burke, 1996)
Zhang & Quintana (2012)	Phases	Online inquiry, middle school	Online inquiry: Generating a scientific question (driving question), Searching for information on the web, Evaluating and making sense of online information, Integrating different pieces of information to answer the driving question (Quintana, Zhang, & Krajcik, 2005)

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