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DEVELOPMENT ARTICLE

Identifying potential types of guidance for supporting student inquiry when using virtual and remote labs in science: a literature review

Zacharias C. Zacharia · Constantinos Manoli · Nikoletta Xenofontos · Ton de Jong · Margus Pedaste · Siswa A. N. van Riesen · Ellen T. Kamp · Mario Mäeots · Leo Siiman · Eleftheria Tsourlidaki

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Abstract The aim of this review is to identify specific types of guidance for supporting student use of online labs, that is, virtual and remote labs, in an inquiry context. To do so, we reviewed the literature on providing guidance within computer supported inquiry learning (CoSIL) environments in science education and classified all identified guidance according to a recent taxonomy of types of guidance. In addition, we classified the types of guidance in phases of inquiry. Moreover, we examined whether the types of guidance identified for each inquiry phase were found to be effective in promoting student learning, as documented in the CoSIL research. This review identifies what types of effective guidance currently exist and can be applied in developing future CoSIL environments, especially CoSIL environments with online labs. It also highlights the needs/shortcomings of these available types of guidance. Such information is crucial for the design and development of future CoSIL environments with online labs.

Keywords Guidance · Computer Supported Learning · Inquiry · Process constraints · Performance dashboard · Prompts · Heuristics · Scaffolds · Direct presentation of information

Z. C. Zacharia (✉) · C. Manoli · N. Xenofontos
University of Cyprus, Nicosia, Cyprus
e-mail: zach@ucy.ac.cy

T. de Jong · S. A. N. van Riesen · E. T. Kamp
University of Twente, Enschede, The Netherlands

M. Pedaste · M. Mäeots · L. Siiman
University of Tartu, Tartu, Estonia

E. Tsourlidaki
Ellinogermaniki Agogi Scholi Panagea Savva, Pallini, Greece

Introduction

Inquiry has dominated science teaching and learning over the years, primarily because it involves a more active, independent and meaningful learning process (Lim 2004). In an inquiry context, learners are expected to identify problems, develop their own hypothesis or research question, collect evidence or conduct self-directed investigations/experiments, analyze the evidence/data collected, reach conclusions, assess their own progress and finally reflect on their inquiry process (van Joolingen and Zacharia 2009). The idea is that learners engage in an investigative process that resembles what scientists do, in order to develop more coherent scientific knowledge and skills as well as an understanding of the inquiry process per se.

While there are many ways to implement inquiry-based learning, computer learning environments have been identified by many researchers to be one of the best means for doing so, because they provide affordances that other traditional means (e.g., paper-and-pencil activities, physical laboratories) cannot offer, such as multiple representations, instant and personal feedback, or non-linear and non-sequential structured information that students can search instantly according to their needs, interests, or goals (de Jong 2006a; Furtak et al. 2012; Gerjets et al. 2008). Research on computer supported inquiry learning (CoSIL) has shown that computer learning environments, if appropriately designed, can augment inquiry through a number of affordances that ultimately result in offering learners more agency in their learning process (Alfieri et al. 2011; van Joolingen and Zacharia 2009; Slavin et al. 2014). Finding or designing appropriate CoSIL environments has great importance for the enhancement of student learning, because research has shown that learning within such environments poses challenges for most students, mainly because of the cognitive and metacognitive complexity of the learning experiences these environments offer (Azevedo 2005; Scheiter and Gerjets 2007). For instance, researchers argue that many of these challenges result from the *richness* and *transparency* of the CoSIL environments (Swaak and de Jong 1996; Zacharia and Olympiou 2011). Richness refers to the amount of information and the diversity of relations a learner can extract from a CoSIL environment, whereas transparency refers to how easily a user of a CoSIL can perceive its content (Swaak et al. 1998). CoSIL environments, including online labs, are usually rich learning environments with a relative low transparency (Zacharia and Olympiou 2011). These characteristics pose several challenges to students' learning (Marshall and Young 2006). For example, the richness of a CoSIL challenges a student to find all the variables involved in a physical phenomenon, whereas low transparency challenges students to identify all the relations among these variables.

In addition to the challenges caused by the CoSIL environment per se, there are cognitive challenges that relate to the phenomenon under study (e.g., the underlying mechanism of a phenomenon is complex), as well as to the inquiry process per se (e.g., students cannot state a proper hypothesis, students cannot design and run a fair experiment, etc.; for more examples see the third column of Tables 2, 3, 4, 5, 6 and 7). According to Davis and Linn (2000), one way to help students overcome the aforementioned challenges is by providing proper guidance. For example, in the case of studying a phenomenon that involves an abstract and complex underlying mechanism, a CoSIL environment could support the students by enabling them to *re-see* the phenomenon under study through a different angle. *Re-seeing* refers to providing individuals with the opportunity to go beyond their current perceptions of everyday objects and viewing them through the lens of new perspectives (Girod et al. 2003). When using online labs, a student can *re-see* the same object through multiple representations, including representations of abstract/conceptual objects (e.g., light rays, electrons) which are not available in real world, and improve his/her understanding of the phenomenon under study (Olympiou et al. 2013). In the case of inquiry related challenges in CoSIL environments, guidance has also proven to be a promising remedy. For instance, the development of proper hypotheses was found to be improved when students received prompts in the form of reflection questions (Kim and Pedersen 2011), or the construction of a model was found to improve through the use of process constraints (i.e., breaking modeling in different steps) (Fretz et al. 2002; Wu 2010). Given these challenges, it becomes quite apparent that the presence of guidance is crucial for CoSIL environments (d'Angelo et al. 2014). As we explain below, there are a number of different ways to provide guidance: through *process constraints, a performance dashboard, prompts, heuristics, scaffolds,* or *direct presentation of information* (de Jong and Lazonder 2014). All of these types of guidance aim to give students personalized support when using a CoSIL environment, in such a way that the CoSIL environment adjusts to the students' cognitive and metacognitive needs for a specific content and at specific times (e.g., during a certain inquiry phase or for a certain inquiry practice/process) (de Jong 2006b; Quintana et al. 2004). In this way, guidance could also serve as a means to support students' self-regulated learning. In a self-regulated learning context, students become responsible for their learning journey and thus are responsible for managing on their own any difficulties that arise (Hadwin and Winne 2001; Pintrich 2000; Zimmerman 2001). The literature on self-regulated learning reports on many of these difficulties that students face (e.g., Azevedo 2002) and presents CoSIL environments and their accompanying guidance as one of the best ways to help students to overcome them (Gerjets et al. 2008).

A question that can be raised at this point, though, is whether research so far in the domain of guidance development for CoSIL environments has advanced to the level of developing effective means/tools to provide all of the forms of guidance to support all of the processes involved in carrying out inquiry, especially with online labs. In a recent review on virtual, physical and remote labs, de Jong et al. (2013) highlighted the essentiality of addressing this question and urged the community to focus its research efforts on developing and using proper guidance for inquiry-based enactments when CoSIL environments with virtual and remote labs are involved. Building on this suggestion, this review contributes towards that goal, by identifying the means/tools already developed for all of the types of guidance that have shown to support student inquiry in CoSIL implementations and, therefore, have the potential to serve student inquiry when using CoSIL environments with science online labs (virtual and remote labs offered through computer technology). By remote labs, we mean physical labs whose material and equipment are manipulated at a distance via the use of computer technology (e.g., internet connection, computer controlled robotic arms). By virtual labs, we mean computer simulations, which allow the manipulation of virtual material and equipment on a computer screen via the computer equipment (e.g., mouse, keyboard, touchscreen).

To accomplish this purpose, we reviewed the literature on the provision of guidance within CoSIL environments in science education with a specific focus on online labs. To classify the types of guidance that currently exist for different inquiry phases we used the most recent taxonomy of types of guidance (*process constraints, performance dashboard, prompts, heuristics, scaffolds,* and *direct presentation of information*; for details, see below and de Jong and Lazonder 2014) and a framework for inquiry that uses the following phases as constituting the inquiry cycle: *Orientation* phase, *Conceptualization* phase, *Investigation* phase, *Conclusion* phase, and *Discussion* phase (for details, see below and de Jong et al. 2014). In the literature many inquiry cycles are proposed (see e.g., Friedler et al.

1990; Kuhn et al. 2000; Njoo and de Jong 1993; Quintana et al. 2004) that differ in level of detail but basically present the same series of phases that are often used to organize students' learning process (see e.g., White and Frederiksen 1998; Sharples et al. 2014). The cycle that we use in this paper is based on an analysis of and a synthesis of a large set of cycles as proposed in the literature (de Jong et al. 2014; Pedaste et al. in press). In particular, we report on the types of guidance used thus far for each inquiry phase and the means/tools that were developed to provide each type of guidance. Moreover, we checked whether these means/tools were found in the CoSIL literature reviewed to be effective in promoting student learning for each inquiry phase. The idea was to identify (i) which of these existing means/tools appear to be effective and can be used in future CoSIL environments, especially CoSIL environments with online labs, to support the inquiry phases they were designed for, (ii) which of these means/tools have flaws and need improvements, and (iii) which of the aforementioned types of guidance are missing for each inquiry phase and have the potential to support the learner, and which tools/means could be developed to offer this guidance. Such information is crucial for the design and development of future CoSIL environments.

An inquiry framework for online lab implementations

A number of versions of the inquiry cycle have appeared in the relevant domain literature, with these versions having relatively high overlap in terms of the phases involved in the cycle (also referred to in the literature as processes or steps). The differences arise primarily due to the use of different names for the same phase or the breakdown of a phase into smaller pieces/sub-phases. In this review we adopt a classification, which distinguishes the following inquiry phases for online lab implementations: *Orientation, Conceptualization, Investigation, Conclusion,* and *Discussion* (de Jong et al. 2014). We selected this framework because it is the most recently offered framework that specifically focuses on the inquiry-based use of online labs, and because it emerged from a thorough review of the literature (up until 2013) on inquiry frameworks in general.

According to this framework, the inquiry-learning process for online lab implementations starts with the *Orientation* phase, in which students are introduced to the problem to be investigated. This can take place in the learning environment, it can be provided by the teacher or it can be investigated by the learner on his/her own (Scanlon et al. 2011). The purpose of this phase is to familiarize students with the main variables of the domain, and the problem and issues involved. In the following phase, labeled *Conceptualization*, students become familiar with the concepts related to the problem under investigation and choose between two alternative sub-phases, namely the *question* sub-phase or the *hypothesis* sub-phase. The selection of one of these sub-phases rather than the other depends on the nature of the inquiry task at hand. While both of them rely upon theoretical justification and consider independent and dependent variables, only the *hypothesis* sub-phase requires the specification of a certain relationship between the variables under investigation. The *question* sub-phase is more open-ended in this respect, and calls for an examination of the relationships among variables. Then, students move to the *Investigation* phase, in which they get involved in either an *exploration* or *experimentation*, depending on whether they stated a question or a hypothesis, respectively, in the *Conceptualization* phase.

During the *exploration* and *experimentation* sub-phases students design and carry out the experimental procedure, while in the *data interpretation* sub-phase, they try to interpret the collected data and understand the relations between variables (Bruce and Casey 2012; Justice et al. 2001; Lim 2004; White and Frederiksen 1998; Wilhelm and Walters 2006). The *exploration* sub-phase involves the examination of more than one pair of variables or possible relation that were identified in the *question* sub-phase, while the *experimentation* sub-phase concerns the particular pair of variables/possible relation specified in the *hypothesis* sub-phase.

In the *Conclusion* phase, students state their conclusions after determining whether their research questions or hypotheses formulated at the beginning of the investigation are answered or supported by the results of the study (Scanlon et al. 2011; White et al. 1999). For an open research question, the *Conclusion* phase leads to identifying a relation between variables, whereas for a hypothesis the *Conclusion* phase ends with acceptance or rejection of the hypothesis. The *Discussion* phase is based on sharing one's inquiry with others, either fellow students or the teacher. It is comprised of two sub-phases, *communication* and *reflection*. In the *communication* sub-phase, students can articulate their findings and conclusions to other students (Scanlon et al. 2011), while at the same time they listen to the findings and conclusions of others (Bruce and Casey 2012). This mutual exchange aims at enriching an individual's understandings. On the other hand, *reflection* allows students to reflect on the success of the inquiry and suggest how it could be improved (Lim 2004; White and Frederiksen 1998). Furthermore, *reflection* involves receiving and providing feedback to others. Finally, it should be noted that both the *communication* and the *reflection* sub-phases can occur throughout the inquiry process.

Guidance and computer-supported inquiry learning

At this point, it has been well documented that any type of inquiry-based learning, including CoSIL, is more likely to fail if students do not have the necessary self-regulation skills (Azevedo 2005; Quintana et al. 2004; Zhang et al. 2004). Self-regulated learning involves skills that enable learners to set goals for their learning, while monitoring, regulating, and controlling their cognition, motivation, and behavior, in an attempt to fulfill their goals (Pintrich 2000; Zimmerman 2001). This can be facilitated by providing students with a well-designed CoSIL environment that provides students with the necessary guidance for being metacognitively, motivationally, and behaviorally active participants in their own learning process (Shapiro 2008).

Guidance in CoSIL environments can be provided in different forms. In the literature of the domain (e.g., de Jong 2006b, de Jong and Lazonder 2014; Quintana et al. 2004; Veermans 2003; Veermans et al. 2006; Zhang et al. 2004; Zhang and Quintana 2012), six different types of guidance are identified. According to the de Jong and Lazonder (2014) taxonomy, guidance in CoSIL environments takes the form of: (i) adapting an individual's inquiry behaviour through providing information about their results and processes (*performance dashboard*), (ii) giving students specific directions on what to do (*prompts*), (iii) reducing or restricting unnecessary student activities (*process constraints*), (iv) suggesting to students what to do (*heuristics*), (v) helping students to perform a specific task by providing them with the structure and/or components of the task (such support is suitable when students do not have the expertise to perform the task themselves and helps them to perform a task that would otherwise be outside their capabilities) (*scaffolds*), and (vi) providing information to students, who lack prior knowledge or cannot find the information needed for a task on their own, for completing a task (*direct presentation of information*). One of the advantages of this particular taxonomy, which basically differentiates it from others, is that it is more analytic and classifies guidance according to the form it takes or its type, rather than according to the learning process it supports, as was done in prior taxonomies/classifications of guidance. In particular, this taxonomy provides "a typology of guidance that is organized according to the (increasing) specificity of the support students need to successfully perform their inquiry" (de Jong and Lazonder 2014, p. 375). This specificity supports higher granularity in classifying a given type of guidance. Moreover, de Jong and Lazonder (2014) specify the types of guidance in a manner that makes them independent of any context (e.g., learning process, inquiry phase, subject domain). As a result, a wider spectrum of types of guidance emerges, that could possibly be applied across all inquiry phases (e.g., we can have *process constraints, performance dashboard, prompts, heuristics, scaffolds,* and *direct presentation of information* in the *experimentation* phase). Finally, finer granularity allows better understanding of the particular types of guidance and thus more accurate selection of an appropriate type of guidance when it comes to supporting students in a certain inquiry phases and situations.

Thus far, the research has not documented which types of guidance are needed for each inquiry phase, whether certain types of guidance are better for certain inquiry phases, or whether a combination of different types of guidance could optimize support and therefore student learning. Needless to say, there is a strong need for further future research along these lines. Below, we present each of the six types of guidance more analytically.

Process constraints

A process constraint aims at reducing the complexity of the inquiry learning process. For instance, this can be achieved by restricting the number of options that students must consider during the process. However, this type of guidance should only be used when students can apply the basic inquiry processes, but still have limited experience in applying them when more demanding/complex inquiry activities are at task (de Jong and Lazonder 2014). Moreover, constraints are not necessary all of the time, especially once students have gained enough experience with the inquiry processes. One way to address this issue is to apply a fading mechanism, which gradually reduces the support provided as the student's experience grows.

Performance dashboard

A performance dashboard provides students with feedback on "their own learning process or about the quality of their learning products and outcomes" (de Jong and Lazonder 2014, p. 375–376). This type of guidance is useful for students who understand how to use the information provided by the performance dashboard. For example, a performance dashboard can present the student with an overview of the variables involved in an exploration or experiment. Moreover, this tool could support the possibility of replaying an experiment, when students want to see it again, or sorting variables to compare different experiments (Veermans 2003).

Prompts

Prompts are provided in the form of hints, and their purpose is to remind students to carry out certain actions, assignments, or learning processes they may have overlooked (de Jong and Lazonder 2014). An example could be, "Do you have enough data for drawing/producing a graph?" or "Is the line in your graph a good fit to your data? Why?"

Prompts can also be provided in the form of assignments. According to de Jong et al. (1994), such assignments can be separated into six categories, *Investigation, Optimization, Fault diagnosis, Specification, Explication* and *(Normal) operation.* Investigation, Explication and Fault diagnosis assignments refer to the relation between variables. Specifically, Investigation assignments ask learners to explore the relation between two or more variables, Explication assignments ask them to explain a phenomenon appearing in some sort of representation (e.g., in a simulation) and Fault diagnosis assignments ask them to figure out where there is a faulty relation between variables. In Optimization assignments learners must supply the values for an input variable that will produce a specific output for another variable (e.g. maximal, minimal, or optimal value). The goal of Specification assignments is to predict the value of a variable in a given situation. Finally, in Normal operation assignments the learner must provide information about the input variables when the output variables are specified (other input variables are maintained under control by the system). Veermans (2003) further extends these categories and adds the categories *Explanation, Do-it, Open answer* and *Do-them.* In Explanation assignments students are provided with a situation in the simulation environment and have to explain the phenomenon that is presented. In Do-it assignments, learners are presented with a goal and take responsibility for achieving this goal. In order to do this, they need to specify a situation in the simulation. Open answer assignments are analogous to Do-it assignments, but in this case learners are also asked to write their ideas and conclusions. Do-them assignments are also analogous to Do-it assignments, but in this case the goal can be set for multiple situations.

Heuristics

Heuristics resemble prompts, but offer more specific guidance. In other words, as well as providing students with more detailed suggestions about performing certain actions or learning processes, they also provide instructions on how to perform these actions or learning processes. Thus, heuristics are more appropriate when students are not familiar with when and how an action or learning process should be carried out. An example of a heuristic is showing students that an efficient experiment follows the Control of Variables Strategy (CVS). CVS is the approach that students need to follow for designing an unconfounded experiment. Otherwise, they will end up producing invalid data and conclusions (Chen and Klahr 1999).

Scaffolds

Scaffolds are tools that help students carry out a learning process by structuring and supporting the process in the activities involved (e.g., a modeling tool or an experiment design tool). They are used when a process is too complicated or when students do not have the appropriate skills to carry out the process on their own. A specific example of a scaffold is the hypothesis scratchpad, which supports students in forming their hypotheses (de Jong 2006b; van Joolingen and de Jong 2003). In this case, students are provided with the variables (e.g., mass, weight, volume, density) involved in the task under study and guided to form hypotheses by selecting variables and relations (e.g., increases, decreases) to fill in the terms of an if-then clause (de Jong 2006b, p. 113). In other words, the students are provided with a twofold support, namely the provision of the structural materials (i.e., variables involved and possible relations between variables) and the provision of the structure of a hypothesis per se (i.e., if-then clause).

Direct presentation of information

Direct presentation of information is a type of guidance provided when students lack prior knowledge or cannot find the information needed for a task on their own. In both cases, the students receive direct information that aims at keeping them on track. An example of such guidance is the provision of explanations. According to Veermans (2003), explanations can be offered to the student through different means (i.e., audio, video, text, html, images, or a combination of text and images) and can take the form of feedback or background information concerning the activity under study.

Method

To identify CoSIL tools/means that provide the six types of guidance for each inquiry phase and sub-phase of the inquiry framework adopted for this study, a literature search was carried out using different databases: Google Scholar, Web of Science, EBSCOhost EJS, Academic Search Complete, MasterFILE Premier, Psychology and Behavioral Sciences Collection, Hellenic Academic Libraries Link, OmniFile Full Text Select, ERIC, Taylor & Francis Education Collection, and so forth. For our search we used the terms: *science, inquiry, learning scaffolds, scaffolding tools, cognitive scaffolds, scaffolding process, inquiry cycle support, guidance, heuristics, prompts, process constraints, performance dashboard, assignments and inquiry based scaffolding*. After the first round of search, we decided to search among the results for any literature reviews similar to the one we were pursuing, to avoid overlaps. In addition we used a paper by de Jong (2006b) concerning guidance and scientific discovery/inquiry learning, which included the literature that interests us up through 2005. We therefore decided to use the de Jong (2006b) review as a point of reference for studies conducted before 2006 and focused our search on literature from 2006 onward. Given this boundary, we found a total of 36 relevant studies (scientific articles, books, book chapters, proceedings of national and international conferences, and PhD dissertations) that were published after 2006 and matched the purpose of our review. Five of them were excluded because they did not provide any empirical findings on any of the types of guidance. In addition to this pool of 31 studies and the de Jong (2006b) literature review, we also reviewed 30 additional studies for clarification purposes. These additional studies were mentioned in either our pool of identified relevant studies or the de Jong (2006b) literature review, but information/details we needed for the purposes of this review were not included there.

The identified papers were then categorized/separated according to the six types of guidance in the de Jong and Lazonder (2014) taxonomy (*process constraints, performance dashboard, prompts, heuristics, scaffolds,* and *direct presentation of information*). For the identification and categorization of the tools in these six types of guidance we used rubric tables, which included a definitions/description of the type of guidance as well as its specific characteristics. These unique characteristics provided the key features that enabled us to categorize a tool under a certain type of guidance. For instance, a unique characteristic that enabled us differentiate prompts from heuristics is that heuristics provide students with more detailed suggestions about performing certain actions or learning processes than prompts. Additionally, heuristics provide instructions on how to perform these actions or learning processes, whereas prompts do not. Overall, all of our rubrics information was extracted by the descriptions that de Jong and Lazonder (2014) provided for each type of guidance. Inter-rater reliability was calculated for this classification between the second author and an external rater. Cohen's K was found to be 0.92. Any disagreements were resolved through discussion. The results for all six categories are presented in the Findings section (see Tables 2, 3, 4, 5, 6, 7).

Each category was further separated in subcategories according to the phases identified in the selected framework for the phases of inquiry learning with online labs, namely *Orientation, Conceptualization, Investigation, Conclusion,* and *Discussion*. While in some cases the literature clearly defined the phase to which each guidance tool belonged, in others it was up to the researchers to classify it according to the description provided by its developers. For the latter, we also used rubric tables that included criteria for depicting in which of the five aforementioned inquiry phases a guidance tool belonged. In addition, a number of the identified guidance tools/means were applicable in more than one phase. For these tools/means a new category was created, *Multiple phases* (see Table 1). For this case, inter-rater reliability was also calculated between the second author and the same external rater. Cohen's K was found to be 0.90. Any disagreements were resolved through discussion. Overall, a total of 89 guidance examples were identified and reviewed (9 process constraints, 3 performance dashboards, 16 prompts, 24 heuristics, 31 scaffolds and 6 direct presentations of information) and then classified according to the six categories of inquiry phases (see Table 1).

Finally, we provide in Tables 2, 3, 4, 5, 6 and 7 a short description of each guiding tools/means identified and results from prior research concerning their effectiveness (where available).

Analysis

After all guiding tools/means were identified and categorized, as shown in Tables 2, 3, 4, 5, 6 and 7, we examined each research study associated with each tool/means to decide whether there was sufficient evidence showing its effectiveness for supporting students when they are working in the inquiry phase(s) for which it was designed. When there was not enough evidence, or no evidence at all for a particular guiding tool/means, along with reporting this, we proceeded with suggestions for further research. When no guiding tool/means of a particular type was found for a particular inquiry phase, we proceeded with suggestions concerning which missing types of guidance we consider potentially useful for that particular inquiry phase and possible means/tools that could provide such guidance.

Table 1 Overview of guidance per phase of the inquiry cycle

Phases	Forms of guidance						
	Process constraints	Performance dashboard	Prompts	Heuristics	Scaffolds	Direct presentation of information	Total
Orientation	1	–	–	–	2	1	4
Conceptualization	1	–	1	4	6	2	14
Investigation	4	1	4	13	5	–	27
Conclusion	–	1	2	1	3	–	7
Discussion	–	–	2	2	1	1	6
Multiple phases	3	1	7	4	14	2	31
Total	9	3	16	24	31	6	89

Table 2 Guidance for the orientation phase

Tool	Type of guidance	Description of tool	Research findings about the tool	References
SEEK Tutor (hint button, on-line ratings and note-taking interface)	Process constraint	The three affordances of the SEEK Tutor promote planning, monitoring and reflective strategies for self-regulated learning. The Hint button provides randomly spoken hints to remind the user of his/her goal and gives suggestions for dealing with the websites. The online rating pop-up window appears if the user stays for 20 s in a webpage. It consists of a rating scale for evaluating the reliability of the page accompanied with a written justification. The note taking interface asks students to answer five questions about the reliability and the trustworthy of the information found. This interface appears each time a user exits a page	The presence of the SEEK Tutor helped students think more critically concerning the activities at task	Graesser et al. (2007)
Tuolumne River module—support for orientation phase	Scaffold	The Tuolumne River module combines an intelligent tutoring system and scaffolding tools to support the orientation phase. The Fuzzy view tool presents the initial photo and students are guided by the Tutor to observe carefully in order to find out if there is something notable or unusual. The Photo zoom-in tool provides functions like enlargement and movement to other views	N/A	Woolf et al. (2002)
Artemis	Scaffold	Artemis software provides a digital library of websites and contains features to help students manage them, such as search, saving and viewing, maintenance, organizational and collaborative features. Thus, students can view abstracts of the websites, save and retrieve search results, edit or delete information, develop and organize folders and share information	A positive relation was found, but the interpretation of its origin is unclear	Butler and Lumpe (2008)
Access to domain knowledge	Direct presentation of information	Access to the domain knowledge is granted through the provision of definitions of the concepts involved in the activity at task (Veermans 2003)	N/A	Veermans (2003)

Table 3 Guidance for the Conceptualization phase

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Tuolumne River module—support for Conceptualization phase	Process constraint	The Tuolumne River module combines an intelligent tutoring system and scaffolding tools to support the observation (Conceptualization) phase. The Observation Pad and the Identify Focus of Attention tool were developed to help students organize their discussion	N/A	Woolf et al. (2002)
Metacognitive scaffolds in animal investigator	Prompts	Animal Investigator is a computer-supported problem-based learning environment in biological and environmental context. During the hypothesis development students were presented with prompts in the form of reflection questions, e.g. "Why do you think the current clue is important?", self-questions, e.g. "What do I need to know?" and checklist statements, e.g. "I found a clue from the…" (Kim and Pedersen 2011, p. 1784)	The prompts enhanced students' performance during hypothesis development; in comparison to their performance without this tool	Kim and Pedersen (2011)
Simplify problem	Heuristic	"Simplify the problem, or try to solve part of the problem (Polya 1945; Schoenfeld 1985)" (Veermans et al. 2006, p. 344)	N/A	Veermans et al. (2006)
Identify hypothesis	Heuristic	"Generate a small amount of data and examine for a candidate rule or relation (Glaser et al. 1992)" (Veermans et al. 2006, p. 344)	N/A	Veermans et al. (2006)
Slightly modified hypothesis	Heuristic	"Address slightly modified problems: Weaken or strengthen conditions slightly in reformulating hypotheses (Glaser et al. 1992)" (Veermans et al. 2006, p. 344)	N/A	Veermans et al. (2006)
Set expectations	Heuristic	"Expectations for a class are used, as expectations for members of the class not previously tested or if a law in one context is found, expect a similar form of law to hold in a new context (Kulkarni and Simon 1988; Langley 1981)" (Veermans et al. 2006, p. 344)	N/A	Veermans et al. (2006)
Hypothesis scratchpad	Scaffold	Hypothesis scratchpad helps students define their hypothesis by selecting the proper variables to fill in "if–then" statements (de Jong 2006b), or to construct a concept map which represents the relations between variables (Wirth et al. 2009)	"The hypothesis scratchpad appeared to be quite complex for learners to use (van Joolingen and de Jong 1991)." (van de Jong 2006b, p. 113)	de Jong (2006b); Wirth et al. (2009)

Table 3 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Shared proposition scratchpad/shared proposition table	Scaffold	The shared proposition scratchpad contains dropdown menus with variables and relations for the creation of hypotheses combined with a chat tool for discussion about them. The shared proposition table provides students with a list of predefined propositions combined with three questions for each one. The questions ask if students are familiar with a proposition, if it is true or false and if it is worth to test it	The shared proposition table led to significant gains for knowledge about relations and motivated students to make more related comments. In addition, students spent less time discussing a variety of propositions than in the scratchpad and control (no scaffolding) conditions	Gijlers and de Jong (2009)
Prediction	Scaffold	Students are supported to complete semi-structured sentences in order to generate predictions (de Jong 2006b)	Lewis et al. (1993) found that scaffolding led to correctly stated predictions (correct in the sense of their structure and not necessarily in terms of their content)	de Jong (2006b) and Lewis et al. (1993)
Concept map template	Scaffold	For the organization of concepts. It involves spaces in which variables are reported and arrows for denoting relationships	The use of the concept map template helped students in the organization and synthesis of information and therefore led to higher-order learning	McGregor and Lou (2004)
Tuolumne River module—support for hypotheses phase	Scaffold	The Tuolumne River Module combines an intelligent tutoring system and scaffolding tools to support the hypothesis phase. The Open Hypothesis Pad allows students to write down causes for the phenomenon and use them later in the Structured Hypothesis Tool to create a flow chart of their hypothesis. Students have to identify the causes and effects of their hypothesis by moving nodes in their flow chart	N/A	Woolf et al. (2002)
Articulation box—model-it software	Scaffold	A box for explaining the reasoning behind the creation of objects, variables and relations between them during a modeling activity with the Model-it software	By offering students the opportunity to articulate their reasoning, they consequently improve their modeling practices and identify possible errors	Fretz et al. (2002)
Issues	Direct presentation of information	Students are presented with a problem statement where the main idea of the domain and the related variables are identified. This statement is later used for further experimentation	N/A	de Jong (2006b)

Table 3 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Complete predefined hypotheses	Direct presentation of information	Students are presented with already defined hypotheses	There is some evidence that this kind of support could be beneficial for developing a hypothesis	de Jong (2006b)

Table 4 Guidance for the investigation phase

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Model progression	Process constraints	Model progression segments the simulation model into separated parts (de Jong et al. 1999; Quinn and Alessi 1994). These parts might differ in the kind of view (numerical, graphical, and animated), the complexity and the type of representation (Veermans 2003)	Model progression did not have a positive effect on students' performance (Quinn and Alessi 1994) or intuitive knowledge (de Jong et al. 1999)	Quinn and Alessi (1994); de Jong et al. (1999); Veermans (2003)
Process map (Model-it software)	Process constraints	The process map segments the modeling process into three modes; plan, build and test mode. In the plan mode students create objects and variables, in the build mode they identify the relations among variables and test their model in the test mode	In general, this scaffold helped the students in the creation of their models	Fretz et al. (2002)
Textual/graphical modelling representation (SimQuest modelling tool)	Process constraints	Textual and graphical representation refers to the type of information students receive during the modeling process: text, lists and quantitative information and diagrams and qualitative information, respectively	Each representation triggers different strategies during the modeling process and therefore students need both in order to exploit their benefits	Lohner et al. (2003)
Air pollution modeling tool (APoMT)	Process constraints	APoMT breaks the modelling process into four modes; build, test, apply and case mode. Thus, students first predict the relations among variables and create their models. Then they test their models. In the apply mode they visualize and interpret their data and finally they draw conclusions and apply their results in different cases	APoMT led to better conceptual understanding and better student performance	Wu (2010)
Monitoring tool—SIMQUEST	Performance dashboard	The monitoring tool constitutes a storage place for the experiments and students can also later review and replay them if needed (van Joolingen and de Jong 2003)	Found efficient in supporting the learners in monitoring virtual experiments (Veermans 2003)	van Joolingen and de Jong (2003); Veermans (2003)
Experiment prompting	Prompts	Students test their knowledge before running an experiment and are provided with prompts on how to conduct an experiment (e.g., "Conduct the scientific experiment by varying one thing at a time"). Moreover, they are prompted to keep notes while they are working	Comparing the use of experiment prompting and the step guidance heuristic (see below), learning performance was better under the first condition	Chang et al. (2008)

Table 4 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Prompts for Experimentation	Prompts	Students are prompted to reflect on the strategies they use during the experimentation phase concerning the control of variables	Lin and Lehman (1999) found a "positive effect of prompts that helped students reflect on their experimentation design." (de Jong 2006b, p. 120)	de Jong (2006b); Lin and Lehman (1999)
Tuolumne River module—support for design and data collection phase	Prompts	The Tuolumne River Module combines an intelligent tutoring system and scaffolding tools to support the design and data collection phase. Slider bar and Sticky notes, in combination with prompts and questions, stated by the tutor, help promote the identification of the focus of attention in the experimentation phase and the evaluation of the hypotheses. With the Slider bar students can enter their data in a graph and with the Sticky notes record facts and data	N/A	Woolf et al. (2002)
Design diaries in a learning by design approach	Prompts	The Design Diaries include macro-prompts to help students justify for each design process, micro-prompts for reflecting on the activities in each design phase and metacognitive prompts to encourage students to monitor their learning	The use of Design Diaries led to students' deeper understanding and articulation of new knowledge	Puntambekar and Kolodner (2005)
VOTAT	Heuristic	"If not varying a variable, then pick the same value as used in the previous experiment (Glaser et al. 1992; Klahr and Dunbar 1988; Schunn and Anderson 1999; Tschirgi 1980)" (Veermans et al. 2006, p. 344)	"…subjects who employ the VOTAT strategy are not aware of its logical structure…(*and*) the young children require further experience to infer the necessity of a VOTAT strategy." (Tschirgi 1980, pp. 8–9)	Veermans et al. (2006); Tschirgi (1980)
Simple values	Heuristic	"Choose special cases, set any parameter to 1, 2, 3 (Schoenfeld, 1979)" (Veermans et al. 2006, p. 344)	N/A	Veermans et al. (2006)
Equal increments	Heuristic	"If choosing a third value for a variable, then choose an equal increment as between first and second values. Or if manipulating a variable, then choose simple, canonical manipulations (Schunn and Anderson 1999)". (Veermans et al. 2006, p. 344)	"The participants' experiments were coded as to whether they ever violated this heuristic. Domain-Experts never violated this heuristic, whereas Task-Experts and both groups of undergraduates frequently violated this heuristic" (Schunn and Anderson 1999, p. 23). No indication as to whether it works as a heuristic	Veermans et al. (2006); Schunn and Anderson (1999)

Table 4 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Confirm hypothesis	Heuristic	"Generate several additional cases in an attempt to either confirm or disconfirm the hypothesized relation (Glaser et al. 1992)". (Veermans et al. 2006, p. 344)	N/A	Veermans et al. (2006)
Extreme values	Heuristic	"Try some extreme values to see there are limits on the proposed relationship (Schunn and Anderson 1999)". (Veermans et al. 2006, p. 344)	N/A	Veermans et al. (2006); Schunn and Anderson (1999)
Make a graph	Heuristic	"If you have a number of data points with values for variables, then make a graph to get an indication about the nature of the relationship (Polya 1945)". (Veermans et al. 2006, p. 344)	N/A	Veermans et al. (2006)
Heuristics for experimentation	Heuristic	Students received heuristics for experimentation, which were either fixed, adaptive to the learning behaviour, or adaptive with an explanation as to why they were given	Only the adaptive heuristics with an explanation as to why they were given influenced experimentation behaviour, but there were no differences in knowledge between the three groups	Marschner et al. (2012)
Plausibility heuristic	Heuristic	"Use the plausibility of a hypothesis to choose experimental strategy." (Klahr et al. 1993, p. 134)	"…both children and adults varied their approach to confirmation and disconfirmation according to the plausibility of the currently held hypothesis…" (Klahr, et al. 1993, p. 134)	Klahr et al. (1993)
Focusing heuristic	Heuristic	"Focus on one dimension of an experiment or hypothesis." (Klahr et al. 1993, p. 135)	"Use of this focusing heuristic (*focus on one dimension of an experiment or hypothesis*) was manifested in different ways with respect to hypotheses and experiments…" (Klahr et al. 1993, p. 135)	Klahr et al. (1993)
Observing heuristic	Heuristic	"Maintain observability"(Klahr et al. 1993, p. 135)	"This heuristic (*maintain observability*) depends upon knowledge of one's own information processing limitations as well as of the device…" (Klahr et al. 1993, p. 136)	Klahr et al. (1993)
Designing heuristic	Heuristic	"Design experiments giving characteristic results." (Klahr et al. 1993, p. 136)	"Adults and children differed widely in their use of these heuristic (*design experiments giving characteristic results*)." (Klahr et al. 1993, p. 136)	Klahr et al. (1993)

Table 4 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Step guidance	Heuristic	Students are required to follow certain steps in order to conduct their experiments	When students follow pre-defined steps their freedom is limited and this consequently impairs the learning outcomes	Chang et al. (2008)
Unexpected findings	Heuristic	Focus on unexpected findings. "According to this view, scientists work with a heuristic assumption such as: *If the finding is unexpected, then set a goal of discovering the causes of the unexpected finding* (Dunbar 1993; Kulkarni and Simon 1988)". (Dunbar 2000, p. 52)	N/A	Dunbar (2000)
Tools for data interpretation	Scaffold	Tools that support the performance of curve fitting or drawing graphs	N/A	Veermans (2003)
Dynamic testing scaffold (Model-it software)	Scaffold	This scaffold promotes interaction between the student and the model in a real time, helps students detect errors and encourages them to test their model multiple times in order to make improvements	Dynamic testing helps students do better with data interpretation, error detection and the proposition of alternative solutions	Fretz et al. (2002)
Data interpretation—Worldwatcher	Scaffold	Worldwatcher (see Edelson et al. 1999) visualizes data coming from real data sets and helps students to understand their complexity or/and compare them with other data sources. (de Jong 2006b)	N/A	de Jong (2006b); (Edelson et al. 1999)
Data interpretation—BGuIle	Scaffold	BGuILE uses technological supports for inquiry learning in biology. During the analysis of the data from a video, students were asked questions which supported their interpretation of the data	N/A	de Jong (2006b)
SCYED: experimental design tool	Scaffold	With SCYED, students can create a step by step procedure for their experiments by choosing the variables under investigation and their values and by describing how to conduct the experiment. They have predefined steps (e.g., *Hypothesis/anticipated results, Principle of manipulation, Material,* etc.) and they have to write the appropriate information under each one	N/A	van Joolingen et al. (2011); de Jong et al. (2012)

Table 5 Guidance for the conclusion phase

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Tuolumne River module—Support for Conclusion and final report phase	Performance dashboard	The Tuolumne River Module combines an intelligent tutoring system and scaffolding tools to support the conclusion phase. In the conclusion phase, students have access to a review of all their observations and hypotheses tested and can edit this review in order to create their final report. The tool for this purpose is the Final Case Review Tool	N/A	Woolf et al. (2002)
Prompts for writing scientific explanations	Prompts	Students are guided to write scientific explanations following the structure of claim-evidence-reasoning. They are provided with related prompts for each of the three elements, "Write a sentence that states…", "Provide two pieces of data that supports your claim that…" and "Write a sentence that connects your evidence to your claim that…" respectively (McNeill et al. 2006, p. 164)	Fading support was more successful than continuous support	McNeill et al. (2006)
Questions prompts (eCase environment)	Prompts	In a case-based learning environment students are provided with three questions prompts; the observe prompt, the recall prompt and the conclude prompt, in order to identify important information, link them with similar ones and use reasoning to reach useful conclusions	The three questions prompts had a positive effect on students' domain knowledge and knowledge transfer	Demetriadis et al. (2008)
Present evidence	Heuristic	"If you state a conclusion about a certain hypothesis, present evidence to support that conclusion (Schoenfeld, 1985)". (Veermans et al. 2006, p. 344)	N/A	Veermans et al. (2006)
Self-explanation and meta-level feedback (description of causal diagram)	Scaffold	In an instructional condition, students were given an explanatory text diagram; in a self-explanation and meta-level condition they were prompted to write their explanation of the diagram and make inferences beyond the diagram; in addition, in the meta-level feedback condition, they were asked to compare their own explanation with the instructional one	In general, the meta-level feedback enhanced the self-explanation process	Cho and Jonassen (2012)

Table 5 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
ExplanationConstructor (Investigation journal)	Scaffold	"In BGulLe (Reiser et al. 2001), …learners are offered a scaffold that forces them to directly connect their data and their explanations. The so-called investigation journal gives students the opportunity to link the claims they make with evidence collected during the investigations." (de Jong, 2006b, p. 117)	The ExplanationConstructor seems to help students to move between the investigation and explanation environment (Reiser et al. 2001)	de Jong (2006b); Reiser et al. (2001)
Argumentation task—graphical mind mapping tool/text editor	Scaffold	Students were supported in representing their arguments with either a text editor tool or a graphical mind mapping tool. In the first case, they were asked to classify pro and con arguments. In the second case, they were asked to connect these arguments and mark them either with "+" or "-" respectively	Both argument representations benefit the acquisition of knowledge	Zumbach (2009)

Table 6 Guidance for the discussion phase

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Prompts for self-reflection	Prompts	Students self-assess their inquiry process and describe their reasoning using the reflective assessment tool. Examples of prompts are: "Did you initially think about the problem and did you make a prediction subsequently?; Did you vary only one variable before you started with the computer simulation?" (Eckhardt et al. 2013, p. 114)	When students were prompted to assess their work the acquisition of conceptual knowledge improved	Eckhardt et al. (2013)
Hints	Prompts	"Veermans et al. (2000) supported the process of experiment design and the drawing of conclusions by giving hints for designing proper experiments, by analyzing the experimentation behaviour of learners, and by providing the students with feedback on the accuracy of their conclusion from the experiment." (de Jong 2006b, p. 115)	"Compared to a group of students who received pre-defined feedback…, the group with adaptive feedback did not score better on knowledge post-test, but differences in processes were found, indicating that the students who received the adaptive feedback used a better inquiry approach … than the other students." (de Jong 2006b, p. 116)	de Jong (2006b)
Keep track	Heuristic	"Keep records of what you are doing (Klahr and Dunbar 1988; Kulkarni and Simon 1988; Schauble et al. 1991". (Veermans et al. 2006, p. 344)	"…although the good learners were more likely to keep systematic records, doing so was neither necessary nor sufficient for success in this explanatory world." (Schauble et al. 1991, p. 22)	Veermans et al. (2006); Schauble et al. (1991)
Science writing heuristic (SWH)	Heuristic	"The SWH is a tool for promoting thinking, negotiating meaning, and writing about science laboratory activities" (Hand, 2004, p. 131). The students' task is divided in seven points: "Beginning Ideas – What are my questions? Tests – What did I do? Observations – What did I see? Claims – What can I claim? Evidence – How do I know? Why I am making these claims? Reading – How do my ideas compare with other ideas? Reflection – How have my ideas changed?". (Hand, p. 132)	The SWH in combination with a textbook explanation task can benefit conceptual understanding and metacognition. In addition, Keys (2000) and Keys et al. (1999) reported that the SWH promoted the understanding of the nature of science	Hand (2004); Keys (2000); Keys et al. (1999)

Table 6 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Evidence palette, belief meter	Scaffold	"Lajoie et al. (2001) argue that in BioWorld, learners are encouraged to reflect on their process and results by means of the so-called "evidence palette" and the "belief meter. The evidence palette (an overview of all evidence collected for a hypothesis) makes students reflect in their plans and actions, and the belief meter (a measure in which students can indicate how credible their hypothesis is, based in the evidence collected) makes them think about the data collected and screened" (de Jong 2006b, p. 120)	"Making actions and results visible in the evidence palette facilitates reasoning by supporting memory". (Lajoie et al. 2001, p. 161)	de Jong (2006b); Lajoie et al. (2001)
Argumentation palette	Direct presentation of information	In the Argumentation palette "the students' conclusions are compared to an expert conclusion, which helps students reflect on their own argumentation process." (de Jong 2006b, p. 120)	The provision of the expert conclusion enables the students to "both categorize the evidence that they have posted as well as prioritize their importance" (Lajoie et al. 2001, p. 180)	de Jong (2006b); Lajoie et al. (2001)

Table 7 Guidance for multiple phases

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Belvedere inquiry diagram	Process constraints	The Belvedere inquiry diagram looks like a concept map tool and contains pre-defined concepts and links so that students can make connections, for example, connecting the hypothesis with the data indicating whether the hypothesis is confirmed or rejected	"Toth et al. (2002) report positive effects on "reasoning scores" for students using the Belvedere inquiry diagram…" (de Jong 2006b)	de Jong (2006b)
Instructional support (problem-solving tasks—feedback/worked-out examples)	Process constraints	When students work with problem-solving tasks they either get feedback with an explanation about the error or they request to review the certain information once again. The other type of instructional support is the worked example where students are provided with a step-by-step problem solution (Yaman et al. 2008)	Worked examples seem to be more beneficial concerning deeper understanding, especially for students with high interest. For students with low interest, feedback and worked examples were supportive in similar ways (Yaman et al. 2008). In addition, self-explanation prompts can improve students' performance, skills and motivation (Crippen and Earl 2007)	Yaman et al. (2008); Crippen and Earl (2007)
Process coordinator/regulative support tool (in Co-Lab inquiry learning environment)	Process constraints	The process coordinator tool contains a process model with the learning goals prompts and cues so that students are able to perform their inquiry (Manlove et al. 2007)	The full version of the tool led to better lab reports, however, students did not construct better models (Manlove et al. 2007). In addition, Process Coordinator was effective in promoting goal viewing (Manlove et al. 2009).	Manlove et al. (2007); (Manlove et al. 2009)
Reflective support	Performance dashboard	Reflective support refers to prompts provided to students in order to be aware of the learning process. For example, students could be prompted to keep track of their experiments and reflect on the process followed by answering questions (de Jong 2006b; Zhang et al. 2004)	The review of studies that examined the presence of reflective support suggests that it could have positive effects on students' performance and understanding	de Jong (2006b); Zhang et al.(2004)
Prompts for generating/processing information	Prompts	Students are presented with prompts in the form of "FIND OUT whereof it depends whether…"	When these types of prompts are presented to students, they use the generating and processing information strategy more and this positively affects the learning outcome	Thillman et al. (2009)

Table 7 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Reason-justification/rule-based/emotion-focused prompts	Prompts	The reason-justification prompts were used to enhance students' awareness concerning the process and strategies they used, e.g. How are you deciding what to do next? The rule-based prompts were used to help students realize what the task is for, e.g. "What variables are you testing?" Emotion-focused prompts were used to help students express their feelings, e.g. "How are you feeling right now in dealing with this problem?" (Lin and Lehman 1999, p. 841)	Only the reason-justification prompts help students in problem-solving, planning and monitoring of their activities	Lin and Lehman (1999)
Generative learning strategy prompts/metacognitive feedback	Prompts	Students were asked to highlight important information and keep notes in order to organize this information. In a later phase, a feedback message appeared when an incorrect answer was selected, encouraging students to review and revise their highlights and notes	Generative learning strategy prompts, in combination with metacognitive feedback, improve students' self-awareness and performance	Lee et al. (2010)
Prompts—checking our understanding	Prompts	"…the KIE (and WISE) environments can use 'Checking our Understanding' prompts as well as other more generic reflection prompts to encourage students to monitor their progress and understanding (Quintana et al. 2004)." (de Jong 2006b, p. 120)	N/A	de Jong (2006b)
Strategic prompts/general advice and graphic advance organizer (as metacognitive support)	Prompts	Strategic prompts in the form of a list with general advice (e.g. take your time to…, get an overview about…) and a graphical advance organizer were used as metacognitive support	No benefits were found for students' performance and knowledge from the use of metacognitive support	(Stahl and Bromme 2009)
Explanation/regulation prompts	Prompts	Explanation prompts are used to help student conduct appropriate experiments. Regulation prompts are used to help students to regulate their thoughts when formulating explanations during an inquiry cycle	More extensive prompts asking students to perform certain tasks worked better than simple prompts. Students supported with explanation and regulation prompts outperformed students supported with explanation prompts and students with basic inquiry support on a knowledge and application test	(Wichmann and Leutner 2009)

Table 7 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Assignments	Prompts	"Assignments tell the learner what to do, and in this way support the planning process. Assignments are small exercises that point the learner to specific elements of the simulation model." (de Jong et al. 1999, p. 598). De Jong et al. (1998) define five types of assignments, *do-it*, *investigation*, *explicitation*, *specification* and *optimization*	Adding assignments to the simulation environment worked as a successful type of instructional guidance for students (de Jong et al. 1996, Swaak et al. 1998)	de Jong et al. (1996), de Jong et al. (1998); de Jong et al. (1999), Swaak et al. (1998)
HOTAT—CA	Heuristic	HOTAT—hold one thing at a time CA—change all. This heuristic could be used mainly for experimentation purposes (investigation phase). It could also be used in sorting variables and establishing their relationships before experimentation (e.g., via concept mapping; Conceptualization phase)	"Subjects (overall)…did not appear to be sensitive to the fact that with only two variables to manipulate a proof using a HOTAT strategy is logically equivalent to one using a VOTAT…" (Tschirgi, 1980, pp. 8–9)	Tschirgi (1980)
Planning of the inquiry process	Heuristic	"The planning of the inquiry process can be supported by making the different steps (orientation, creating a hypothesis, etc.) clear for the students… More specific process support can then be given within each of these steps." (de Jong, 2006b, pp. 118–119)	After reviewing several studies, it is evident that planning helps students proceed through tasks by providing structure	de Jong (2006b)
Heuristics (explicit/implicit condition)	Heuristic	Students receive heuristics in an implicit or explicit condition. In the first condition, students are provided with guidance and feedback based on the heuristics while in the second one, they receive additional information about the heuristic itself	Both implicit and explicit heuristics improved students' knowledge, with the explicit heuristics triggering more self-regulation in students	Veermans et al. (2006)
Heuristics	Heuristic	A general definition of heuristics is given and it is noted that they can support problem solving or discovery learning. According to Veermans (2003), a heuristic is "A rule of thumb, simplification, or educated guess that reduces or limits the search for solutions in domains that are difficult and poorly understood …" (p. 23)	N/A	Veermans (2003)

Table 7 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Data interpretation and self-regulation support (SimBioSee)	Scaffold	The students worked with a water-ecological computer program and receive support for data interpretation or self-regulation, or both. At the beginning, students have to make a prediction and run the simulation in order to verify or reject it. During the data interpretation, students were either asked to give their explanations or they receive feedback from the simulation outcome (description and expert interpretation). At the end, students were asked to complete a self-assessment and justifying, or not, their answers	When students received support for both data interpretation and self-regulation, learning success decreases. It is better to provide support only for one of the phases	Eckhardt et al. (2013)
Pocket PiCoMap	Scaffold	Pocket PiCoMap is a mobile device which includes scaffolds (concept colors, link scaffold, concept, link and map notes, and text map) in order to help students create concept maps	Students created concepts maps which were difficult to read	Luchini et al. (2003)
Adaptive/fixed/ no scaffolding conditions (hypermedia learning environment - Microsoft Encarta)	Scaffold	Three scaffolding condition were tested. In the adaptive scaffolding condition (AS), students had access to a human tutor in order to support them with self-regulation aspects, such as planning and monitoring. In the fixed scaffolding condition (FS), students received a fixed list with the learning goals. Finally, in the no scaffolding (NS) condition, students did not receive any scaffolding	Both AS and FS led to a better conceptual understanding. In addition, AS condition helped students to regulate their learning successfully	Azevedo et al. (2004)
Guiding questions	Scaffold	Guiding questions are "… higher-order questions…to foster students' conceptual knowledge…" (Moos and Azevedo 2008, p. 210). The students worked with the Microsoft Encarta Reference Suite™ and learned about the circulatory system. In the experimental condition, students receive five domain specific questions as a cognitive scaffold	Providing students with guiding questions helped students' learning of challenging science topics and led to more use of the planning process	(Moos and Azevedo 2008)

Table 7 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Metacognitive scaffolding (structuring scaffolds/ problematizing scaffolds)/ Ontdeknet e-learning environment	Scaffold	Structuring scaffolds are intended to structure metacognitive activities on an interpersonal level, while problematizing scaffolds are intended to elicit metacognitive activities and support group discussion, e.g. Structuring scaffold—"I am going to show you an example of how to introduce yourselves…" and Problematizing scaffold – "Why are you going to introduce yourselves?" (Molenaar et al., p. 1731)	"The form of scaffolds does not significantly influence activation of metacognitive activities on the interpersonal plane." (Molenaar et al. 2010, p. 1736)	Molenaar et al. (2010)
Web knowledge forum (software)	Scaffold	Using this software, students can keep notes of their ideas and thoughts, add pictures, movies, links and then arrange them by linking them together. Furthermore, they can review and revise their notes	The off- and on-line communication facilities of the Web knowledge forum helped students in the process of searching for new ideas from the database	Oshima et al. (2006)
Co-Lab—graphical modelling tool	Scaffold	"This tool can be used to make initial sketches of the domain, to make testable hypotheses as parts of models or complete models, and to create a final model that reflects the students' (Co-Lab is a collaborative environment) final idea of the domain. The Co-lab modelling tool contains facilities to indicate relations between variables at different levels of precision: qualitative and quantitative" (de Jong, 2006b, p.112)	This scaffold was found to serve its purpose. There are numerous studies supporting the use of such a modelling tool (e.g. Löhner et al. 2003)	de Jong (2006b); Löhner et al. (2003)
Machine-learned detectors	Scaffold	Supports provision of scaffolds. These detectors were basically designed to estimate students' transfer of inquiry skills. Therefore "they can be used to determine when and how to adaptively scaffold students to support their learning." (Sao Redro et al. 2013, p. 25)	N/A	Sao Pedro et al. (2013)

Table 7 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Animated pedagogical agent	Scaffold	An agent that usually looks like a cartoon with whom students can interact in order to get feedback when they provide an input	When a computer-based learning environment includes an agent, the learning is deeper and students become more active participants. Thus, students prefer such an environment to one without an agent	Moreno et al. (2001)
Intelligent tutoring systems	Scaffold	The tutor presents "the stimuli the learner has to respond to, and if the learner responds incorrectly, it presents it again, and if the learner responds correctly it presents the next stimulus". (Veermans 2003, p.16)	It supports the learners' activities in discovery learning. (Veermans, 2003)	Veermans (2003)
Smithtown	Scaffold	"Smithtown is an intelligent tutoring system designed as a guided discovery world whose primary goal is to assist individuals in becoming more systematic and scientific in their discovery of laws for a given domain." (Shute, and Glaser, 1990, p. 51)	"Overall, the system performed as expected. Tutoring on scientific inquiry skills resulted in increased knowledge" (Shute, and Glaser, 1990, p. 51)	Shute and Glaser (1990)
Feedback protocol (norm-referenced/self-referenced feedback)	Scaffold	"…the norm-referenced feedback group, receive feedback in relation to all other learners….the self-referenced feedback group, received feedback on cumulative quiz performance in comparison only to their own prior attempts…" (Biesinger and Crippen 2010, p. 1475)	"…changes in goal orientation, self-regulation, self-efficacy, and achievement as a result of differing feedback protocol were not statistically detectable…" (Biesinger and Crippen 2010, p. 1479)	Biesinger and Crippen (2010)
Thinkertools/Inquiry Island environments (It includes a fading mechanism)	Scaffold	"Thinkertools/Inquiry Island has several advisors, each of them related to a specific part of the inquiry cycle" (de Jong, 2006b, p. 112) "All phases (*of the inquiry cycle*) contain detail support, but during the course of working with the environment the support gradually disappears" (Veermans 2003, p. 14)	N/A	de Jong (2006b); Veermans (2003)
Connection log	Scaffold	The Connection Log is a web-based space with guidance that helps students during the creation of evidence-based arguments. The task is divided into six stages, *define problem*, *determine needed information*, *find needed information*, *organize information*, *develop claim* and *link evidence to claim*	The use of the Connection Log led to a significant impact to performance for average-achieving middle school students	Belland (2010)

Table 7 continued

Tool	Type of guidance	Description of tool	Research findings about the tool	References
Glossary—hyperlinks (STOCHASMOS platform)	Direct presentation of information	The Glossary in the Stochasmos platform is available to students at any time and provides definitions of the main related concepts	N/A	Kyza et al. (2007)
Explanations	Direct presentation of information	"Explanations can contain audio, video, text, html, images, or a combination of text and images. They can be used to provide feedback, but also to provide background information about the domain or the learning environment". (Veermans 2003, p. 30)	N/A	Veermans (2003)

Findings

In this section we present the guidance related to each inquiry phase separately. Specifically, we present/name the guidance tools identified per type of guidance. Information for all the guidance tools can be found in Tables 2, 3, 4, 5, 6 and 7. Finally, in this section we report on whether the types of guidance identified for each inquiry phase were found to be effective in promoting student learning, as documented in the CoSIL research.

Guidance related to the Orientation phase

From the literature review, it is evident that the *Orientation* phase receives the least amount of guidance during the inquiry process. It is natural that this phase does not require a lot of support (guidance means/tools), because it focuses only on stimulating students' interest and curiosity about the problem/topic to be investigated (content knowledge). The latter explains why only four guidance tools related to this phase were identified. Based on our literature review (see Table 2), only one process constraint approach (SEEK Tutor), one use of direct presentation of information (Access to domain knowledge) and two scaffolding tools (Tuolumne River module) were identified. From the results of these four studies, only the SEEK Tutor tool had a positive impact on students' critical thinking (Graesser et al. 2007). No data were provided regarding the Tuolumne River module and the Access to domain knowledge tools, while it was not clear if the Artemis software was related to students' performances.

Guidance related to the Conceptualization phase

The Conceptualization phase consists of the *question* and/or *hypothesis* sub-phases. A large number of guidance tools of all types have been developed for this particular phase, with the exception of the performance dashboard (see Table 3). More specifically, a total of 14 guidance tools were identified: a single tool for process constraints (Tuolumne River module) and for prompts (Metacognitive scaffolds), four heuristics tools (Simplify problem; Identify hypothesis; Slightly modified hypothesis; Set expectations), six scaffolds (Hypothesis scratchpad; Shared proposition scratchpad/table; Prediction; Concept map template; Articulation box; Tuolumne River module) and two direct presentations of information (Issues; Complete predefined hypotheses). Of the studies in which these tools were used, only seven reported findings on the impact of the guidance tool, six of which had positive results. In particular, the use of the Shared proposition scratchpad/table led to significant knowledge gains and motivated students to make more related comments (Gijlers and de Jong 2009), the Metacognitive scaffolds (in Animal investigator) were found to enhance students' performance during hypothesis development (Kim and Pedersen 2011), the Prediction scaffold enabled students to state correctly structured predictions (Lewis et al. 1993), the Concept map template helped students in the organization and synthesis of information and therefore led to higher-order learning (MacGregor and Lou 2004), the Articulation box enabled students through the articulation of their reasoning to improve their modeling practices and identify possible errors (Fretz et al. 2002) and the Complete predefined hypotheses appeared to be beneficial for developing a hypothesis (de Jong 2006b). Only the hypothesis scratchpad did not have a positive impact, as it was too complex for learners to use (van Joolingen and de Jong 1997).

Guidance related to the investigation phase

Investigation is the most tool-populated phase of the inquiry cycle. Due to its experimental nature (*exploration-experimentation-data interpretation*) involving setting up experiments/explorations and analysis/interpretation of the collected data, this phase might require more guidance than the others. This could also explain the high number of tools identified. Specifically, a total of 27 guidance means/tools were identified in this phase, representing all forms of guidance except the direct presentation of information (see Table 4). The majority of them (13) were heuristics (VOTAT; Simple values; Equal increments; Confirm hypothesis; Extreme values; Make a graph; Heuristics for experimentation; Plausibility, Focusing, Observing, and Designing heuristics; Step guidance; Unexpected findings), five of them were scaffolds (Tools for data interpretation; Dynamic testing scaffold; Worldwatcher; BGuIle; SCYED), while four tools fall under process constraints (Model progression; Process map; Textual/Graphical representation; Air Pollution Modelling) and under prompts (Experiment prompting; Prompts for Experimentations; Tuolumne River Module; Design Diaries). Finally, performance dashboard was represented with a single tool (Monitoring tool—SIMQUEST).

Findings for effectiveness were reported for 17 of these 27 guidance tools. Most of these tools (10) had a positive impact (Process map; Textual/Graphical modelling; Air Pollution Modeling; Monitoring tool; Experiment prompting; Prompts for Experimentations; Design Diaries; Plausibility heuristic; Focusing heuristic; Dynamic testing scaffold) but three of them did not (Model progression; VOTAT; Step guidance), while the remaining four appeared to have a partial impact (Equal increments; Heuristics for experimentation; Observing heuristic; Designing heuristic) (see Table 4). The positive impact of the aforementioned tools varied from supporting better construction of models (Process map; Textual/Graphical representation), enhancing student conceptual understanding and performance (Air Pollution Modelling; Design Diaries; Experiment prompting), monitoring virtual experiments (Monitoring tool—SIMQUEST), reflecting on their experimentation design (Prompts for Experimentations), focusing on one dimension of an experiment or hypothesis (Focusing heuristic), and enhancing data interpretation, error detection and the proposition of alternative solutions (Dynamic testing scaffold).

Guidance related to the Conclusion Phase

In contrast with the *Conceptualization* and *Investigation* phases, the literature review revealed a more limited number of guidance tools for the *Conclusion* phase. This was expected due to the phase's theoretical nature, drawing conclusions about the results of the experiment or exploration and responding to the research questions or hypotheses. Only seven tools providing four different types of guidance were identified: a single performance dashboard tool (Tuolumne River Module) and heuristic (Present evidence), two prompt tools (Prompts for writing scientific explanations; Questions prompts) and three scaffolds (Self-explanation and meta-level feedback; ExplanationConstructor; Argumentation task) (see Table 5). Based on the results of the studies, five of the tools (Prompts for writing scientific explanations, Questions prompts, Self-explanation and meta-level feedback, ExplanationConstructor and Argumentation task) had a positive impact. In particular, the Prompts for writing scientific explanations were found to support students for writing scientific explanations that follow the structure of claim-evidence-reasoning (McNeill et al. 2006), the Questions prompts were found to have a positive effect on students' domain knowledge and knowledge transfer (Demetriadis et al. 2008), the Self-explanation and meta-level feedback tool was found to enhance the self-explanation process (Cho and Jonassen 2012), the ExplanationConstructor was found to offer students the opportunity to link the claims they make with evidence collected during the investigations (Reiser et al. 2001), and the Argumentation task tool was found to enhance the acquisition of knowledge (Zumbach 2009). Finally, no data was provided for the Tuolumne River Module tool (Woolf et al. 2002) and the Present evidence tool (Veermans et al. 2006).

Guidance related to the discussion phase

The *Discussion* phase is limited to sharing one's inquiry, thus requiring less guidance than other phases. In total, only six guidance tools in four of the six forms were identified: two tools for prompts (Prompts for self-reflection; Hints) and heuristics (Keep track; Science Writing Heuristic), one scaffolding tool (Evidence palette-belief meter) and one direct presentation of information (Argumentation palette) (see Table 6). Based on the findings from the literature, four tools had a positive impact (Prompts for self-reflection; Science Writing Heuristic; Evidence palette—belief meter; Argumentation palette). The Prompts for the self-reflection tool was found to improve the acquisition of conceptual knowledge (Eckhardt et al. 2013), the Science Writing Heuristic was found to benefit students' conceptual understanding and metacognition, as well as their understanding of the nature of science (Keys 2000; Keys et al. 1999), the Evidence palette facilitated reasoning by supporting memory (Lajoie et al. 2001), and the Argumentation palette enabled students to both categorize the evidence that they have posted and prioritize their importance (Lajoie et al. 2001). The literature review about the *Discussion* phase also revealed a tool with mixed results (Hints). Specifically, the Hints tool was not found to influence students' performance, but was found to have a positive effect on students' inquiry approach (de Jong 2006b). Finally, the Keep track tool was found to have no effect on students' learning.

Guidance related to multiple inquiry phases

While the majority of the guidance tools are phase-specific, a number of them could be used in two or more phases. Thus, an additional category was established in order to describe these tools and the forms they take. Based on the literature, a total of 31 tools from all six forms of guidance were applicable in multiple phases. Most of these tools (14) were categorized under scaffolds, more than in any single phase (Data interpretation and self-regulation support; Pocket PiCoMap; Adaptive/Fixed/No scaffolding; Guiding questions; Metacognitive scaffolding; Web knowledge forum; Co-Lab—graphical modelling tool; Machine-learned detectors; Animated pedagogical agent; Intelligent Tutoring Systems; Smithtown; Feedback protocol; Thinkertools/Inquiry Island; Connection Log). Prompts were also used frequently (7 tools), also more than in any single phase (Prompts for generating/processing information; Reason-justification/rule-based/emotion-focused; Generative learning strategy prompts/metacognitive feedback; Checking our Understanding; Strategic prompts/general advice and graphic advance organizer; Explanation/Regulation; Assignments). Heuristics, process constraints, direct presentation of information and performance dashboard had four tools (HOTAT—CA; Planning of the inquiry process; Explicit/implicit heuristics; Heuristics), three tools (Belvedere inquiry diagram; Instructional support; Process Coordinator tool), two tools (Glossary—Hyperlinks; Explanations) and one tool (Reflective support), respectively (see Table 7).

Considering the impact of each guidance tool, it was evident that most of them (17) were successful (Belvedere inquiry diagram; Instructional support; Reflective support;

Explanation/Regulation; Assignments; Generative learning strategy prompts/metacognitive feedback; Prompts for generating/processing information; Planning of the inquiry process; Explicit/implicit heuristics; Adaptive/Fixed/No scaffolding; Guiding questions; Web knowledge forum; Co-Lab—graphical modelling tool; Animated pedagogical agent; Intelligent Tutoring Systems; Smithtown; Connection Log). Among others, these tools were found to positively impact students' reasoning (Belvedere inquiry diagram, see de Jong 2006b), understanding and performance (Instructional support, see Yaman et al. 2008; Reflective support, see Zhang et al. 2004; Explanation/Regulation prompts, see Wichmann and Leutner 2009; Prompts for generating/processing information, see Thillmann et al. 2009; Adaptive/Fixed/No scaffolding, see Azevedo et al. 2004; Guiding questions, see Moos and Azevedo 2008; Animated pedagogical agent, see Moreno et al. 2001; Smithtown, see Shute and Glaser 1990; Connection Log, see Belland 2010), self-awareness (Generative learning strategy prompts/metacognitive feedback, see Lee et al. 2010), inquiry process (Planning of the inquiry process, see de Jong 2006b), self-regulation (Explicit/implicit heuristics, see Veermans et al. 2006; Adaptive/Fixed/No scaffolding, see Azevedo et al. 2004), searching for new ideas (Web knowledge forum, see Oshima et al. 2006), and modeling process (Co-Lab—graphical modelling tool, see Löhner et al. 2003).

Five tools were found to have no impact on students' learning (Strategic prompts/general advice and graphic advance organizer; HOTAT—CA; Pocket PiCoMap; Metacognitive scaffolding; Feedback protocol), while three others revealed mixed results (Process Coordinator tool; Reason-justification/rule-based/emotion-focused; Experimental design tool). Finally, six studies did not provide any data on the impact of the tools (Checking our Understanding; Heuristics; Machine-learned detectors; Thinkertools/Inquiry Island environments; Glossary—Hyperlinks; Explanations).

Differences in the number of guidance tools among phases

From the findings of our literature review, it is evident that the majority of guidance (27 tools) fall under the *Investigation* phase (see Table 1). This was more or less expected because the *Investigation* phase involves the majority of the activities for carrying out an inquiry, such as designing and conducting experiments, collecting and analyzing data. In addition, this phase has the most sub-phases (*exploration*, *experimentation* and *data interpretation*), which increases the need for guidance tools. In the phase of *Conceptualization*, we identified 14 guidance tools. Because no experimental procedure can take place without a *question* and/or *hypothesis* generation sub-phase, a large number of tools have been developed for this purpose as well.

In contrast, given that the phases of *Orientation*, *Discussion,* and *Conclusion* are less complex, they appeared to have limited and less form-focused guidance, with four, six and seven tools respectively. Finally, a large number of guidance tools described in the literature, 31 in total, are of such a nature as to serve multiple phases of the inquiry cycle. For example, assignments can be used to guide students' learning process in all five phases.

Differences in the number of forms of guidance within each phase

The number of guidance forms varied within each phase of the inquiry cycle as well (see Table 1). The variations, however, can be explained based on the number of activities required within each phase/sub-phase. Consider, for example, the phase of *Investigation*. As the most active phase, it has the potential for a large number of heuristics (13) in order to provide specific guidance to students on how to perform certain actions (design and carry out an experiment, collect and analyze data, and report their findings) during the experimental procedure. To carry out these actions however, several scaffolding tools (5) could also be useful. As the significant number of activities in the *Investigation* phase may appear complex to coordinate, a number of Process Constraints tools (4) help reduce the complexity by restricting the number of options students have to consider. Similarly, a number of prompts (4) are used to remind students to carry out required actions that they may have neglected to do on their own before moving on.

In the *Conceptualization* phase, guidance was also based on the needs of the two sub-phases, *question* and *hypothesis*. Thus, the majority of the identified tools (6) were developed in order to scaffold students to generate research questions and/or hypotheses for their experiments. A comparable number of heuristics (4) were used to point out possible ways to go about generating research questions and/or hypotheses. Finally, students co-ordinate their research questions/hypotheses through direct presentation of information tools (2) in order to avoid getting off target.

Guidance for the phases of *Conclusion* and *Discussion* was very similar. In both cases, the guidance focused primarily on instruction (prompts and heuristics) and scaffolding tools for drawing conclusions and discussing the results. The phase of *Conclusion* appears to have a couple of scaffolding tools as well, and along with *Discussion*, both phases had a direct presentation of information tool for ensuring the same provision of information among students. Finally, in the Multiple Phase category, scaffolds (14), prompts (7) and heuristics (4) were the most frequently used forms of guidance, again following the overall frequency pattern.

Discussion

From our literature review, it is evident that the provision of guidance within CoSIL environments in science education has expanded. However, while a large number of guidance tools were identified during the literature review, there was not always enough evidence to suggest that they can be successfully implemented. Of the 89 guidance tools identified, only half of them (44) provided empirical results/evidence of a promising and/or successful implementation. Five tools appear to have mixed results (partially successful) warranting further investigation in the future, while 14 others were not successful, suggesting that in order to be adopted they would need to undergo major changes or should be applied under different conditions (e.g., domain, prior knowledge and experience of students etc.). Finally, for a total of 26 guidance tools no empirical evidence of their impact was provided, meaning that further research is needed in order to determine whether they are successful in achieving their intended purpose.

Out of the 44 guidance tools that provided positive empirical evidence, a number of them appear to be quite promising for future implementation. Given the findings of our literature review, we provide a description of types of guidance for each inquiry phase that could be useful when designing and developing a new inquiry-based learning platform for online labs. The description of guidance is based on the effectiveness each type of guidance has shown when implemented in each inquiry phase. In some cases, we propose combinations of various types of guidance or suggest guidance tools that we believe could be improved. We also provide suggestions regarding types of guidance that are not currently available for a particular inquiry phase and that we believe could be of added value for students when working in that inquiry phase.

Orientation phase

Given that in the *Orientation* phase students create an initial rough idea of the domain based on the information provided/gathered, a process constraints tool such as the SEEK Tutor (Graesser et al. 2007) can help guide students through the search and evaluation of information and help them rate the reliability of the sources (see Table 2). The SEEK Tutor was found to be a very valuable tool, because it helps organize student activity and it has already been found to promote critical thinking among students (Graesser et al. 2007). Given the complexity involved in all inquiry phases (de Jong 2006a), we believe that every inquiry phase should be supported by process constraints tools, especially when novice students are involved. It is important to ensure right from the beginning that the students are on track. According to de Jong and Lazonder (2014) the complexity of an inquiry phase could be reduced by the use of process constraints. For instance, this can be achieved by restricting the number of options that students must consider during an inquiry phase. Of course, the constraints are not necessary all of the time, especially once the students have gained enough experience with the inquiry processes. One way to address this issue is to apply a fading mechanism, which gradually reduces the support provided as the student's experience grows (de Jong et al. 1999; Veermans 2003).

Should the CoSIL environment provide the students with a library of websites, then an Artemis-like scaffold (Butler and Lumpe 2008) can be an option to help students search and sort information (see Table 2). While it was not clear if the positive relation between the use of the tool and students' performance was due to the software itself, Artemis can be of great help. In particular, it contains search, saving and viewing, maintenance, organizational and collaborative scaffolding features, and warrants further assessment. In addition, when providing information to students, a direct presentation of information tool such as Access to domain knowledge (Veermans 2003) can be used to provide the definitions of the concepts under study (see Table 2). While we identified only one such tool in this phase, we believe that more direct presentation of information tools could further help guide students. By using direct presentation of information tools we make our CoSIL environments more *transparent* to the learners and thus support them to perceive its content more easily (Swaak et al. 1998).

Further, for students to connect the information they gathered with major relevant concepts, we suggest using the Concept map template (MacGregor and Lou 2004) scaffold. MacGregor and Lou found that the use of the template helped students organize and synthesize information, leading to higher-order learning (see Table 3). In addition, an Articulation box scaffold like the one in the Model-It software (Fretz et al. 2002) can encourage them to articulate their reasoning when creating relations (see Table 3). While both tools were identified for the Conceptualization phase, we recommend their use in the *Orientation* phase as well, since this phase also involves gathering and organizing information, namely the main variables of the domain, and the problem and issues involved (Scanlon et al. 2011).

Finally, we note that no prompts, heuristics, or performance dashboard forms of guidance were identified in this phase. Prompts and heuristics are important tools that were found, in other inquiry phases, to provide instructions that keep students on task; thus, it might be a good idea to think how to take advantage of these guidance tools for supporting the *Orientation* phase as well. On the same note, performance dashboard tools allow students to monitor their learning and can be very useful, especially in the phase of *Orientation* where students come across new information. For these reasons, we strongly recommend that these forms of guidance should be further investigated as possible supports for the *Orientation* phase.

Conceptualization phase

When students enter the *Conceptualization* phase without specific ideas of the relations among concepts, they create questions or state “issues” (de Jong 2006b). When they already have some prior ideas related to the domain at hand, the students can also create a set of hypotheses. One well-known tool to help students create hypotheses is the Hypothesis Scratchpad scaffold (de Jong 2006b), which allows students to compose hypotheses from separate elements such as variables, relations, and conditions using “if-then” statements (see Table 3). It also allows students to construct concept maps that represent the relations among variables (Wirth et al. 2009), just like the Concept map template (MacGregor and Lou 2004) scaffold mentioned earlier. While the original Hypothesis Scratchpad tool seemed too complex for students (van Joolingen and de Jong 1997) we believe that a revised version of this tool could be a very valuable asset for future CoSIL environments. Another option is to provide students with complete, pre-defined questions or hypotheses as was the case with the Shared proposition table (Gijlers and de Jong 2009) scaffold (see Table 3). The shared proposition table provided students with a list of predefined propositions, which led to significant gains for knowledge about relations and motivated students to make more related comments (Gijlers and de Jong 2009).

The success of the aforementioned tools could also be supported by prompts similar to those used in the Metacognitive scaffolds in Animal investigator (Kim and Pedersen 2011). During hypothesis development, the students are guided with prompts in the form of reflection questions, self-questions, and checklist statements. In their study, Kim and Pederson found that these prompts enhanced students’ performance during hypothesis development (see Table 3). Kim and Pederson (2011) highlight the essence of stating proper hypotheses for inquiry, since they affect the rest of the inquiry process. Despite the fact that prompts can be of great help to students, we found only one prompting tool for this phase in the reviewed literature. Given the success of the prompts of the Metacognitive scaffolds in Animal investigator tool (Kim and Pedersen 2011) we believe that more such tools should be designed for the purposes of the *Conceptualization* phase.

While the *Conceptualization* phase is not one of the phases that usually takes much time during student inquiry, researchers have developed guidance tools that cover almost all of the types of guidance, which serves to emphasize the importance of this phase. The only type of guidance that was not developed for this phase is the performance dashboard. However, a performance dashboard could be useful in several ways. For instance, it could keep track of the variables considered by the learner. Thus, further research is suggested for developing a performance dashboard for the *Conceptualization* phase.

Investigation phase

In the *Investigation* phase students interact with the online lab and collect data in relation to their questions or hypotheses. However, in order to engage in a sensible investigation process, they need sufficient prior knowledge of the subject domain and in designing and implementing any form of investigation. One way to test this is through experiment prompting (Chang et al. 2008) which ensures that students do not proceed without sufficient background-knowledge. This particular tool prompted students to test their knowledge before running an experiment. Specifically, for making certain that the learner has gained adequate background-knowledge in order to proceed with the conduction of any experiment, this tool provides an online evaluation (there are 20 test items, 5 points for each item), in which the student must reach a minimum threshold of 80 points. Only after students had reached this minimum threshold, they could proceed with their experiments. After allowing students to proceed with experimentation, the Experiment prompting tool provides prompts on how to run an experiment, as well as it encourages the students to take notes throughout an experiment. Using Experiment prompting, students had better learning performance than those using a step-by-step guidance approach, which did not require a background-knowledge check (see Table 4).

Further, students can be supported in identifying the independent and dependent variables involved in the experiment under study and their relations. A scaffold like Dynamic Testing (Model-It software) can help the students to do this (Fretz et al. 2002). This scaffold promotes interaction between the student and the model, helps students detect errors and encourages them to test their model multiple times in order to make improvements (see Table 4). With a performance dashboard, such as the Monitoring tool of SIMQUEST (van Joolingen and de Jong 2003), students can store their experiments and present the values of the variables in a table format. They can later replay the experiments or sort variables to compare different experiments (see Table 4), which is of great importance for successful experimentation.

Finally, a scaffold similar to the Data Interpretation scaffold (BGuILE) could be used for asking students questions to guide their interpretation of the data (Smith and Reiser 1997). While this tool was not supported by empirical evidence (see Table 4), we believe it could be valuable for students. Research shows that one of the obstacles that students face during the *Investigation* phase is data interpretation (see de Jong 2006a). Thus, any support provided in this direction could prove useful.

The *Investigation* phase is the most tool-populated phase of the inquiry cycle; however, during our literature review we identified only one performance dashboard developed for this inquiry phase. Despite the fact that most tools were designed for this phase, we strongly recommend further development of guidance tools for this inquiry phase because of the large number of activities and data management involved in this phase, as well as because of the difficulties students face when enacting this phase. According to de Jong (2006a), in the investigation phase students have difficulties in making predictions, interpreting the data collected and linking them to their hypotheses, designing and running fair experiments, and connecting an experiment's findings with long-term planning.

Conclusion phase

Guidance is crucial in the *Conclusion* phase, because students are trying to make sense of their findings and establish relations among the variables under investigation. A helpful guidance tool for this phase appears to be the "Prompts for writing scientific explanations" (McNeill et al. 2006). This tool helps students write scientific explanations following the structure of claim-evidence-reasoning. Students are provided with related prompts for each of the three elements, namely, "Write a sentence that states…", "Provide two pieces of data that supports your claim that…" and "Write a sentence that connects your evidence to your claim that…", respectively (McNeill et al. 2006, p. 164). The idea is to enable the students through prompts to have all three key elements in their mind at the time a scientific explanation is developed. Another good example for providing support in this phase is the ExplanationConstructor (BGuILE) scaffold, which requires from students to connect their data with their explanations, thus linking their claims with the evidence collected during their investigation (de Jong 2006b). Based on a study by Reiser et al. (2001), this scaffolding tool helps students move between the investigation and the explanation environment, that is the ExplanationConstructor, effectively (see Table 5). A combination of a scaffolding tool, such as the ExplanationConstructor (BGuILE), along with prompts could be more beneficial for students when writing their conclusions than when used individually. Needless to say, further research is needed concerning this topic.

Another combination of different types of guidance that might be valuable to the learners in this phase could be a blend of a performance dashboard and scaffolding tools, such as the Tuolumne River Module tool (Woolf et al. 2002). For instance, while students have already completed analyzing and interpreting their data, it is crucial, when writing their conclusions, to have access to their findings stored in the previous phases (using the Monitoring tool as suggested above; van Joolingen and de Jong 2003). As in the *Investigation* phase, a single performance dashboard tool exists, Tuolumne River Module (Woolf et al. 2002), but because no successful empirical evidence is provided regarding its effectiveness, we further support the design and test of others.

Finally, in the *Conclusion* phase, there was no direct presentation of information or process constraints tools. Based on the needs arising in this phase, we believe that a direct presentation of information tool might not be as necessary as a process constraints tool. A process constraint tool is important because it could reduce the complexity (de Jong and Lazonder 2014) involved in the *Conclusion* phase, such as gathering/identifying proper evidence to accept or reject a hypothesis. For instance, this can be achieved by restricting the number of data (i.e., focusing students' attention to the data associated with the variables of the hypothesis under investigation), along with their corresponding analysis (evidence), that students must consider for reaching to conclusions. Thus, we suggest that more effort be invested in developing process constraint related guidance tools for this phase.

Discussion phase

Similar to the *Conclusion* phase, the *Discussion* phase is quite demanding. For instance, reflecting upon and communicating information to others is a skill-demanding process and guidance can play an important role in completing the inquiry cycle successfully. Thus, we suggest using the Evidence Palette and Belief Meter (Lajoie et al. 2001), as they encouraged students to reflect on their processes and results. The Evidence Palette makes students reflect on their plans and actions while the Belief Meter makes them think about the data collected and screened. Lajoie and her colleagues argue that "making actions and results visible in the evidence palette facilitates reasoning by supporting memory" (2001, p. 161). In addition, by using a direct presentation of information tool such as the Argumentation Palette (Lajoie et al. 2001) students could justify their conclusions by comparing them with those of experts, thus reflecting on their own argumentation process. In this particular case, Lajoie et al. (2001) required from students to use the Argumentation Palette to (a) organize evidence to build a justification for their diagnostic conclusions (the task was to identify a patient's disease), (b) build an argument based on the evidence, (c) compare their argument to the one of an expert (expert arguments were provided by physicians and teachers; a narrated recap of how a physician solved the problem was also provided), and (d) reflect on their argument in comparison to the argument of the expert. The empirical evidence reveals that the Argumentation Palette supports students to categorize as well as prioritize the available evidence based on its importance. The two types of guidance, Evidence Palette/Belief Meter and Argumentation Palette, could be combined for deeper student reflection.

To accompany the aforementioned tools, we also recommend inclusion of the Prompts for self-reflection and the Science Writing Heuristics (SWH) for better guidance. The Prompts for self-reflection (Eckhardt et al. 2013) encourage students to assess their inquiry process and describe their reasoning. When doing so, their acquisition of conceptual knowledge improved (see Table 7). Similarly, the SWH tool aims at "promoting thinking, negotiating meaning, and writing about science laboratory activities" (Hand 2004, p. 131). In combination with a textbook explanation task, the SWH can benefit conceptual understanding and metacognition. In addition, Keys (2000) and Keys et al. (1999) reported that the SWH tool promoted understanding of the nature of science (see Table 7).

Our literature review revealed the absence of process constraints and performance dashboard tools from this phase. We believe that both types of guidance are necessary for this phase, because students are expected to have access to and reflect upon their actions, as well as to stay on task. A performance dashboard could provide students with feedback on whether they progress well in terms of their learning process or the quality of their learning products (de Jong and Lazonder 2014). This way, it could serve as a check mechanism on whether the students are on the right track or they need help. If the latter is the case, the performance dashboard tool could suggest to students to move to the *Discussion* phase in an attempt to get new information from peers that might position them back on track. Moreover, we also recommend the design of more scaffolding tools, because only one was identified in the literature review. For example, a scaffolding tool for writing scientific reports in combination with a presentation tool for sharing information among peers could be very helpful in the *Discussion* phase. The idea is to strengthen the quality of the materials or information exchanged among peers as much as possible.

Conclusions and implications

CoSIL environments have been identified by many researchers to be one of the best means to implement inquiry-based learning, because they provide affordances that other traditional means cannot offer. One such major affordance is the provision of guidance as is also evidenced in recent overview works (Alfieri et al. 2011; Arnold et al. 2014; d'Angelo et al. 2014; de Jong 2006a; de Jong and Lazonder 2014; Donnelly et al. 2014; Furtak et al. 2012; Gerjets et al. 2008; Plass and Schwartz 2014; van Joolingen and Zacharia 2009). Guidance could result in offering learners more agency in their learning process (de Jong and Lazonder 2014) and the means to overcome the challenges posed by CoSIL environments, mainly because of the cognitive and metacognitive complexity of the learning experiences these environments offer (Azevedo 2005; Ødegaard et al. 2014; Scheiter and Gerjets 2007). In other words, guidance is regarded as a means to support students' self-regulated learning, through which students become responsible for their learning endeavors and thus are responsible for managing on their own any challenges that arise (Hadwin and Winne 2001; Pintrich 2000; Zimmerman 2001).

In this paper we aimed to examine whether research so far in the CoSIL domain has advanced to the level of developing effective means/tools to provide all of the forms of guidance to support all of the processes involved in carrying out inquiry, especially with online labs. In so doing, we identified the means/tools already developed for all of the types of guidance that have shown to support student inquiry in CoSIL implementations (*process constraints, performance dashboard, prompts, heuristics, scaffolds,* and *direct presentation of information*) and, therefore, might have the potential to serve student inquiry when using

CoSIL environments with science online labs (virtual and remote labs offered through computer technology).

In particular, the findings of our literature review provide evidence as to which inquiry phases of CoSIL implementations need more guidance (e.g., *Conceptualization*) or which inquiry phases of CoSIL implementations have a reasonable number of guidance tools, but lack empirical evidence concerning their impact on student learning (e.g., *Investigation*), as well as which forms of guidance have been used the most (prompts, heuristics and scaffolds). While our findings make sense given students' needs in CoSIL environments, it should be noted that some of the inquiry phases (*Orientation*, *Conclusion* and *Discussion*) have been poorly supported by a very limited number of guiding tools/means and some of the forms of guidance (Process constraints, Performance dashboard and Direct presentation of information) have been comparatively neglected. This warrants further investigation as to why these phases and forms are so poorly represented and whether more guidance is required. Could more tools for the underrepresented types of guidance and in the less supported phases help promote the positive impact of the other phases, or even the whole inquiry learning process? Finally, while acknowledging this underrepresentation of guidance, one cannot disregard the fact that a large number of guidance tools were applicable in multiple phases, some of which could be applicable in some of the less popular phases and forms. For example, we support the idea of a performance dashboard available in all five phases of the inquiry cycle in order to organize all functions and tools and place them within the immediate reach of the student, making them available at all times. Another example could be the process constraints type of guidance. In this case, this specific type could be present in all inquiry phases guiding students through the different steps within each phase while reducing the complexity of the learning process. Needless to say, these are just conjectures that need to be further examined through future research.

Overall, we believe that for a newly designed CoSIL environment with online labs guidance should continue to be personalised (de Jong 2006b; de Jong et al. 2014; Quintana et al. 2004) and aim at supporting self-regulated learning (Hadwin and Winne 2001; Pintrich 2000; Zimmerman 2001). Researchers report on several difficulties that students face when self-regulating their learning (e.g., Azevedo 2002) and present CoSIL environments, which provide guidance, as one of the best ways to help students to overcome them at their own personal time and pace of learning (Gerjets et al. 2008). This means that guidance should be provided according to the needs of the student, as well as in different forms (Belland and Drake 2013). This is a major issue that the literature fails to inform us about and is definitely worthy of future investigations. For example, hypotheses can be directly offered to students in a ready-made form (direct presentation of information) if students are having difficulties forming a hypothesis on their own, or students can be offered a scaffold that helps them create a hypotheses from different elements/concepts, or students can only be prompted that they should create a new hypothesis because their previous one does not fit the hypothesis profile. Of course, this moves the entire burden onto the teachers, because they are the ones who will program the platform settings to respond to students' difficulties/problems during inquiry endeavours. Again, this is an issue that needs further investigation, because since most teachers do not have the background and/or training to respond to such tasks.

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Zacharias C. Zacharia is an associate professor of Science Education in the Department of Educational Sciences at the University of Cyprus. His research interests focus on the implementation of computer supported inquiry learning in science education.

Constantinos Manoli is a post-doctoral fellow in the Department of Educational Sciences at the University of Cyprus. His research interests focus on the relationship between children's environmental perceptions and their environmental actions.

Nikoletta Xenofontos is a PhD candidate in the Department of Educational Sciences at the University of Cyprus. Her research interests focus on enhancing students' conceptual understanding through the use of computer supported inquiry learning.

Ton de Jong is full professor and department head of the Department of Instructional Technology. His research interests include technologies for learning, inquiry learning and problem solving in STEM education.

Margus Pedaste is a Professor of Technology Education in the Centre for Educational Technology at the University of Tartu. His research interests focus on the computer supported inquiry learning and problem solving in technology enhanced learning environments.

Siswa A. N. van Riesen is a PhD candidate in the Department of Instructional Technology at the University Twente. Her research interests focus on enhancing students' conceptual knowledge and inquiry skills within online learning environments.

Ellen T. Kamp is a junior researcher in the Department of Instructional Technology at the University Twente. Her research interests focus on enhancing students' conceptual knowledge and inquiry skills within online learning environments.

Mario Mäeots is a Junior Research Fellow of technology education in the Centre for Educational Technology at the University of Tartu. His research interests focus on improving students' inquiry skills with computer-based learning environments.

Leo Siiman is a Senior Research Fellow of Technology Education in the Centre for Educational Technology at the University of Tartu. His research interests focus on computer-based inquiry learning environments.

Eleftheria Tsourlidaki is a researcher at the Research and Development Department of the private school "Ellinogermaniki Agogi" in Greece. Her research is focused on the improvement of the educational procedure by implementing new technologies and contemporary pedagogical approaches so as to achieve maximum engagement and interaction between students in the school classroom.