Go-Lab

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3	Ecole Polytechnique Fédérale de Lausanne	EPFL	Switzerland
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17	University of Glamorgan	UoG	United Kingdom
18	Institute of Accelerating Systems and Applications	IASA	Greece
19	Núcleo Interactivo de Astronomia	NUCLIO	Portugal

Contributors

Name	Institution
Siswa van Riesen	UT
Ellen Kamp	UT
Anjo Anjewierden	UT
Lars Bollen	UT
Effie Law	ULEIC
Jan Rudinksy	ULEIC
Matthias Heintz	ULEIC
Mario Mäeots	UTE
Margus Pedaste	UTE
Leo Siiman	UTE
Külli Kori	UTE
Zacharias Zacharia	UCY
Costas Manoli	UCY
Nikoletta Xenofontos	UCY
Eleftheria Tsourlidaki	EA
Georgios Mavromanolakis	EA
Sofoklis Sotiriou	EA
Denis Gillet	EPFL
Sten Govaerts	EPFL
Adrian Holzer	EPFL
Evita Tasiopoulou	EUN
Yiwei Cao	IMC

Legal Notices

Executive Summary

The current deliverable presents a set of initial specifications of the Go-Lab learning spaces, which is the interface that students see and use when learning with a Go-Lab online lab. These specifications are based on an overview of the literature on the use of cycles in inquiry learning and of the guidance that can be given to students involved in an inquiry process with online labs. The current deliverable is organized as follows: We start with summarizing the main learning goals for learning with laboratories. Then we summarize different inquiry cycles and synthesize a cycle that best fits the Go-Lab project. Next, a literature review of guidance for inquiry learning with online labs is given. We organize this guidance according to the types of support given and the different phases of the selected inquiry cycle. These inventories and choices then result in a set of specifications for the Go-Lab learning spaces and are illustrated with the three anchor labs we chose for the current phase of the project: Aquarium, Faulkes Telescopes, and HYPATIA. These specifications should be read in relation to the full versions of the mock-ups of the Go-Lab learning environments.

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1 Physical and online laboratories in science and engineering education

The central theme of the Go-Lab project is inquiry learning with online labs. Online labs is a collective term for virtual (simulated), remote laboratories and databases of research data. Online laboratories nowadays form an alternative for traditional physical laboratories, which traditionally forms a central part of the curriculum in science and engineering education.

In physical laboratories students do “hands-on” science. Physical laboratories serve a multitude of learning goals of which only a few, more specifically handling physical equipment and learning how to deal with measurement errors, are specific for the physical environment (Balamuralithara & Woods, 2009; Feisel & Rosa, 2005; National Research Council, 2006). Other learning goals of physical labs are related to offering students authentic experiences such as for example appreciating the complexity of empirical work, understanding the nature of science, raising interest in science and learning science, and developing collaborative skills. The two pivotal goals of learning in physical labs are mastering the subject matter in the lab and acquiring inquiry skills (National Research Council, 2006, p. 53).

For the latter two goals an inquiry approach to learning, this is a learning mode in which learners follow a scientific approach often materialised in a so-called “inquiry cycle”, is an obvious instructional strategy. Such an inquiry way of learning has proven to be effective, compared to traditional direct instruction, for reaching these goals in a traditional curricular setting (Furtak, Seidel, Iverson, & Briggs, 2012; Minner, Levy, & Century, 2010) and in computer-based (simulation) environments (e.g., Deslauriers & Wieman, 2011) albeit an inquiry approach may require more time, and thus be less efficient, than a direct instruction approach (Eysink et al., 2009). Research also has shown convincingly that students in an inquiry process need guidance to ensure that they learn effectively (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011). Guidance concerns both the inquiry process (guidance through the inquiry cycle as such and support in each of the phases of the inquiry cycle) as well as more metacognitive support for planning and monitoring the learning process (de Jong & Njoo, 1992).

Virtual laboratories nowadays form an alternative for physical laboratories (Waldrop, 2013). Research that compares learning from physical and virtual laboratories generally shows that virtual laboratories offer specific affordances (e.g., by augmenting the domain with “invisible” elements, such as vectors, that cannot be offered by physical laboratories, Olympiou, Zacharias, & de Jong, 2013). There is also evidence that learning with virtual labs is more effective than learning with physical laboratories (de Jong, Linn, & Zacharia, 2013). Virtual laboratories may have additional advantages such as offering more safety and being cheaper than their physical counterparts. Finally, virtual laboratories have the advantage of potentially bringing experimentation facilities in the classroom that cannot be achieved in a normal school laboratory, such as experiments with DNA (Toth, Morrow, & Ludvico, 2009). Virtual laboratories have the advantage that students can do quick experimentations; in physical laboratories experimentation can be costly and students first have to reflect before they perform an experiment (de Jong, et al., 2013). This means that also physical laboratories may have specific cognitive advantages for learning and there are also indications that combining physical and virtual labs may be beneficial for acquiring conceptual knowledge (e.g., Jaakkola & Nurmi, 2008).

Despite the known advantages of virtual laboratories there is still a need for learning in physical laboratories to give students the experience of real equipment. *Remote labs*, these are real labs that students can manipulate from a distance, may offer an interesting option here. Research on the educational effectiveness of remote labs is scarce and most publications on remote labs focus on the technical feasibility and if students are involved it often concerns measurement of students' experiences in working with remote labs through questionnaires (Cooper & Ferreira, 2009).

The third alternative for physical laboratories are *data sets*. Data sets enable students to engage in inquiry without gathering data themselves (for example when doing research on tidal movements over a long period of time). However, by using only data sets students are not confronted with all elements of the inquiry cycle.

Physical laboratories are traditionally present on many different domains. Remote and virtual laboratories are now starting to become available in many domains (also domains that are normally not realizable for schools) such as, for example, DNA gel electrophoresis, (Toth, Ludvico, & Morrow, 2012; Toth, et al., 2009), airbag functioning (McElhaney & Linn, 2011), stoichiometry (Pyatt & Sims, 2012), electronics (Gomes & Bogosyan, 2009), electrical circuits (Campbell, Bourne, Mosterman, & Brodersen, 2002; Kolloffel & de Jong, in press; Zacharia, 2007), spectrum analysers, (Chuang, Jou, Lin, & Lu, 2013), pulleys (Chini, Madsen, Gire, Rebello, & Puntambekar, 2012), heat and temperature (Zacharia, Olympiou, & Papaevripidou, 2008), collision (Marshall & Young, 2006), optics (Martinez, Naranjo, Perez, Suero, & Pardo, 2011; Olympiou & Zacharia, 2012), gears (Han & Black, 2011), chemistry (Sao Pedro, Baker, Gobert, Montalvo, & Nakama, 2013), and buoyancy (Kunsting, Wirth, & Paas, 2011; Schiffhauer et al., 2012; Wirth, Künsting, & Leutner, 2009). An overview of remote laboratories can further be found in Garcia-Zubia and Alves (2012).

The current deliverable formulating specifications of the Go-Lab learning spaces. Go-Lab centres around learning with online (virtual and remote laboratories and data sets) and intends to offer students an inquiry learning experience with integrated and adaptive guidance. A Go-Lab learning space is the interface that students see and utilize when learning with a Go-Lab online lab and its associated guidance.

The building-up of this deliverable is as follows It starts with summarizing the main learning goals for learning with laboratories. Then we summarize different proposals for inquiry cycles and build a cycle that fits best in the Go-Lab project. Next, a literature review of guidance for inquiry learning with online labs is given. This guidance is organized according to the different phases of the defined inquiry cycle and types of guidance that were identified. This then leads to the initial specifications for the Go-Lab learning spaces.

2 Learning goals of (online) laboratories

Laboratories play a central role in science education as they give students the opportunity to engage in inquiry learning. In this laboratories may serve a set of different goals (see, Balamuralithara & Woods, 2009; de Jong, et al., 2013; Feisel & Rosa, 2005; National Research Council, 2006) which are discussed briefly below.

First of all, laboratories help students to acquire insight and conceptual knowledge in the domain of the laboratory. By designing hypotheses and doing investigations students have a strong involvement with the domain under study and have thus the opportunity to experience the deeper characteristics of it.

Second, inquiry learning in labs may facilitate learning about the inquiry process itself. Students may learn how to formulate a hypothesis, plan and design an experiment, make interpretations of data etc. This is especially true if the inquiry process is supported by specific guidance. For example, if students receive heuristics on how to design experiments they will acquire knowledge about the process which will be applicable to future experiments.

Third, laboratories help students to learn about measurement errors. Measurement errors more naturally play a role in physical and remote laboratories but they can also be simulated in a virtual setting.

Laboratories help students to acquire practical skills in handling equipment, including troubleshooting, and also learn them to follow safety procedures. This, by nature is more easily achieved in physical laboratories, however remote laboratories may also offer such opportunities. In this context the facilities of virtual laboratories are limited, but not completely absent.

Laboratory work may also help students to acquire collaboration skills. A lot of work in laboratories is done collaboratively and students can learn how to communicate with others, to work further on other person's products, and to learn about different roles in laboratory work.

Laboratory work can help to get students acquainted with and enthusiastic for science work. Due to its applied and not theoretical character students may see how science works in a practical setting and in this way gain a better idea of the working practice of a scientist.

In Go-Lab all these goals may play a role, some of them more prominent than others. In the current set of specifications there is no distinction between the different learning goals but for follow-up versions different types of guidance or scenarios can be set up to specifically suit a learning goal or sets of learning goals.

In the next sections we move to an inventory of inquiry cycles and guidance and present choices made for the first Go-Lab learning spaces prototype.

3 Inquiry phases and pathways

Inquiry learning with online labs is central to Go-Lab. The Go-Lab learner interface will therefore be based on an inquiry cycle and guide learners through different steps of the cycle. To synthesize an inquiry cycle most suitable for the diversity of online labs we expect to be included in the Go-Lab, we conducted a literature survey. On the basis of this survey a Go-Lab inquiry cycle was formed by combining the core of existing inquiry cycles. We present this cycle in Section 3.2 and indicate the different possible pathways through the cycle in Section 3.3.

3.1 Literature review process

In order to design a scientifically justified list of inquiry phases for the Go-Lab environment a literature review was conducted. The review focused on clarifying the most common phases or stages (usually used as synonyms) applied in inquiry-based learning. The EBSCO host Library (referring to Academic Search Complete, Central & Eastern European Academic Source, E-Journals, ERIC, PsycARTICLES, PsycINFO, Teacher Reference Center) was used to access scientific papers under the search terms: *inquiry phases; inquiry stages, inquiry cycle; inquiry models, inquiry learning processes, inquiry-based learning.* The search for articles was based on the following criteria: 1) boolean or phrase search mode; 2) related words applied; 3) search within the full text of the articles; 4) full text available; 5) published since 1972 (the earliest year available); 6) academic journals as a source type. According to the search criteria 60 papers were found; according to deeper analysis 32 out of them described inquiry phases or stages and were included in the comparative analysis. An overview of these papers is presented in Appendix 1. A comparative analysis of the articles was carried out to extract an overview of common phases, and based on that an inquiry-based learning framework is proposed. In the following section the results of the analysis are discussed.

3.2 Phases of inquiry learning based on literature review

According to the comparative analysis of papers found by systematic search, at least 109 slightly different but often overlapping terms for phases of inquiry-based learning can be distinguished. Several similar phases were labelled with different terms by different authors. Therefore, it was necessary to group similar phases using consistent criteria and suitable terminology.

Based on the initial analysis, the following eleven common and most frequent phases were identified: *1) Orientation, 2) Question, 3) Hypothesis, 4) Planning, 5) Observation, 6) Investigation, 7) Analysis, 8) Conclusion, 9) Discussion, 10) Evaluation, 11) Reflection*. However, it was not reasonable to rely on eleven phases, because inquiry learning is often referred as a complex and difficult learning process for the learners (de Jong & van Joolingen, 1998). Also, too many phases and activities may significantly increase students' cognitive load preventing a successful learning process (Paas, Renkl, & Sweller, 2003). Therefore, the initial list of eleven inquiry phases was reduced, not by eliminating any particular phase, but by doing an in-depth analysis to organize similar phases into groups (e.g., Plan, Observation, Analysis were re-grouped under Exploration, Experimentation, and Data analysis and all three of these phases were grouped under Investigation). The reason for performing this grouping was to accommodate different learning pathways applicable in the context of inquiry-based learning scenarios for the Go-Lab.

The analysis of descriptions and definitions of inquiry phases presented in the papers, and discussions held in Work Package 1 meetings resulted into five general inquiry phases that will be applied in the Go-Lab learning environment (see Table 1 for definitions): *Orientation,* *Conceptualisation, Investigation, Conclusion,* and *Discussion.* In the following, descriptions of each phases and sub-phases involved are presented.

Orientation is focused on stimulating students' interest and curiosity towards the problem at hand. During this phase the learning topic is introduced by the environment or given by the teacher or defined by the learner (Scanlon, Anastopoulou, Kerawalla, & Mulholland, 2011). In the *Orientation* phase the main variables of the domain are identified. The outcome of the *Orientation* phase is a problem statement in the form of an abstract overview of the domain and the issues involved.

Conceptualisation is a process of understanding a concept or concepts from the stated problem and is divided into two (alternative) sub-phases, *Question* and *Hypothesis*. The reason for merging these sub-phases relies on the fact that the outcomes have similar components. They both are based on theoretical justifications and contain independent and dependent variables. However, the presence of a hypothetical direction of the relation between variables that is given in the hypothesis is not present in the case of research question (Mäeots, Pedaste, & Sarapuu, 2008). In general, hypothesizing is a formulation of a statement or a set of statements (de Jong, 2006b), and questioning in this context is a formulation of investigable questions (White & Frederiksen, 1998). Thus, the outcomes of the *Conceptualisation* phase are research questions and/or hypotheses that will be investigated next.

Investigation is the phase where the curiosity is turned into action in order to respond to a stated research question or hypothesis (Scanlon, et al., 2011). Students design plans for experiments, investigate by changing variable values, explore (observe), make predictions, and interpret outcomes (de Jong, 2006b; Lim, 2004; White & Frederiksen, 2005). The sub-phases are *Exploration*, *Experimentation*, and *Data interpretation*. In general, *Exploration* is a systematic way of carrying out data manipulation with the intention to find indications for a relation between the variables involved (Lim, 2004). In *Exploration* there is no specific expectation of the outcome of the data manipulation and *Exploration* naturally follows the *Question* phase. *Experimentation* concentrates on developing and applying a plan for a data manipulation with a specific expectation of the outcome in mind and naturally follows the *Hypothesis* sub-phase. Both sub-phases, *Exploration* and *Experimentation*, consist of the design and the actual execution of the activities. If the domain requires that actual equipment or material is used, the choice for the material and equipment is part of the design in the *Exploration* or *Experimentation* sub-phases. The *Data interpretation* sub-phase focuses on making meaning out of collected data and a synthesis of new knowledge (Bruce & Casey, 2012; Justice et al., 2001; Lim, 2004; White & Frederiksen, 1998; Wilhelm & Walters, 2006). The final outcome of this phase is an "interpretation" of the data (the relations between variables).

Conclusion is a phase for stating the basic conclusions of a study (de Jong, 2006b). In this phase learners address their original research questions or hypotheses and consider whether these are answered or supported by outcomes of the investigation (Scanlon, et al., 2011; White, Shimoda, & Frederiksen, 1999). It leads to new theoretical insights – a more specific idea is created on the relation between variables (following Question) or whether the hypothesis is supported by the results of the study (following *Hypothesis*). The outcome of the *Conclusion* phase is a final conclusion about the study responding to the research questions or hypotheses.

Discussion is sharing one's inquiry process and results and contains the sub-phases *Communication* and *Reflection*. *Communication* can be seen as a process where students present and communicate their inquiry findings and conclusions (Scanlon, et al., 2011), while listening to others and articulating one's own understandings (Bruce & Casey, 2012). *Reflection is* defined as the process of reflecting on the success of inquiry while proposing new problems for a new inquiry and suggesting how the inquiry process could be improved (Lim, 2004; White

& Frederiksen, 1998). Reflection is also defined as receiving feedback (from students themselves, teachers or peers) with the idea of improving this (sub-)phase or the whole inquiry process in a next trial. Both Discussion sub-phases can be seen at two levels – discuss or reflect the whole process at the end of the inquiry or in relation to every other phase during the inquiry.

Table 1. The Go-Lab inquiry phases

General phases	Definition	Sub-phases	Definition
Orientation	A process of stimulating curiosity about a topic and addressing a learning challenge through a problem statement.		
Conceptualisation	A process of stating questions and/or hypotheses.	Question	A process of generating research questions based on the stated problem.
		Hypothesis	A process of generating hypotheses to the stated problem based on theoretical justification.
Investigation	A process of planning, exploration or experimentation, collecting, and analysing data based on the experimental design or exploration.	Exploration	A process of systematic and planned data generation on the basis of a research question.
		Experimentation	A process of designing and conducting an experiment in order to test a hypothesis. In experimenting students also make a prediction of the expected outcome of an experiment.
		Data interpretation	A process of making meaning out of collected data and synthesizing new knowledge.
Conclusion	A process of making conclusions out of the data. Comparing inferences based on data with hypotheses or research questions.		

Discussion	A process representing findings by communicating to others and controlling the whole learning process by using reflecting activities.	Communication	A process of presenting results of an inquiry phase or of the whole inquiry cycle to others and collecting feedback from them.
		Reflection	A process of describing, critiquing, evaluating and discussing on the whole inquiry process or on a specific phase.

3.3 The Go-Lab inquiry pathways

Based on the proposed overview and Work Package 1 discussions about the inquiry-based learning phases and their definition an inquiry-based learning framework for the Go-Lab learning environment was developed (see Figure 1). In this figure the three main possible inquiry pathways are indicated with arrows:

a) Orientation—Question—Exploration—Data Interpretation—Conclusion;

b) Orientation—Hypothesis—Experimentation—Data Interpretation—Conclusion; and

c) Orientation—Question—Hypothesis—Experimentation—Data Interpretation—Conclusion.

The *Discussion* phase can be seen as a process that is "optional" in the inquiry cycle, while in the individual learning process inquiry outcomes can be reached without any discussion. However, the quality of the whole inquiry and related learning gain can depend on the discussions in each inquiry phase and/or after completing all other phases. Several authors have defined *Discussion* as a phase of inquiry (Bruce & Casey, 2012; Conole, Scanlon, Littleton, Kerawalla, & Mulholland, 2010; Valanides & Angeli, 2008) while some others see *Conclusion* as a final stage of an inquiry learning process (de Jong & van Joolingen, 1998; National Research Council, 1996; Tatar, 2012).

Based on the analysis, the inquiry-learning process should start with *Orientation*, where students are introduced to the problem but also get an idea about the lab that is applied in the learning scenario. In the following step, students have two possibilities. Either they have an idea on what to investigate (so the phase is hypothesis driven) or they start from a more open question(s) only (in which case the inquiry is more data driven). Depending on the way the experiment is designed it may differ between both occasions: question preceding exploring and hypothesizing preceding experimenting. In any case, *Data interpretation* is the next step. Here, the students analyse their data on specific methods planned in the *Exploration/ Experimentation* phase and make their first interpretations of the data. From the *Investigation* phase it is possible to move forward to the *Conclusion* phase or go back to the *Conceptualisation* phase. If the student got all necessary data for confirming his/her hypothesis or answers to the stated question(s), then she/he moves to the next phase stating final conclusions (essentially output of the *Conclusion* phase is compared with output of the *Conceptualisation* phase). In case the data-collection was not as successful as planned the student can go back to the Conceptualisation phase to re-state question(s) or hypotheses, which is as a new input for the *Investigation* phase. However, going back to the *Conceptualisation* phase does not have to be always caused by unsuccessful data. Moving back may also rely on new ideas, which came out of the collected data.

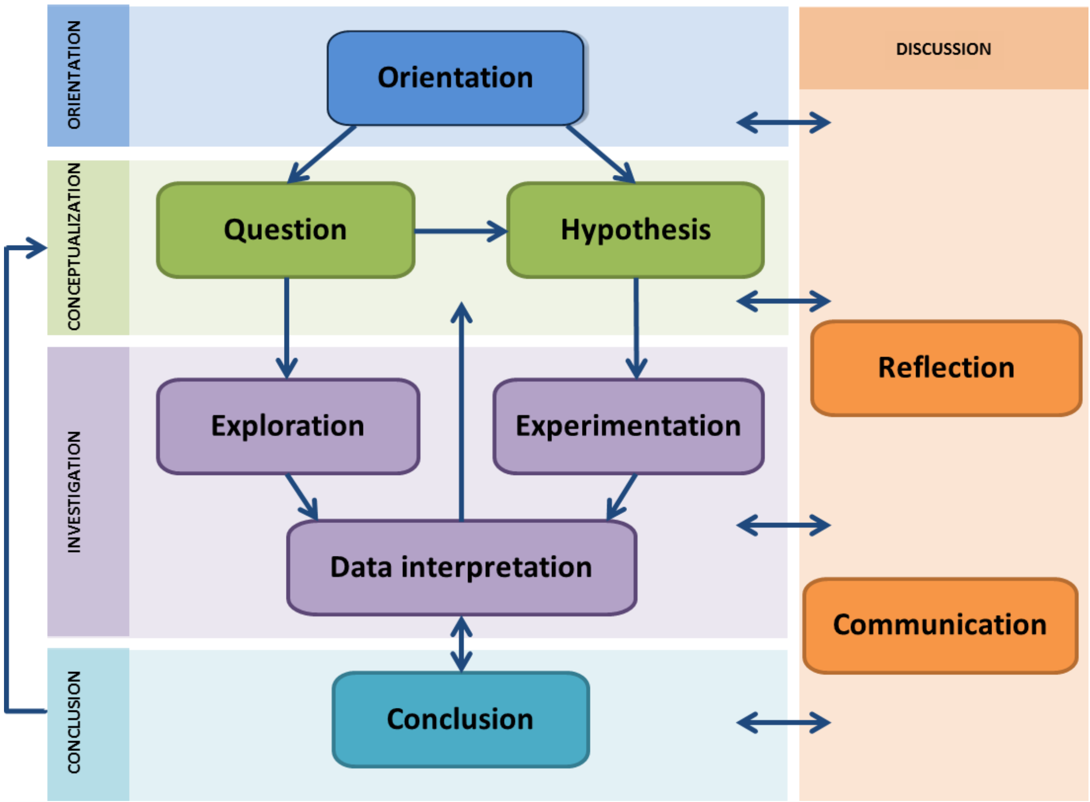


Figure 1. Inquiry-based learning framework and possible pathways in Go-Lab (general phases are shown with capitalized letters)

All the phases described above are related to the *Discussion* phase consisting of two sub-phases of *Reflection* and *Communication*. These phases help students to get feedback about their learning process and results by discussing with others (e.g., fellow students, the teacher, or other peers) and think about their learning by using activities of reflection.

It should be emphasized that the pathways indicated above should be seen a “norm” pathways. The actual sequence that students will follow depends on the scenario that is used. So, a scenario may prescribe a completely linear inquiry cycle and thus limits the number of phase or sub-phase transitions, it may ask students to start with a some exploration, or s/it may allow complete freedom for students to move more freely between phases and sub-phases.

4 Guidance for inquiry learning

The literature is very clear on the role of guidance for inquiry learning: guidance is needed to make inquiry learning effective (Alfieri, et al., 2011; de Jong, 2006a; Eysink, et al., 2009). In Go-Lab we will provide students with guidance in all phases of the inquiry cycle. Guidance consists of different components possibly in combination. Which guidance will be made available to the students is a teacher's/designer's choice and may depend on the knowledge and skills a student brings to the task. In a later stage of Go-Lab we will make guidance adaptive to the learner's behaviour.

Guidance has a specific form for each of the (sub-)phases in the inquiry cycle, it can be present or absent depending on the choice of the designer/teacher, it can sometimes be presented in combination (e.g., a scaffold with built-in heuristics), it can be stated in a general way or be very specific for the domain at hand and it needs to be combined in one interface with the laboratory itself.

In this chapter we first present a typology of guidance (based on de Jong & Lazonder, in press). Then we describe how the literature search has been conducted and display the quantitative results in a table. After this, we highlight some types of guidance per phase from the inquiry cycle.

In Appendix 2, the full overview of guidance as we found it in the literature is presented. Here, the types of guidance are taken as the starting point and examples of these types of guidance are presented per phase form the inquiry cycle. How this results in a specification for the Go-Lab leaning spaces can be found in Section 5.

4.1 Types of guidance

Guidance can take different forms. The next typology guidance is based on how much the guidance interferes with the students' own initiative. Some types of guidance just inform students about their results and process and students have to this information themselves to adapt their inquiry behaviour (performance dashboard), some types of guidance give students a specific direction on what to do (e.g., prompts (in their more specific form also called exercises or assignments)) or do so by restricting students' activities (process constraints), some types of guidance provide students only with suggestions on what to do (heuristics), some types of guidance give student support in performing a specific activity (scaffolds) and others even take over the activity of a student by presenting a desired outcome (direct presentation of information). What type of guidance is required for a student depends on the interaction between the student (knowledge and inquiry skills) and the domain. In the final version of the Go-Lab learning environments each type of guidance can be switched on and off by an editor of the Go-Lab learning spaces (teacher, lab provider, designer).

4.1.1 Process constraints

Process constraints aim to reduce the complexity of the discovery learning process by restricting the number of options students need to consider. This type of guidance should be used when students are able to perform the basic inquiry process, but still lack the experience to apply it under more demanding circumstances. When students gain experience the constraints can gradually be relaxed. Model progression, in which a domain is first presented in a restricted form and the complexity is gradually increased, is probably the best-known example of a process constraint (Mulder, Lazonder, & de Jong, 2011).

4.1.2 Performance dashboard

A performance dashboard helps students gain insight in their own learning process or in the quality of their learning products and outcomes. A performance dashboard should be presented to students who can be assumed to know how to follow up on the information they receive. An example of a performance dashboard is presenting the student with an overview of the variables from the domain that have included in an exploration or experiment or an overview of parts of the domain that have been visited by the learners (Hagemans, van der Meij, & de Jong, 2013).

4.1.3 Prompts

Prompts/hints are reminders or instructions to carry out a certain action or learning process. Prompts are given to students who are (expected to be) capable of performing that action but may not do so on their own initiative. An example of a prompt is: “Do you think your results will differ compared to your last experiment? Why?” (Wichmann & Leutner, 2009, p. 121). Prompts may also be more specific and take the form of small assignments or exercises that tell students what to do in a certain phase of the inquiry cycle. For example, an assignment may tell a student to perform a specific experiment, ask the student for the outcome in a multiple-choice way and give feedback to the student’s choice (Swaak, van Joolingen, & de Jong, 1998).

4.1.4 Heuristics

Heuristics give students general suggestions on how to perform a certain action or learning process. They remind students of a particular action and, in addition, point out possible ways to perform that action. Heuristics should therefore be used when students are unlikely to know exactly when and how an action or learning process should be performed. An example of a heuristic is telling students that a neat experiment follows the CVS strategy (CVS stands for Control of Variables, the strategy to change the value of only one variable at a time) (Veermans, de Jong, & van Joolingen, 2000; Veermans, van Joolingen, & de Jong, 2006).

4.1.5 Scaffolds

Scaffolds are tools that help students perform a learning process by supporting the dynamics of the activities involved. Scaffolds often provide students with the components of the process and thus structure the process. Scaffolds are appropriate when students do not have the proficiency to perform a process themselves or when the process is too complicated to be performed from memory (Marschner, Thillmann, Wirth, & Leutner, 2012). An example of a scaffold is a hypothesis scratchpad (van Joolingen & de Jong, 1991) but also a modelling tool or an experiment design tool can be regarded as scaffolds (Jackson, Stratford, Krajcik, & Soloway, 1996).

4.1.6 Direct presentation of information

Scientific discovery learning, by definition, requires that the learning content is not explicitly presented to students. But when students have insufficient prior knowledge or are unable to discover the target information on their own, (parts of) this information can be offered before or during the learning process. After having seen the information, students may then further explore and check the information in the discovery environment (Hmelo-Silver, Duncan, & Chinn, 2007).

4.2 Literature review process

For the purpose of identifying possible guidance, a literature search was carried out, between November and July of 2013, using different databases such us Google Scholar and Web of Science (EBSCOhost EJS, Academic Search Complete, MasterFILE Premier, Psychology & Behavioral Sciences Collection, Hellenic Academic Libraries Link, OmniFile Full Text Select, ERIC, Taylor & Francis Education Collection, etc.). Using terms such as *science inquiry learning scaffolds, scaffolding tools, cognitive scaffolds, scaffolding process, inquiry cycle support, heuristics, prompts, learning scaffolds and inquiry based scaffolding*, a total of 54 manuscripts (scientific articles, books, book chapters, proceedings of national and international conferences, PhD dissertations and websites) were selected and reviewed during the first literature search. Further review of the bibliography of the 54 manuscripts selected during the first search pointed to related literature on guiding tools for computer-based learning. Additionally, 29 more manuscripts were selected and reviewed for this purpose. Overall, a total of 83 manuscripts were reviewed.

The results of the review were separated into the six types of guidance identified in Section 4.1: *process constraints, performance dashboard, prompts, heuristics, scaffolds, and direct presentation of information*. The results of the literature review for all six categories are presented in Appendix 2. Each category is further divided into subcategories that correspond to the phase of the inquiry cycle described above in Section 3.2 (*Orientation, Conceptualisation, Investigation, Conclusion, and Discussion*). While in some cases the literature clearly defined the phase the guidance belongs to, in others it the classification was less obvious. In addition, in a number of cases the guidance found was applicable in more than one phase, thus, could not be clearly classified. Appendix 2 presents a brief description of the guidance, along with the results of evaluations (where available) of the applicability and effectiveness of the guidance.

Over all, a total of 86 guidance examples were found; 9 process constraints, 3 performance dashboards, 16 prompts, 24 heuristics, 28 scaffolds and 6 direct presentation of information, addressing all five phases of the inquiry cycle of Go-Lab (see Table 2). While developed for a specific task, the majority of the guidance (29 examples) seems to be applicable in more than one of the five phases. More specific, the *Investigation* phase had the most with 27 types of guidance, while the remaining four phases, *Conceptualisation, Conclusion, Discussion* and *Orientation,* had much less with 12, 7, 6, and 5 types of guidance respectively. A summary overview is given in Table 2.

Table 2. Overview of guidance per phase of the inquiry cycle

	Types of Guidance						
Phases	Process constraints	Performance dashboard	Prompts	Heuristics	Scaffolds	Direct presentation of information	**Total**
Orientation	1	-	-	-	3	1	**5**
Conceptualisation	1	-	1	4	4	2	**12**
Investigation	4	1	5	13	4	-	**27**
Conclusion	-	1	2	1	3	-	**7**
Discussion	-	-	2	2	1	1	**6**
Multiple Phases	3	1	6	4	13	2	**29**
Total	**9**	**3**	**16**	**24**	**28**	**6**	**86**

In the next section we present of first selection of scaffolds that could fit in Go-Lab's learning environment and we propose combinations of scaffolds for each of the five phases of the inquiry cycle. One of the selection criteria was if the type of scaffold was proven to be effective or, alternatively, that we saw ways to improve the scaffold. Further, the scaffolds also needed to have an overall coherence. The selection presented here formed the basis for developing the first set of guidance as specified in Section 5. In this guidance, apart from scaffolds also prompts/assignments, heuristics, direct presentation of information and performance dashboards will appear. In a later stage, also after having performed evaluations with Go-Lab prototypes, we will redesign the Go-Lab guidance with this literature overview as a background again.

4.3 Guidance and the inquiry cycle

4.3.1 Orientation

In the *Orientation* phase students create a first rough idea of the domain based on available information. In this context a more holistic guidance such as the SEEK tutor (Graesser et al., 2007) seems valuable. Using the SEEK tutor students can be guided through the search of information, evaluate/rate the information collected and take notes about the reliability of the sources. Using a concept-map template (MacGregor & Lou, 2004) students can connect the information they acquired with major relevant concepts. In addition, an Articulation box like the one in the Model-It software (Krajcik, n.d.) would encourage them to articulate their reasoning when creating relations (Fretz et al., 2002). In the occasion Go-Lab provides the information to the students (e.g., a library of websites), then “Artemis” (Butler & Lumpe, 2008) can be an option for students to search and sort information Artemis software contains search, saving and viewing, maintenance, organizational and collaborative scaffolding features.

4.3.2 Conceptualisation

When students enter the *Conceptualisation* stage without specific ideas of the relations between concepts they create questions or state “issues” (de Jong, 2006b). If they do have ideas they may create a set of hypotheses as a starting point for the next phase. To create hypotheses the most known tool is a “Hypothesis Scratchpad” (SimQuest) which allows students to compose hypotheses from separate elements such as variables, relations, and conditions (van Joolingen & de Jong, 2003). A similar scaffold can be found in WISE (Slotta, 2004) and in the work of Sao Pedro, et al. (2013). Another option is to provide students with complete, pre-defined, questions or hypotheses (de Jong, 2006b).

4.3.3 Investigation

In the investigation phase students collect data in relation to their questions or hypotheses. In this phase students start to really interact with the online lab. To engage in a sensible *Investigation* process they need sufficient prior knowledge. One way to test this is “Experiment prompting” (Chang, Chen, Lin, & Sung, 2008) which ensures that students do not proceed without sufficient background knowledge. Further, students can be supported in identifying the independent and dependent variables and their relations. A scaffold like “Dynamic Testing” (Model-It software) helps the students in doing so. This scaffold allows students detect any errors and proceed with corrections (Fretz, et al., 2002). In combination with the “Monitoring tool” (Veermans, et al., 2000), 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 (van Joolingen & de Jong, 2003). Finally, the “Data Interpretation” scaffold (BGuILE) can ask students questions to guide their interpretation of the data (Smith & Reiser, 1997).

4.3.4 Conclusion

During the conclusion phase, the “Prompts for writing scientific explanations” helps students write scientific explanations following the structure claim-evidence-reasoning (McNeill, Lizotte, Krajcik, & Marx, 2006). In each of the three elements they are provided with related prompts. In addition, using the “Investigation journal” (BGuILE), students are required to connect their data with their explanations, linking their claims with the evidence collected during their investigation (Reiser et al., 2001).

4.3.5 Discussion

Guidance relevant to the *Reflection* phase are the “Evidence Palette and Belief Meter” (Lajoie, Lavigne, Guerrera, & Munsie, 2001). Using the two scaffolds, the students are encouraged 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. In addition, using the “Argumentation Palette” (Lajoie, et al., 2001) students will be able to justify their conclusions by comparing them with those of experts, thus, reflecting on their own argumentation process. The two types of guidance could be combined for deeper student reflection.

4.4 Personalized guidance in Go-Lab

In Go-Lab guidance should be personalised. This means that based on settings of the teacher before students start with their Go-Lab experience guidance can have different forms. As an example, hypotheses can be directly offered to students in a ready-made form (direct presentation of information), students can be supported in the form of a scaffold (that helps them create a hypotheses from different elements) or students can only be prompted that they should create a hypotheses. These types of guidance need an increasingly competent and informed student. Teachers can determine this before students start and fix the type of support.

5 Go-Lab learning spaces specifications

The next section presents the Go-Lab learning spaces specifications. These specifications reflect the conclusions from our literature review for both the inquiry cycle and the guidance that will be provided to students (the guidance may still be developed based on the on-going literature examination. Moreover not all the conclusions drawn are currently included in the specifications). The specifications are presented through an on-line mock-up[1] from which examples are included in the current document. Each set of mock-ups demonstrates an activity which includes one of the three prototype labs that have been selected as the initial anchor labs at the start of the project: Aquarium (Buoyancy/Archimed's law), Faulkes Telescopes (Interacting Galaxies), and HYPATIA (Conservation of momentum). These labs are representatives of different kinds of online labs, namely, remote labs (Aquarium, Faulkes), virtual experimentations (Aquarium; available soon), and data sets with associated analysis tools (HYPATIA). These labs also cover a wide age range and different subject domains: Aquarium (approximately ages 10-14), Faulkes Telescopes (10-18) and HYPATIA (16-18).

In the following sections we present the current specifications of the Go-Lab learning spaces. We first (Section 5.1) present the starting points for the design of the learning spaces which then are illustrated in a pictorial sketch of the Go-Lab learning spaces (Section 5.2) for which we have taken one of the anchor labs (Aquarium) as an example. Then we present a brief overview of the three anchor labs (Section 5.3) which is followed by a detailed view on each phase of the inquiry cycle illustrated in each of the three anchor labs.

5.1 Design specifications starting points

One of the first decisions that was taken during the design process concerned the *different elements* that were to be included in the learning spaces. These are:

- The different phases of the inquiry cycle;
- Different types of guidance. We decided, for each phase, to have a) an element explaining the phase and presenting assignments/prompts on what to do in this phase b) an element presenting heuristics and/or domain information c) a tool/scaffold that helps students perform the activity for the specific phase, d) to have an element in which to present feedback to a student (performance dashboard). Process constraints are not directly visible, for example if students can only manipulate a restricted number of variables this is a process constraint, that they will not recognize directly;
- Generic tools displayed in all the phases of the inquiry cycle. For the moment the generic tools include: a calculator, a notepad, a formula creator, and a chat facility;
- Manual(s) for students to facilitate them in using the labs and the different scaffolds;
- Phase-specific material such as explanatory texts, webpages, and videos.

For some elements (such as an inquiry cycle overview) it was decided to postpone their inclusion until after the first round of evaluation.

The next step concerned how these elements would be displayed within the learning space. The following decisions were made:

- Inquiry phases are presented in the form of tabs.
- The guidance will be in the form of two (clickable) boxes and a scaffold window. A box in the top of the window presents the assignments/prompts, a box in the lower part of the window presents the heuristics. Scaffolds/tools can be activated through a button in the

[1] See https://golab.mybalsamiq.com/projects/golab/naked/Go-Lab+Portal?key=a0502e554e2838fc744d76bd45773aab6d5ea442

bottom menu. The performance indicator will appear as a pop-up window when students press the "feedback"-button of the scaffold/tool.

- The generic tools and the manuals will be available through a menu at the bottom of each page.
- Phase-specific materials will be accessible through an "About…" button at the menu at the bottom of each page. Scaffolds, if closed, will also be accessible in the same way.

The third step was about outlining how students will navigate within the learning space. The following decisions were made:

- In this first version of the learning spaces students are able to navigate freely between the phases of the inquiry cycle.
- It is possible to transfer scaffolds automatically from one phase to another (for example the "Concept map" scaffold initially displayed in the *Orientation* phase will appear automatically in the *Conceptualisation* phase as well). Thus, students are provided with support during their learning process and with a consistent flow of information throughout the inquiry cycle.

Next, decisions were made on the specific form of the elements:

- The "assignment/prompts" and "heuristic" elements in the interface comprise of a generic part (that will be created by the Go-Lab team) and/or a domain specific part that needs to be created by a domain/instructional expert. The generic part displays a domain-free prompt or assignment of what should be done in a specific phase ("in this *Conclusion* phase you will …") or generic heuristics (e.g., "also try extreme values for your variables"). In the domain specific part subject specific assignments (e.g., "based on your calculations, draw the vectors for the momentum of each particle") or heuristics ("think about hypotheses that include density (mass/volume)). The prompts/assignment and heuristics boxes may display either the generic or the specific part or both. (The texts currently provided in the mock-ups are not final and will be subjected to further refinements.)
- Additionally, the features of the tools/scaffolds will also be further developed. For example, the exact use and form of the concept map (there may be a need to be make it more like a mind map or a runnable model) or which elements will be included in the hypothesis scratchpad (now based on variables and functions but this may take a very different form depending on the subject domain) maybe altered. Further developments will also be realized based on users' feedback.

In the future we will provide authoring facilities: 1) to include or leave out elements 2) to restrict or open movements of students through the environment 3) to add domain specific elements or to rephrase existing ones.

A final important point taken into consideration is that currently the team's focus is on creating a "complete" learning space. During the creation of full classroom scenarios, certain actions may be conducted outside the environment (in the classroom or during a field-trip). In this case, the related elements may not be included in the learning space. Additionally, after taking into consideration further personalization features some elements may be changed and presented dynamically.

5.2 An example interface illustrating the different learning space elements

Figure 2 presents an example interface in which all types of guidance are open. The *Conceptualisation* phase of the Aquarium lab as taken as an example. These are the elements represented:

- The inquiry cycle is represented as a set of tabs at the top of the interface.
- Guidance is presented in the following ways:
    - The "Instructions" box (top left) presents students with prompts/assignments. These instructions may be generic (indicating what should be done in a specific phase) or domain specific (informing students about what to do while using the specific lab).
    - The "Heuristics" box (bottom left) presents suggestions on how to proceed and what to take into consideration. This element may also present students with direct subject domain information in case they are not able to perform this part of the activity themselves. These "Instructions" and "Heuristics" boxes can be closed an opened by the students.
    - The "Hypothesis Scratchpad" scaffold is presented in a separate window (middle left). The "My Concept Map" scaffold (middle right) that was initially presented to students in the previous phase of the Inquiry cycle is also present in this phase. Students can drag and drop elements from that scaffold to their "Hypothesis Scratchpad". (In each phase a specific tool/scaffold will be present). Students have access to the scaffolds/tools through a button in the lower toolbar.
    - A performance dashboard is presented as a pop-up window. In case for example feedback on the quality of a concept map is given this will appear in a pop-up window (see Section 5.4.1).
    - Process constraints are not directly visible to students but they appear as limitations to what they can do. For example, in the Investigation phase the experimental design scaffold (see Section 5.4.3) may force students to vary only one variable at a time in order to introduce to them the "Control of Variables" strategy)only change the value of one variable at a time).
- The bottom toolbar presents additional functionality:
    - Buttons to access generic tools such as a calculator, notepad, and formula creator.
    - An "about …" button which gives access to background information about the domain
    - A button that gives access to the relevant scaffolds/tools.
    - A button to access products (e.g., hypotheses or experiments) that students have created
    - A button to access a chat function
    - A button that gives students access to manuals on how to operate the Go-Lab learning environment.

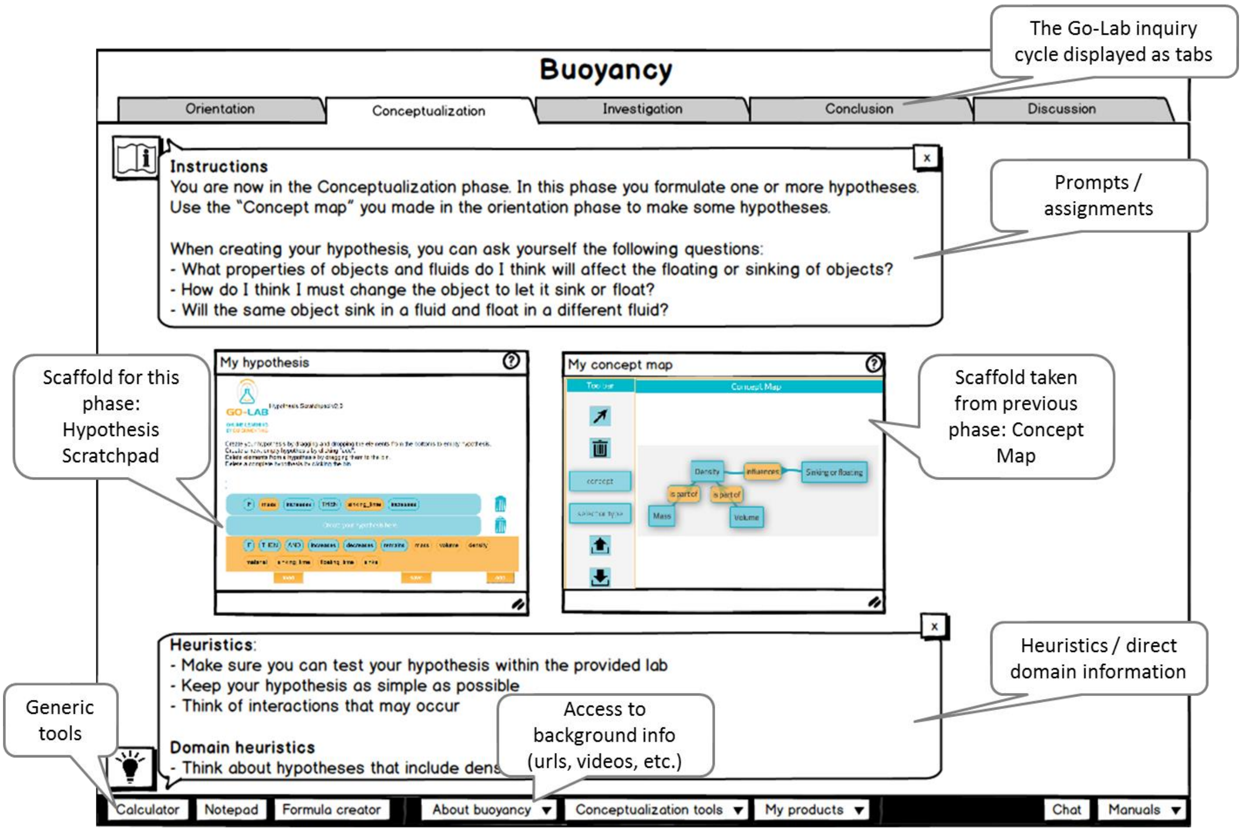
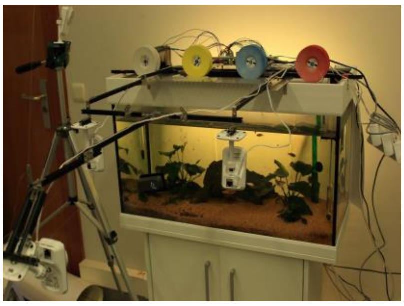


Figure 2. Example interface

5.3 *The Go-Lab prototype labs*

5.3.1 Aquarium (remote lab/virtual lab)

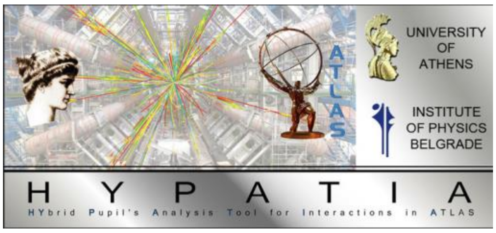


The aquarium lab is a remote lab situated in Bilbao (Spain) in which students can study Archimedes' principle (the upward force exerted on a body immersed in a fluid is equal to the weight of the fluid the body displaces). In this remote lab students can drop objects with different density and observe if they float or sink. In the future, this remote lab will be combined with a virtual lab that allows students to change the mass, the volume and the shape of solid objects, the type of fluid (water etc.) and observe the sinking or floating of objects and the respective fluid displacement.

5.3.2 Faulkes Telescopes (remote lab)

The Faulkes Telescopes are a network of two 2-metre telescopes, one located in Hawaii and one located in Australia. The two telescopes along with their data archives (which currently include more than 80.000 observations) are available for use to schools and other educational groups. This remote laboratory offers the opportunity to school classes to make their own observations of the night sky and thus exploring celestial objects like stars, galaxies, nebulas and many others. The lab is apt for use by students of any grade and depending on their age they may engage in various activities; from simple game-based activities to complex ones that are close to the work done by scientists. The use of the lab is also supported by a collection of astronomy-based school activities and supporting tools like image processing applications.

5.3.3 HYPATIA (data-set/analysis tool)

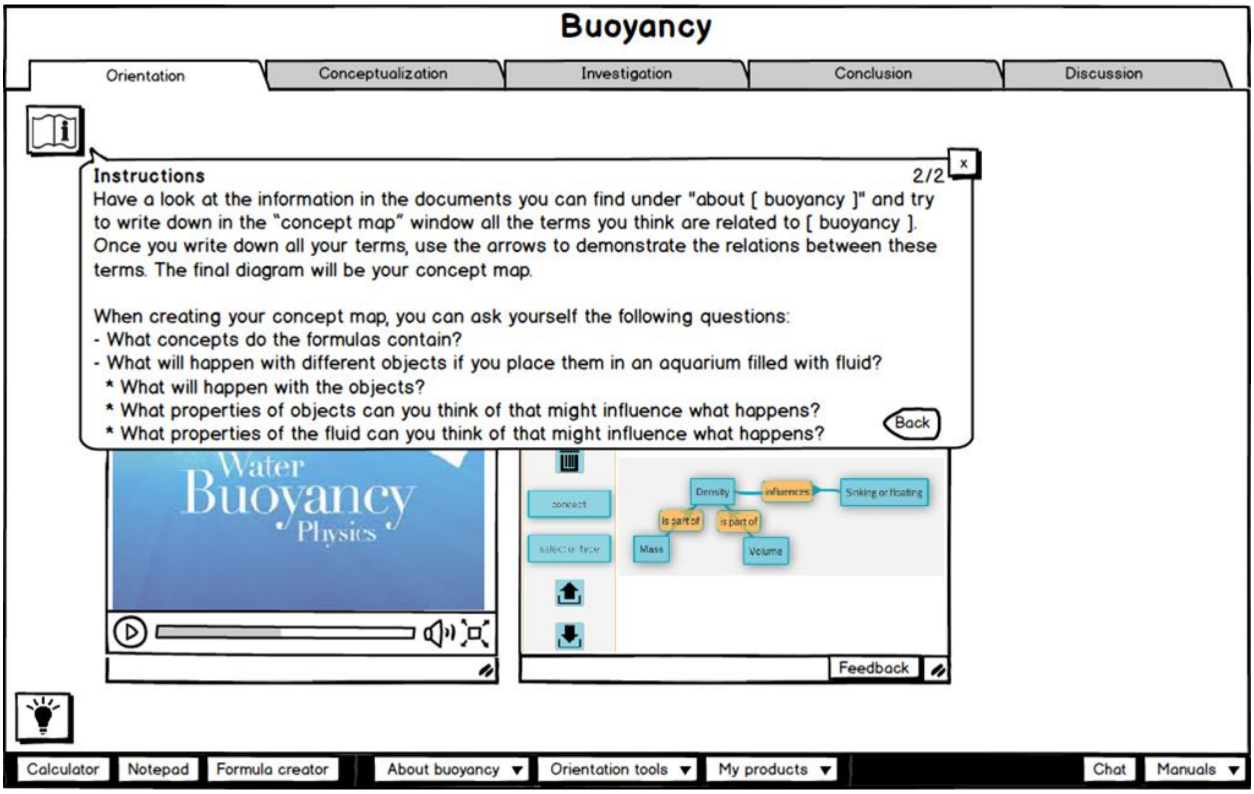


HYPATIA (**HY**brid **P**upil's **A**nalysis **T**ool for **I**nteractions in **A**tlas) is a 2D event analysis tool which allows students to use and manipulate data collected by the ATLAS experiment of the Large Hadron Collider (LHC) at CERN. Its goal is to allow high school and university students to visualize the complexity of the hadron - hadron interactions through the graphical representation of ATLAS. Students are given the opportunity to work with real scientific data and learn about the building blocks of matter. In parallel, the use of this online lab allows students to learn about fundamental principles in physics like the conservation of momentum or the conservation of energy while also practicing in mathematics.

5.4 The Aquarium lab

5.4.1 Orientation

In the *Orientation* phase students have to explore the subject of buoyancy by reading through texts and observing videos. Part of this material is open when students enter this phase. In the "Instructions" box students are invited to create a concept map based on this material. In Figure 3 students are provided with instructions while the "My concept map" tool is visible in the background. The concept map tool appears when the instructions box is closed.



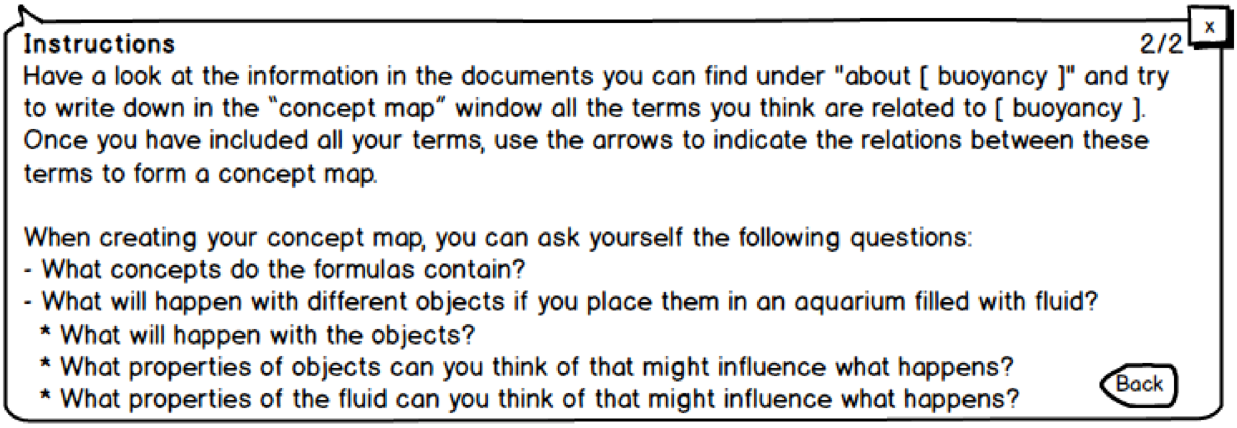


Figure 3. Orientation phase

Additional material can be accessed through the “About buoyancy” button at the bottom of the screen as shown in Figure 4. When materials are closed they can be retrieved through this button.

In the *Orientation* phase (Figure 4) students are presented with a preview of the online lab that they will have fully available in the *Investigation* phase.

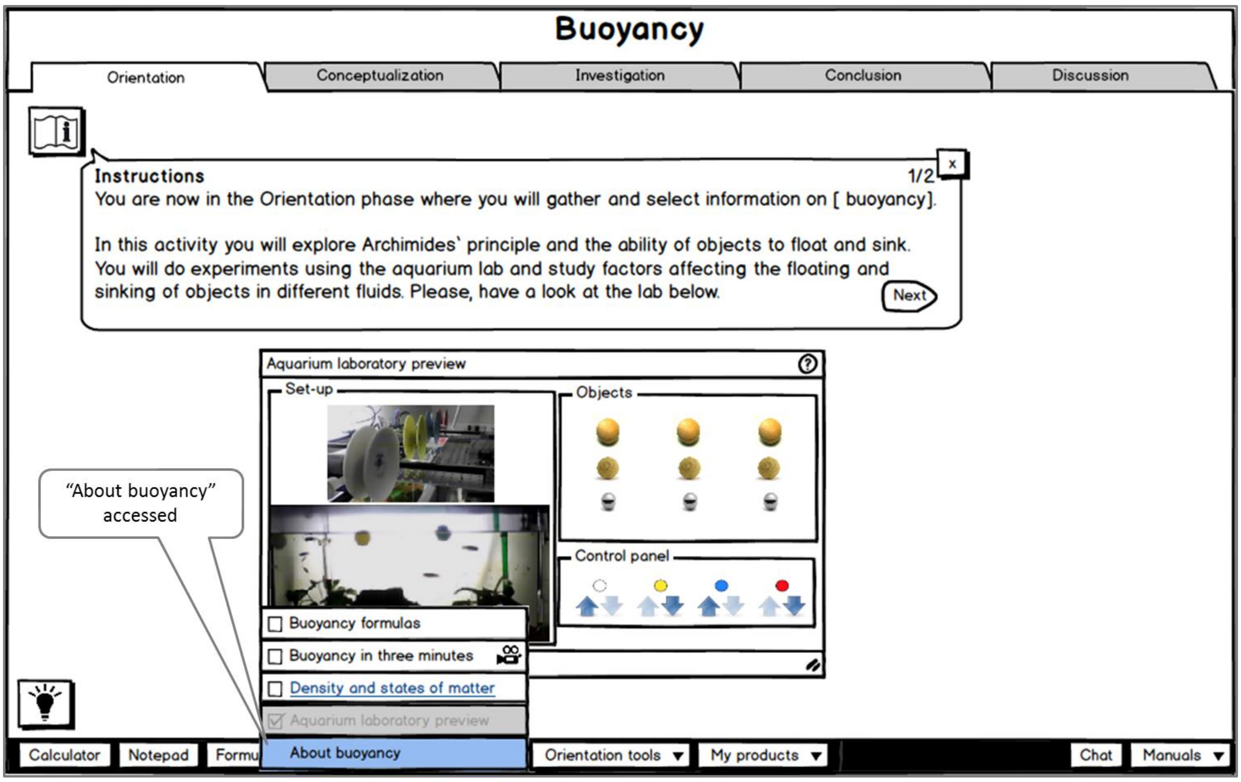


Figure 4. “About buoyancy” accessed

Students can request feedback on the products they create using the tools. Figure 5 shows an example of a “performance dashboard” that, in this case, informs students which elements might still be missing from a concept map that was created.

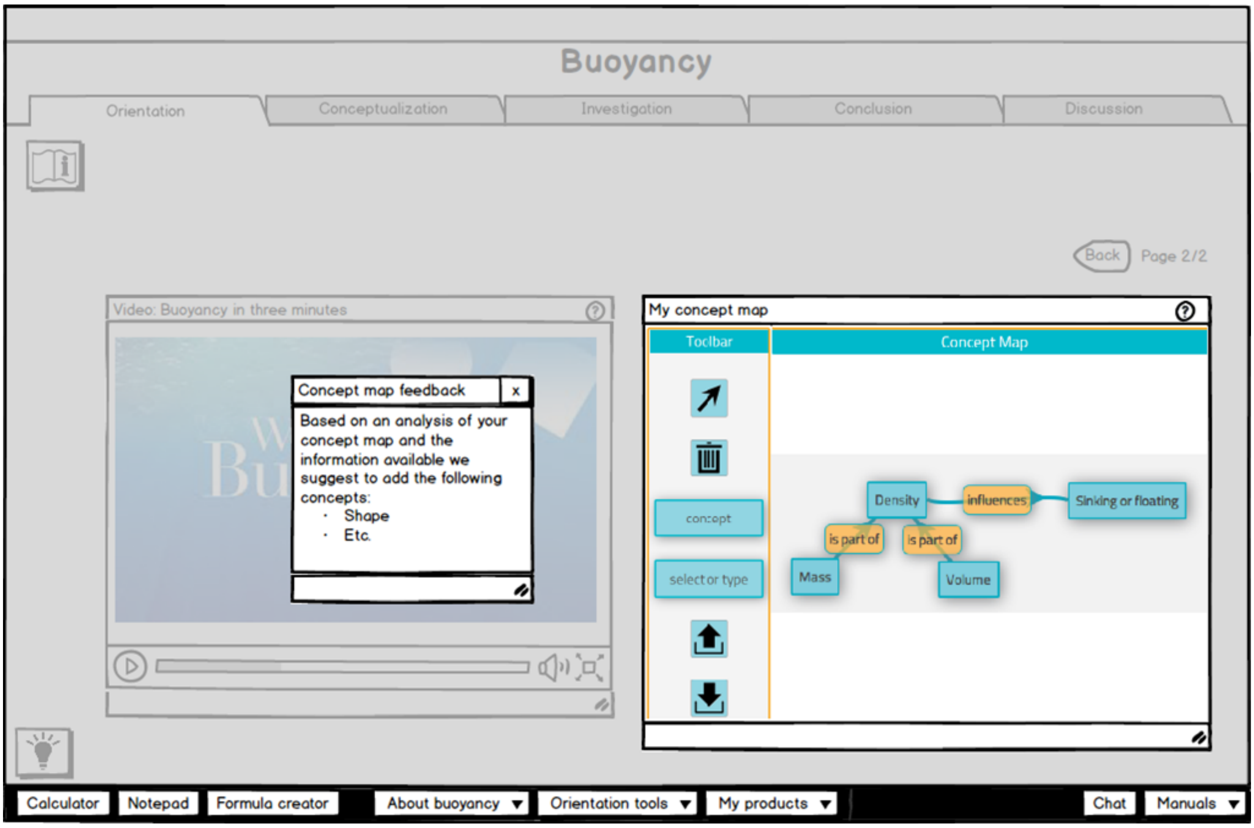


Figure 5. Performance dashboard providing feedback on the concept map

5.4.2 Conceptualisation

In the *Conceptualisation* phase students create hypotheses or research questions using the "*My hypothesis*" or the "*My Question*" tool[2]. When making hypotheses students receive instructions on how to create them while they are also able to use the concept map they created in the *Orientation* phase. Both the hypothesis tool and the concept map tool are presented when students first enter the Conceptualisation phase as shown in Figure 6. Students are instructed to use the concept map as a basis for creating their hypotheses with the hypothesis tool. They can drag and drop variables from one tool to the other.

At the bottom of the screen the "Heuristics" scaffold is displayed (marked with a light bulb). It provides students with heuristics of both general and subject domain specific nature, as well as tips on how to create hypotheses about buoyancy. If students wish to view and/or use the information about buoyancy as input for their hypotheses, they can access that information from the "About buoyancy" button included in the menu at the bottom of the screen like in the *Orientation* phase.

[2] At the moment the "question tool" has not been specified. This will be a variant of the "hypothesis tool" and will be available in a next version of these specifications.

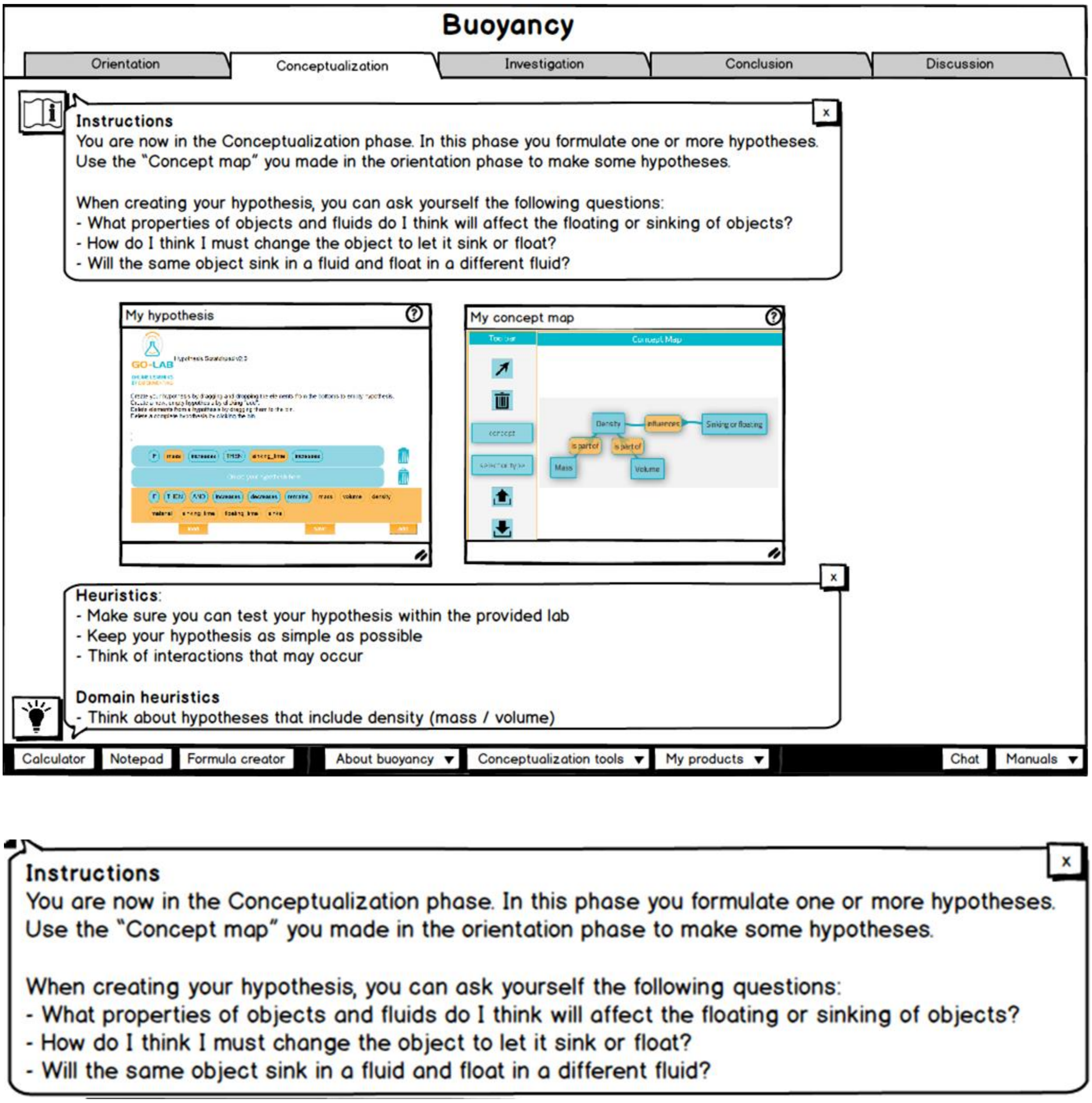


Figure 6. Conceptualisation phase

5.4.3 Investigation

In the *Investigation* phase students plan, conduct and analyse their experiment(s). An experiment consists of multiple experimental runs. An experimental run can be seen as one (set of) action(s) that results in one observation or measurement. For example, a wooden sphere of 300 cm^3 is dropped in the water during the first experimental run and the student observes whether it sinks or floats. Then, in the second experimental run, the student drops a wooden sphere of 200 cm^3 and again observes whether it sinks or floats.

As depicted in

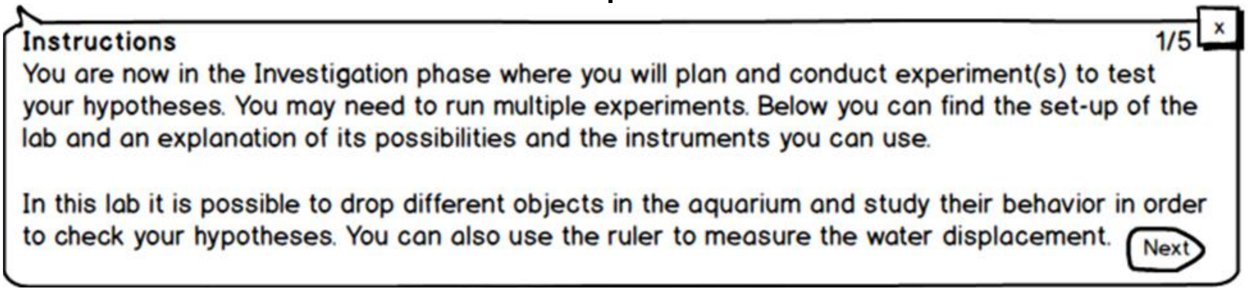
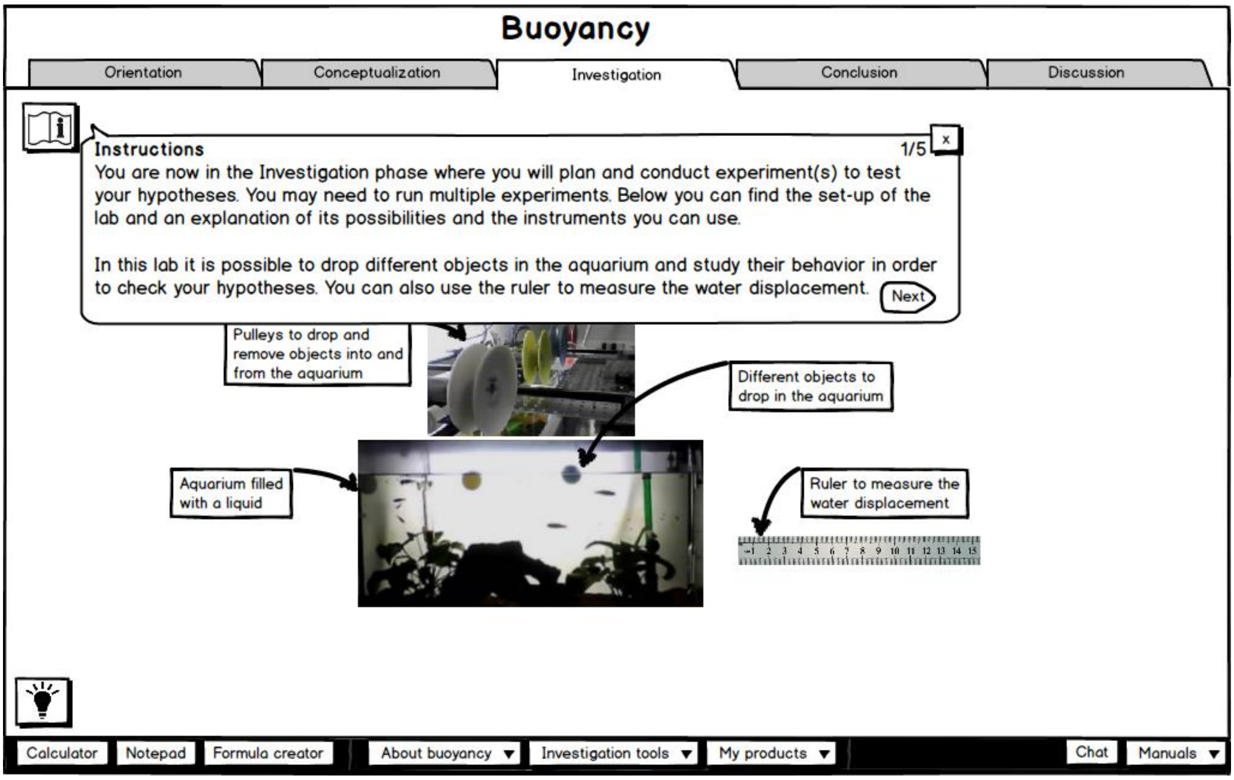


Figure 7, when students enter this phase, they are first presented with an instructional text about what the *Investigation* phase is about and what they can do with the online laboratory at hand. They see an image of the aquarium laboratory, the instruments they can use for their experiments and a brief explanation regarding the use of these instruments. Once they have viewed the laboratory they can continue on to the second of five pages where they can practice with the laboratory instead of simply viewing a still picture. This allows them to operate the lab, get familiarized with its functionalities and understand what they can and cannot do. After these preliminary stages in which students explore the laboratory, they move on and start planning their own experiment on the third page of the *Investigation* phase.



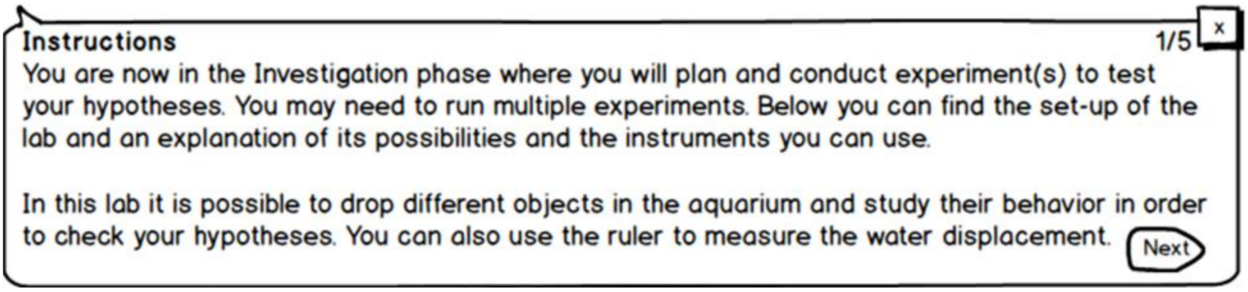


Figure 7. Explaining the laboratory in the Investigation phase

On the third page students are presented with the “Experiment design” tool and the “Hypothesis” tool that contains the hypotheses they created in the Conceptualisation phase as shown in Figure 8. The experiment design tool helps students plan their experiment in a structured and systematic manner. Students can see variables they can manipulate or measure. These variables are presented in a box at the right side of the experiment design tool window from which students can drag and drop variables one by one in the design space of the same window. For each variable they must decide if they want to vary it (independent variable), keep it the same across experimental runs (control variable), or observe or measure it (dependent variable). For example, if students want to observe the sinking or floating of objects, they can drag this variable from the variables box to the observe/measure box within the design space. If they want to change the mass of the objects across experimental runs, they can drag this variable to the vary box. The shape and volume can only be dragged to the “Keep the same” box in the design space in order to teach students the idea that during experimentation only one variable at a time should be changed. When students are done, they move to the fourth page of the *Investigation* phase.

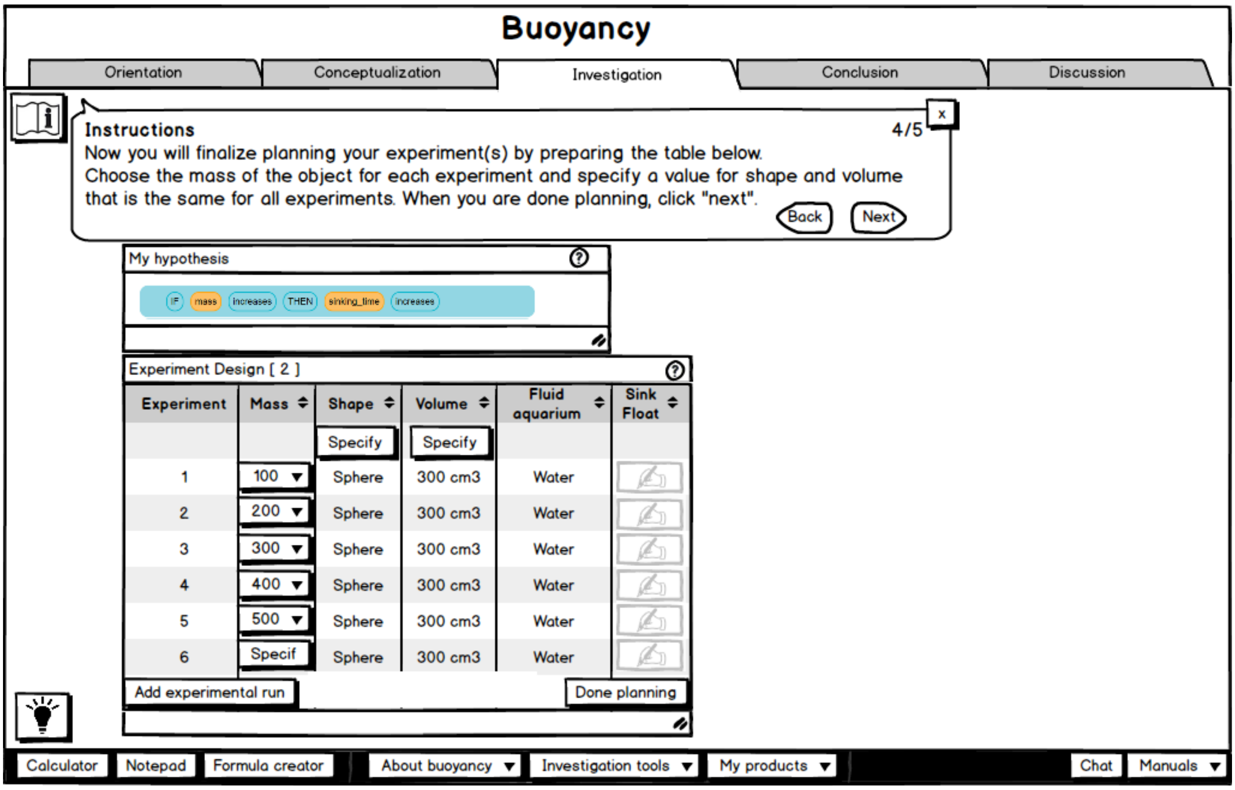


Figure 8. Specifying values in the Experiment design tool

Once the students have dragged all variables to the design space, they continue on to the next screen where they assign a value to each variable by means of selection (e.g., the shape can be a sphere and the volume can be 300 cm^3) in the “Experiment design” table, as shown in Figure 8. Students can assign one value per control variable that remains the same across all experimental runs within an experiment. Furthermore, they can assign a unique value to the independent variables for each experimental run. After filling out the table they continue by clicking “Done planning”.

In the final screen of the *Investigation* phase, students conduct experimental runs and fill out results in the Experiment design tool, as shown in Figure 9. After each experimental run, students write their observations and measurements in the table. Besides the presentation of the experimental data in the table on the right, students can also view the results in the form of a graph by clicking on the graph button at the bottom of the experiment design tool. Once students have conducted all the planned experiments, they can either draw conclusions or create a new hypothesis.

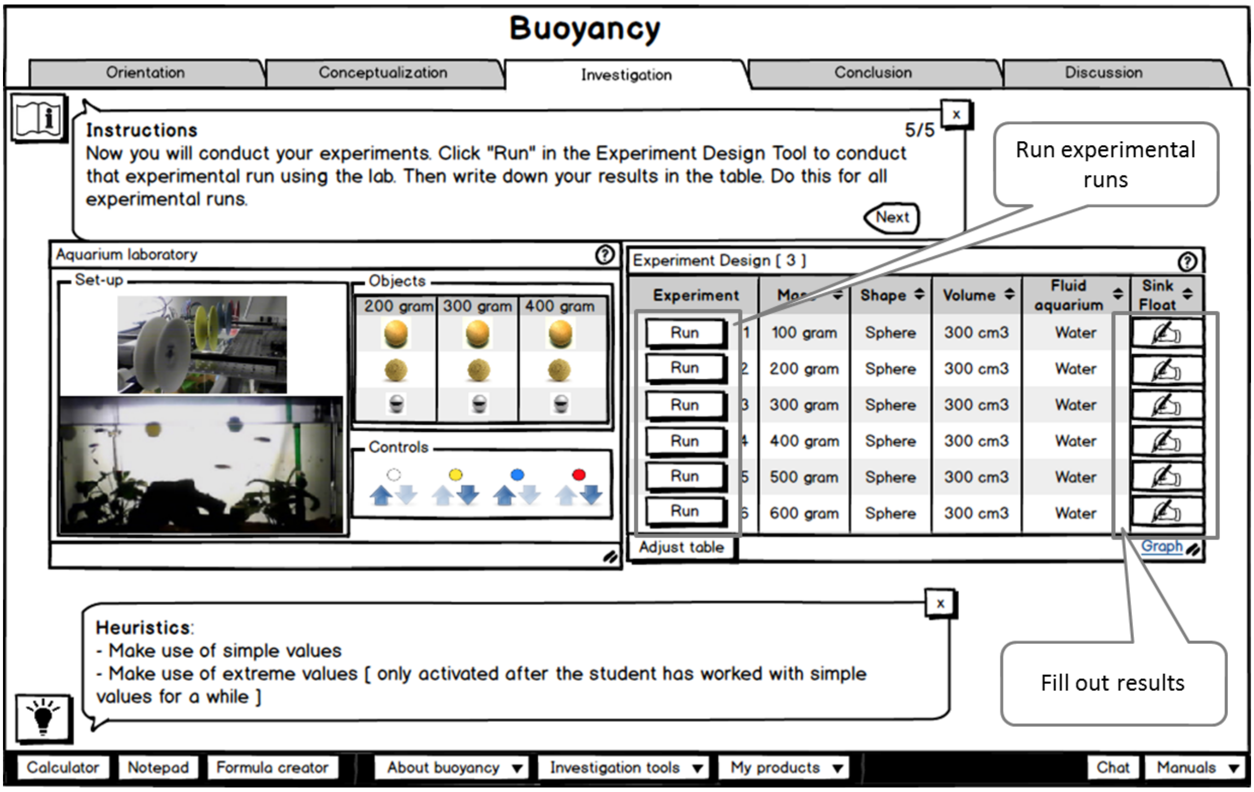


Figure 9. Run experiments and fill out results in the Investigation phase

5.4.4 Conclusion

In the *Conclusion* phase, students are guided to draw conclusions based on their hypotheses and data. When they enter the *Conclusion* phase they are presented the “Conclusions” tool with which they draw conclusions as shown in Figure 10. By means of drop-down menus students add a structured conclusion in which they indicate which experiment(s) or experimental set(s) verifies, rejects or doesn’t relate to the hypotheses. Furthermore, they are encouraged to express their conclusions in their own words. Students are also invited to specify the conditions under which their conclusions are valid.

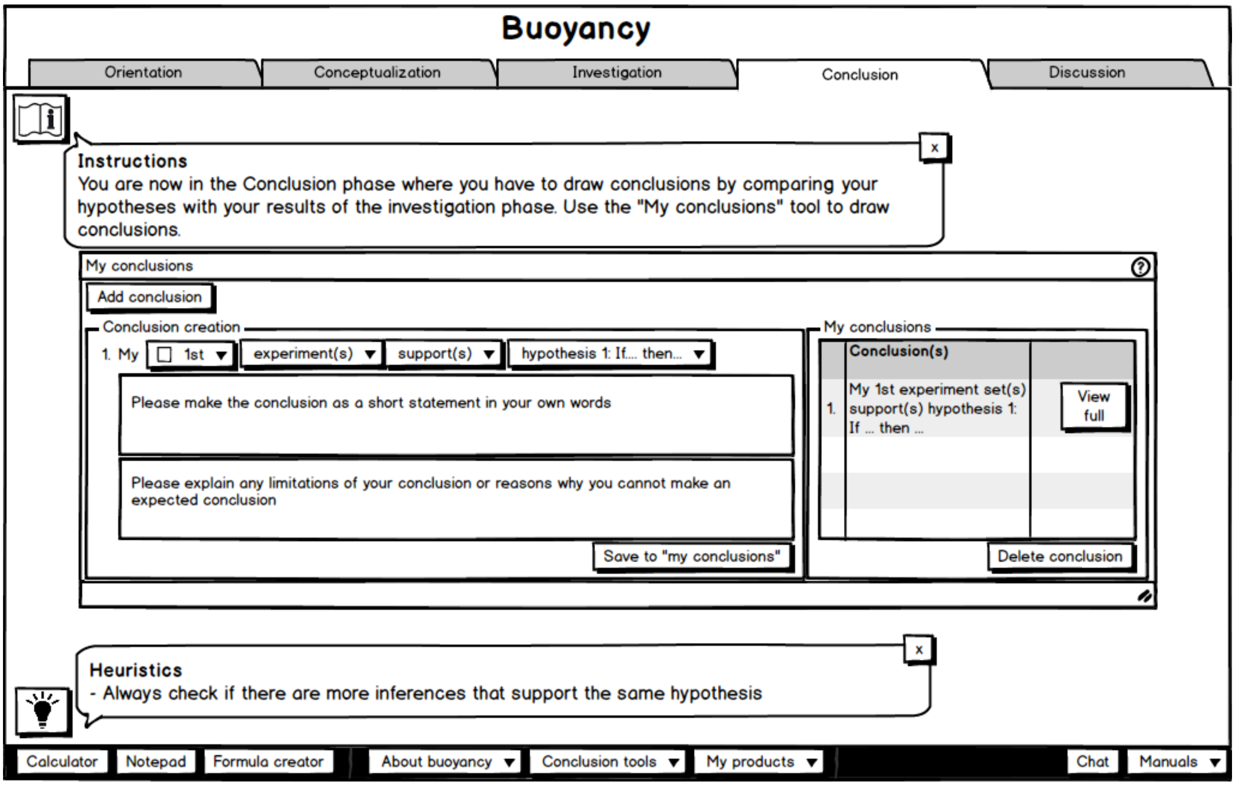


Figure 10. Conclusion phase

5.4.5 Discussion

In the *Discussion* phase, students reflect upon what they learned throughout the inquiry cycle and communicate their inquiry, including results and conclusions drawn, by making a report as shown in Figure 12. Students may choose to make their report in any form they wish, for example, a PowerPoint presentation or a poster.

When students first enter the *Discussion* phase, they see the “My report” tool with which they create a report of their experiment(s). They are encouraged to start writing a general section about the topic. By clicking on the first box in the tool students access their products from the *Orientation* phase as shown in Figure 12. They write the introductory section in their own words and can include their products from the *Orientation* phase, as shown in Figure 12.

After having written the introduction, students are guided to write down their (initial) hypothesis, the set-up of their experiment, the investigation they carried out, the collected data, and their conclusions by clicking on the different boxes within the report tool. Each box represents one of the phases of the inquiry cycle. The products of the particular phase appear on the screen when students click on that box within the report tool. This allows them to use those products and write something based on these, and or drag and drop these products into their report as shown in Figure 12. If students created multiple hypotheses they follow these steps for each hypothesis.

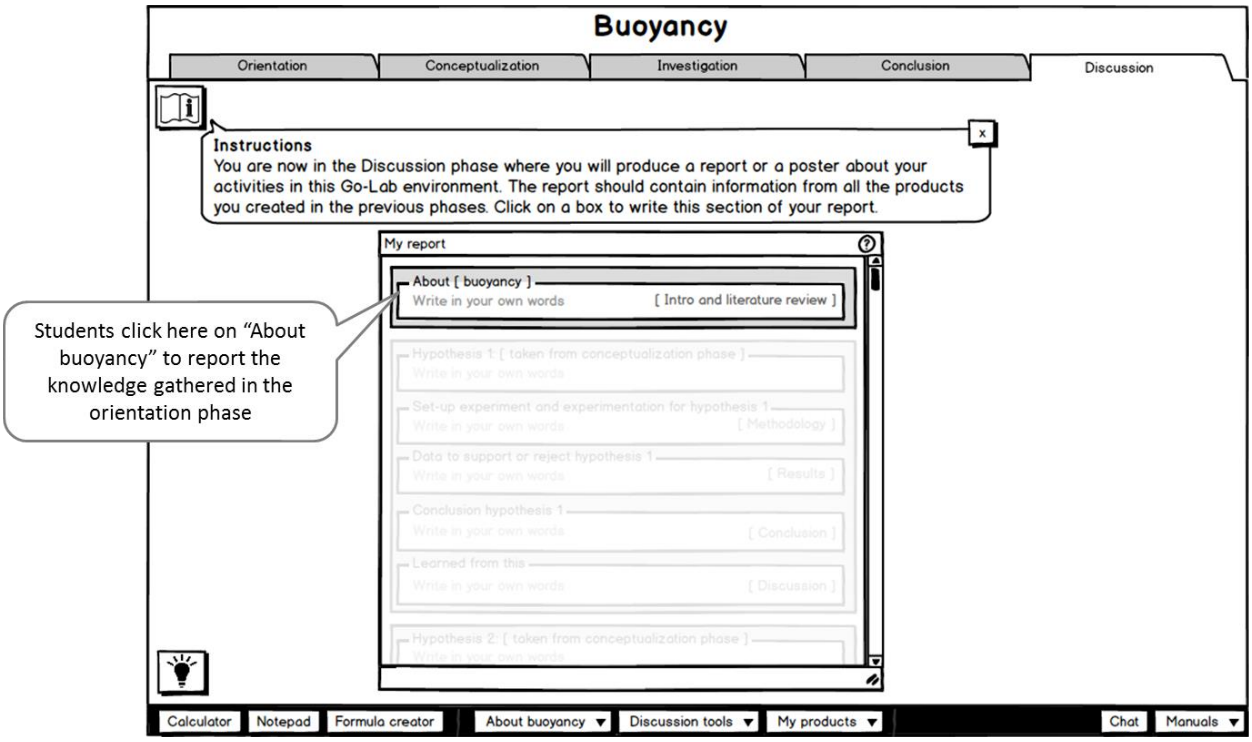


Figure 11. Discussion phase

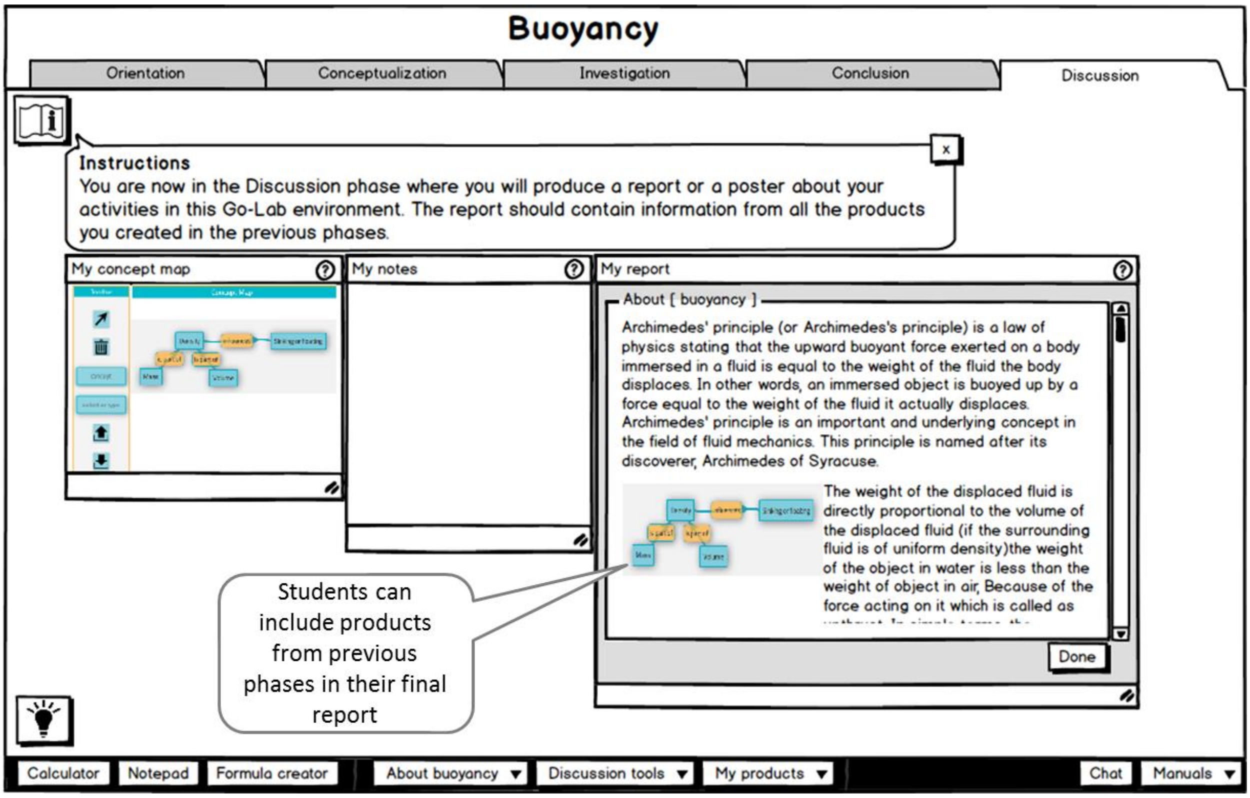


Figure 12. Writing a report in the Discussion phase

5.5 The Faulkes Telescopes lab

In this laboratory students use the Faulkes telescopes remote lab in order to perform an activity called “Interacting Galaxies”. In this activity students use images captured by one of the Faulkes Telescopes and a simulation in order to study the origin of galaxies. In terms of subjects taught, this activity aims to help them learn how to identify different morphologies of galaxies, get acquainted with processing astronomical data, and study the gravitational force.

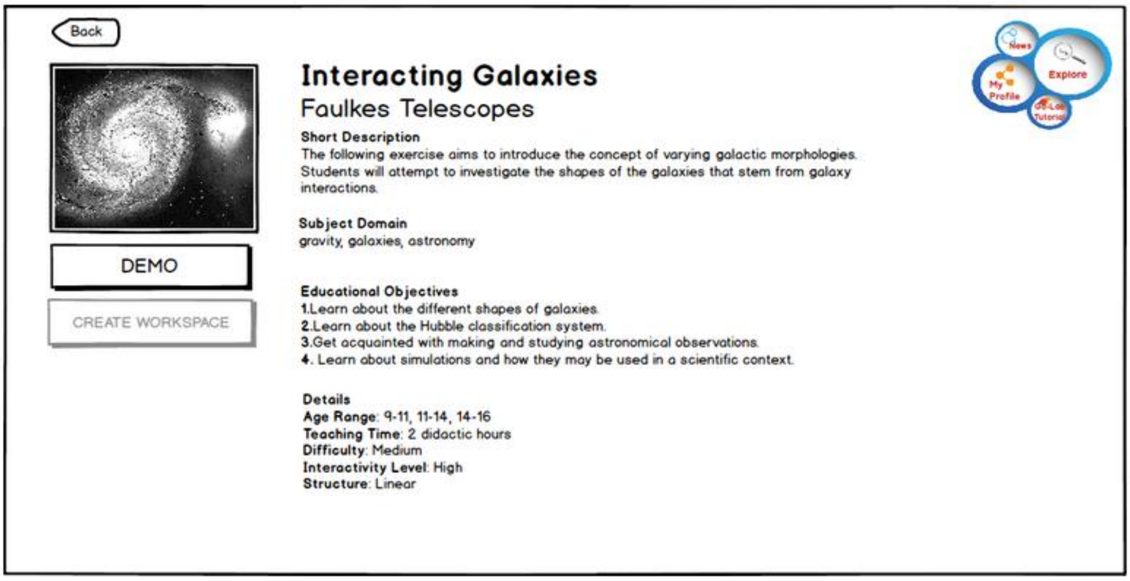


Figure 13. Main page of the “Interacting Galaxies” laboratory

5.5.1 Orientation

In the *Orientation* phase students are introduced to the different kinds of objects in the universe through the demonstration of a video. Instructions and explanatory texts are provided in each step through the “Instructions” box on the top of the page. By clicking on the “Orientation tools” button at the menu at the bottom of the page, students may also have access to the “My Concept map” tool.

By clicking on the “About Interacting Galaxies” button at the menu at the bottom of the page (available in all phases) students may access additional material such as a guide for the lab and the other tools they will use as well as related activities.

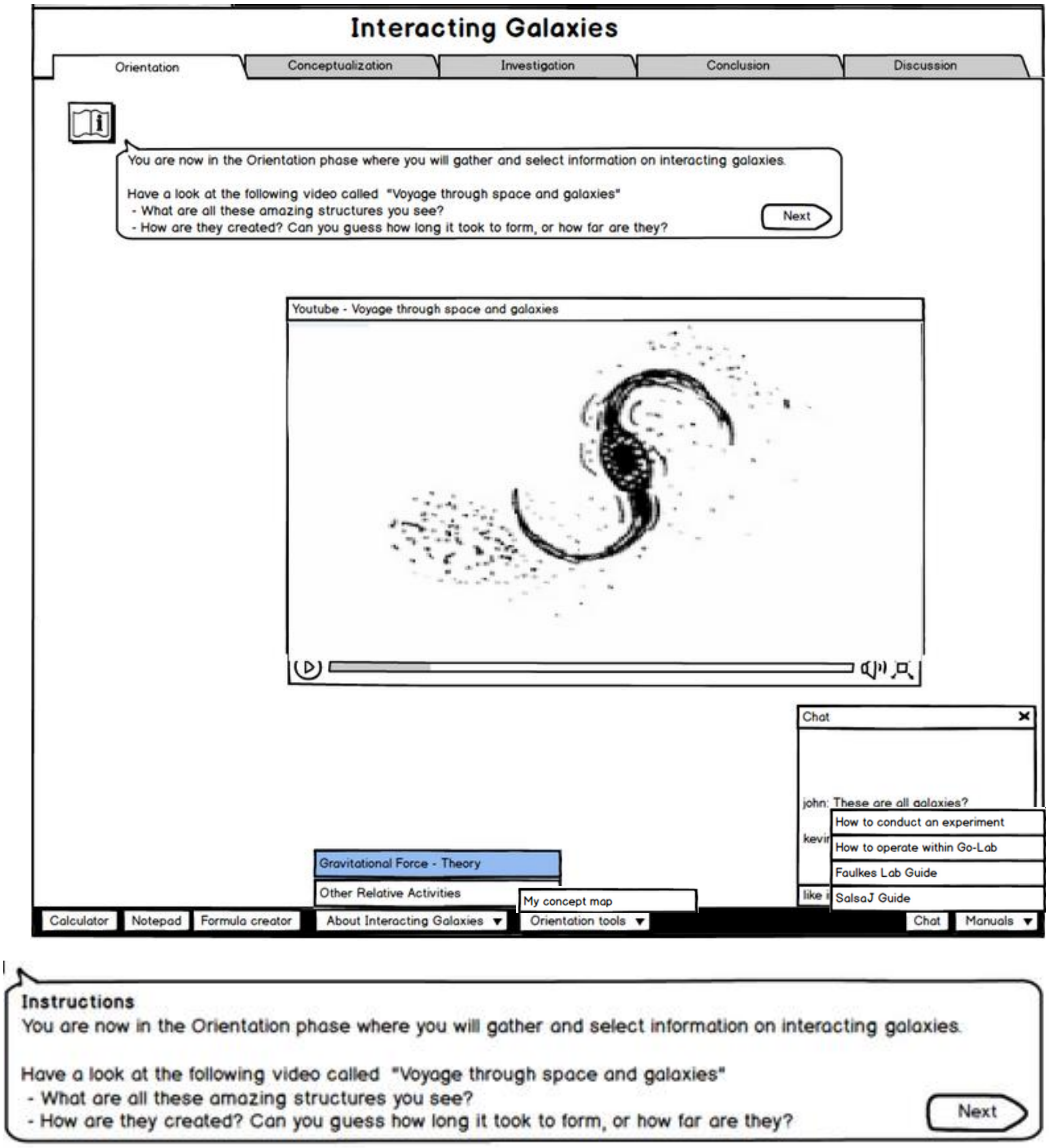


Figure 14. Orientation phase

5.5.2 Conceptualisation

After the *Orientation* phase, students move onto the *Conceptualisation* phase. In this phase they are asked to create a concept map, using the “My concept map” tool, which helps them understand which physical quantities are involved when galaxies interact. Then, they can use the “Hypothesis” tool in order to make a prediction on what happens when galaxies interact as indicated in the “Instructions” box. Both, the “My concept map” tool and the “Hypothesis” tool are available at the “*Conceptualisation* tools” section of the generic tools menu at the bottom of the page. Students may also use the “Notes” tool to make notes on informatrion they find useful.

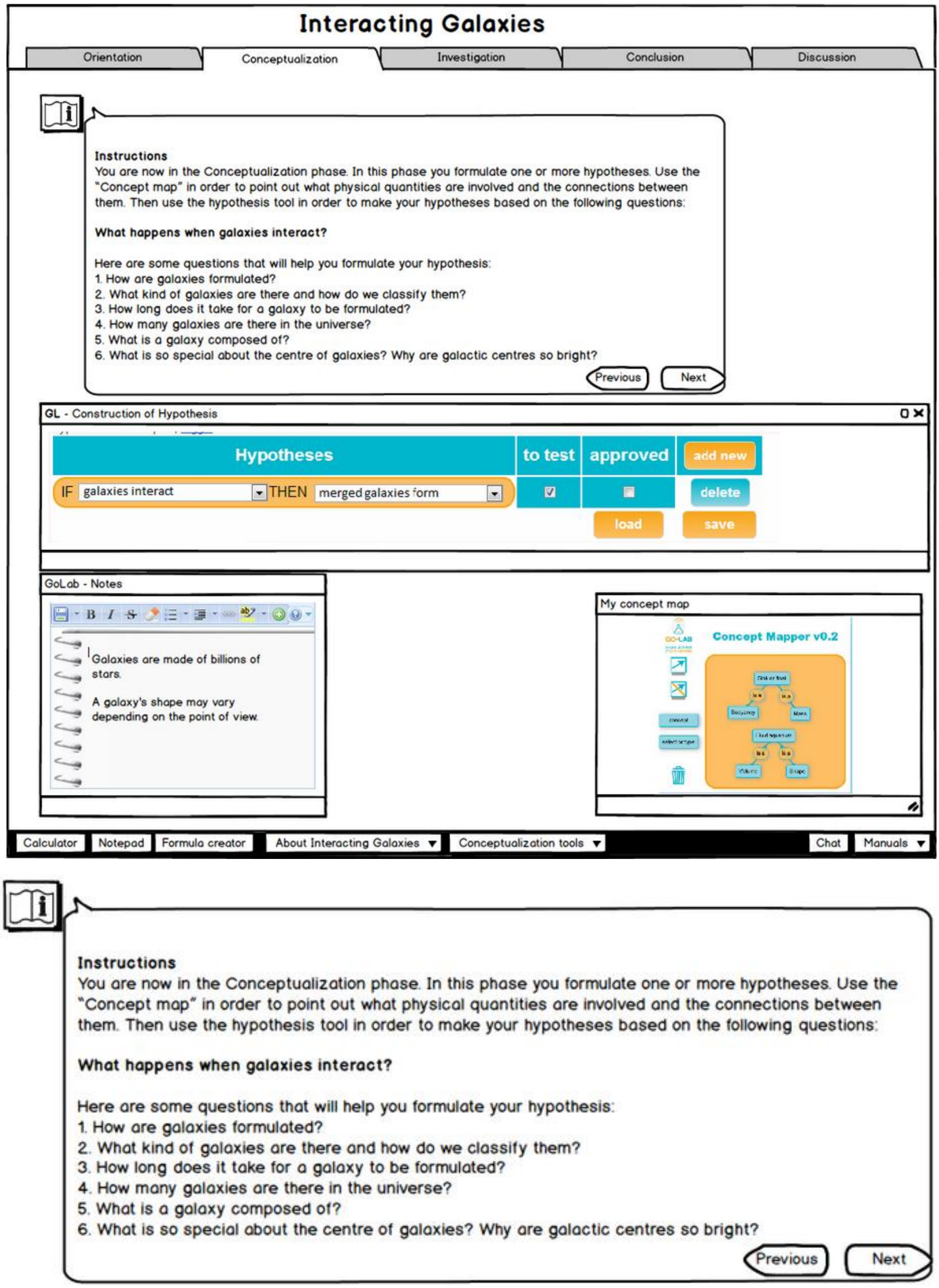


Figure 15. Conceptualisation phase

5.5.3 Investigation

The main objective of this experiment is to allow students to study the shape of galaxies and help them understand that these shapes are due to gravitational interactions. To perform their investigation students have to follow four steps. In order to facilitate the students during their investigation, explanatory texts and guidelines are available through the “Instructions” box. Tips and advice for the successful realisation of the investigation are provided through the “Heuristics” box.

In the first step students will use one of the Faulkes telescopes to make observations of interacting galaxies. Students use the coordinates of selected galaxies available in the “Data table” in order to make observations (Figure 16).

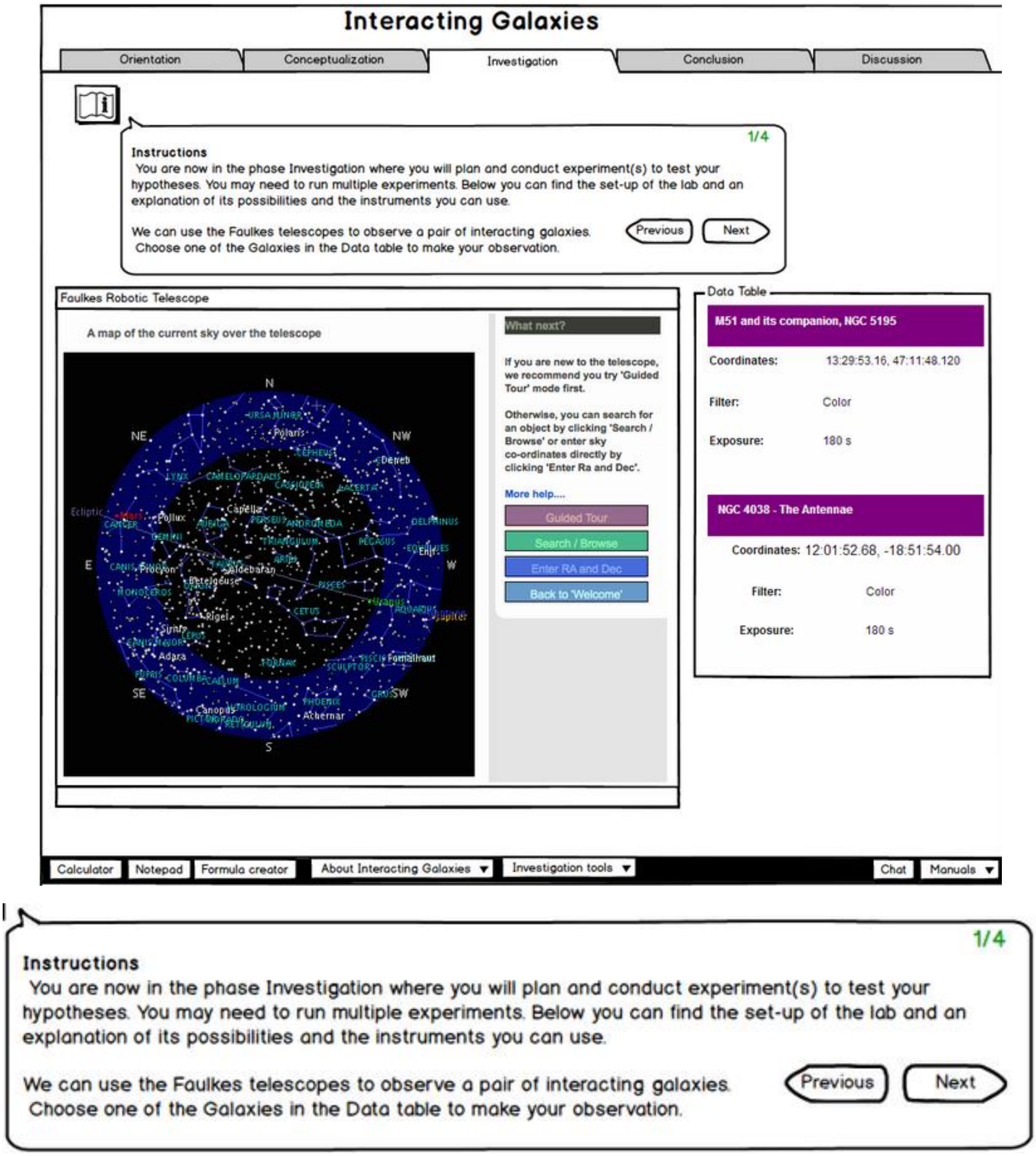


Figure 16. First page of the Investigation phase

In the second step (Figure 17), students use the SalsaJ image processing tool to process the images received. Information and guidelines on how to use the Salsa J tool are available in the "About Interacting Galaxies" section at the bottom of the page.

Figure 17. Second page of the Investigation phase

Next (Figure 18) students use a simulation applet in order to try to recreate the image of the galaxies observed and thus investigate how these galaxies have come to look the way they do today. Within the simulation students can change the mass, the relative position (angle) of the two initial galaxies and the initial distance between them. Data on the elapsed time of the simulation and the relative velocity of the two galaxies are also available. In the "Heuristics" section students are provided with tips in order to carry out their investigation successfully.

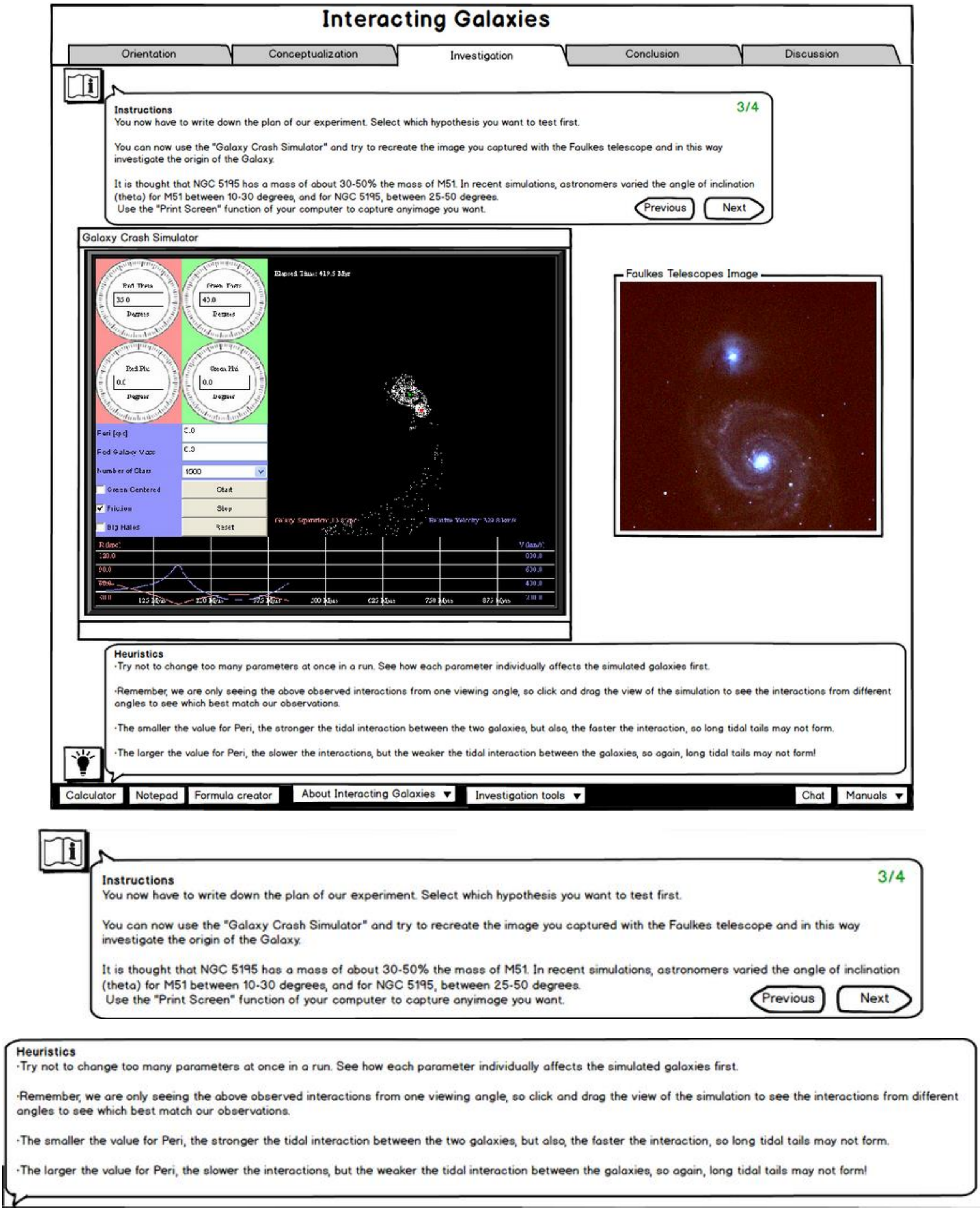


Figure 18. Third page of the Investigation phase

When students successfully simulate the image of the real galaxies then they may take a screenshot and process that image using a drawing tool. They can rotate and rescale the image captured from the simulation so as to achieve a better resemblance to the real image.

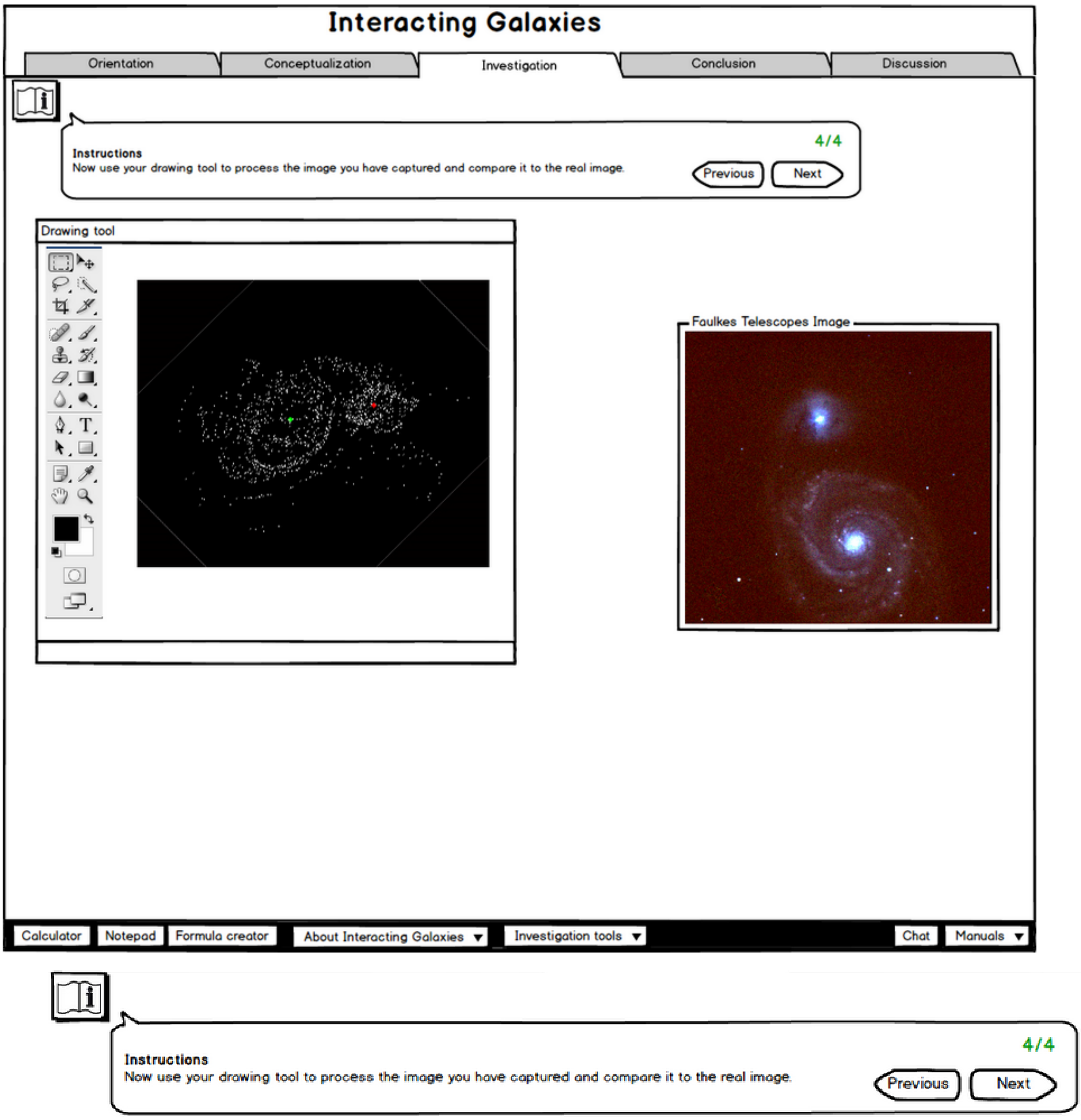


Figure 19. Fourth page of the Investigation phase

5.5.4 Conclusion

In the *Conclusion* phase, students look back to what they have done so far and based on their findings they draw conclusions about how galaxies are formed. The “My Conclusions” tool which is available in the “Conclusion tools” part of the menu at the bottom allows them to organize their thoughts and produce accurate conclusions. The questions presented in the tool aim to help students draw their conclusions. Before moving onto reporting their work students are also asked to compare their final conclusions to the hypothesis made earlier in the *Conceptualisation* phase.

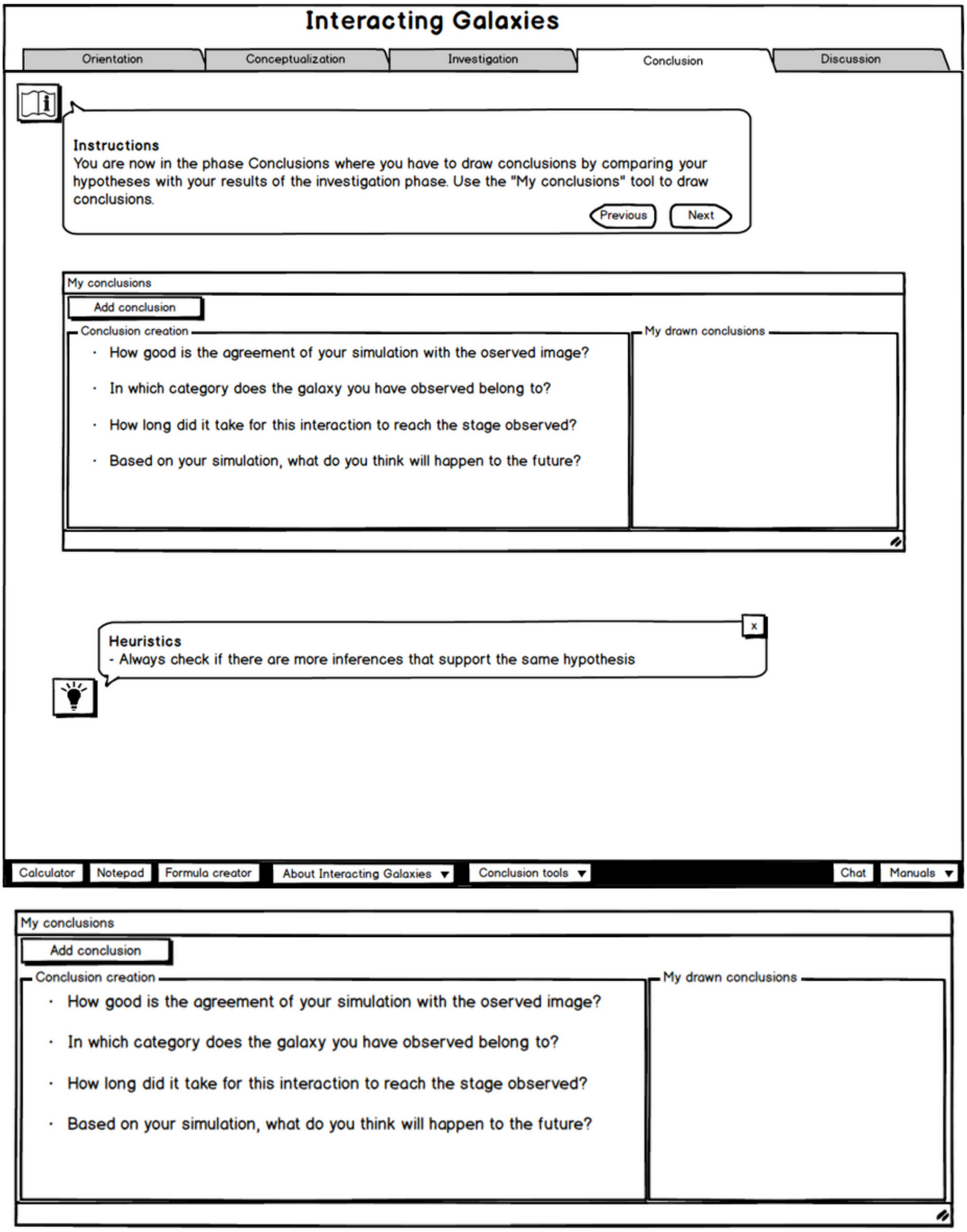


Figure 20. Conclusion phase

5.5.5 Discussion

The last phase of the activity is the *Discussion* phase. Here students use the “My report” tool to create a report of their lab work (Figure 21). Although the report may have any form the students prefer, the “My report” tool helps them understand what should be included in the report and organize effectively the different parts that have to be integrated.

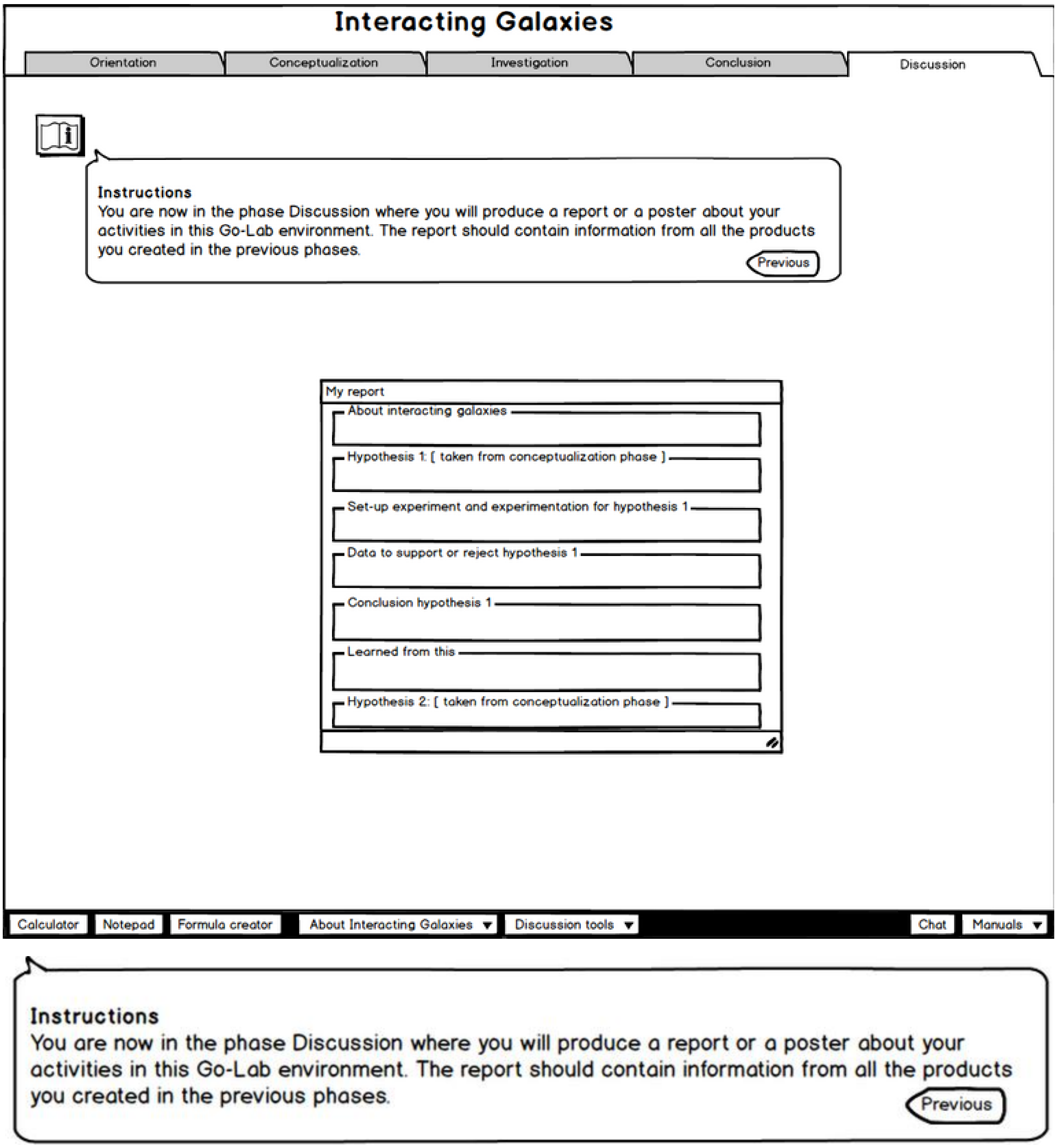


Figure 21. Discussion phase

5.6 The HYPATIA lab

In this laboratory students use the HYPATIA laboratory to perform an activity called "Conservation of momentum". In this activity students use the data derived from the lab to calculate the total momentum after a particle collision which occurred in the ATLAS detector. In terms of subjects taught, this activity aims to help them learn how to identify elementary particles (physics), understand the concept of the conservation of momentum (physics) and practice with adding vectors (mathematics).

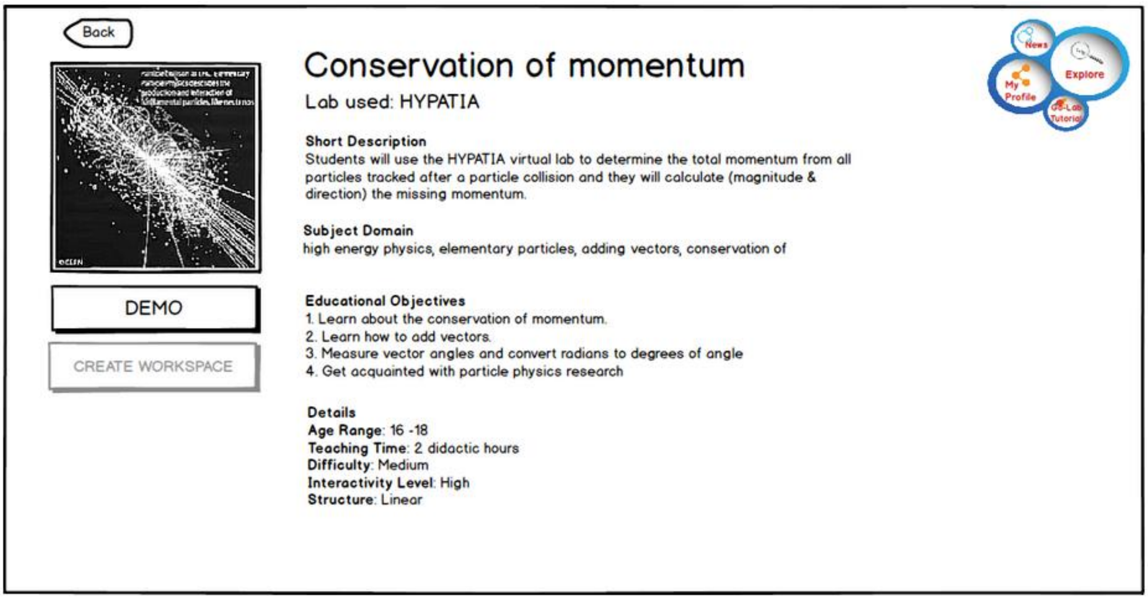


Figure 22. Main page of the "Conservation of momentum" laboratory

5.6.1 Orientation

In the *Orientation* phase students are introduced to the work done at CERN, they get a first glimpse of how particle collisions occur in the ATLAS detector and how elementary particles are categorized. The *Orientation* phase is completed in three steps during which students have the chance to view a video, an animation and some images. During the *Orientation* phase, students can use a notepad to keep notes of anything they find interesting. The notepad can be accessed from the generic tools menu at the bottom of the page. Instructions and explanatory texts are provided in each step through the "Instructions" box on the top of the page. By clicking on the "Orientation tools" button at the menu at the bottom of the page, students may access to the "My Concept map" tool. By clicking on the "About conservation of momentum" button at the menu at the bottom of the page (available in all phases) students may have access to additional material such as a guide for the lab, other related activities and an e-tour of the ATLAS detector.

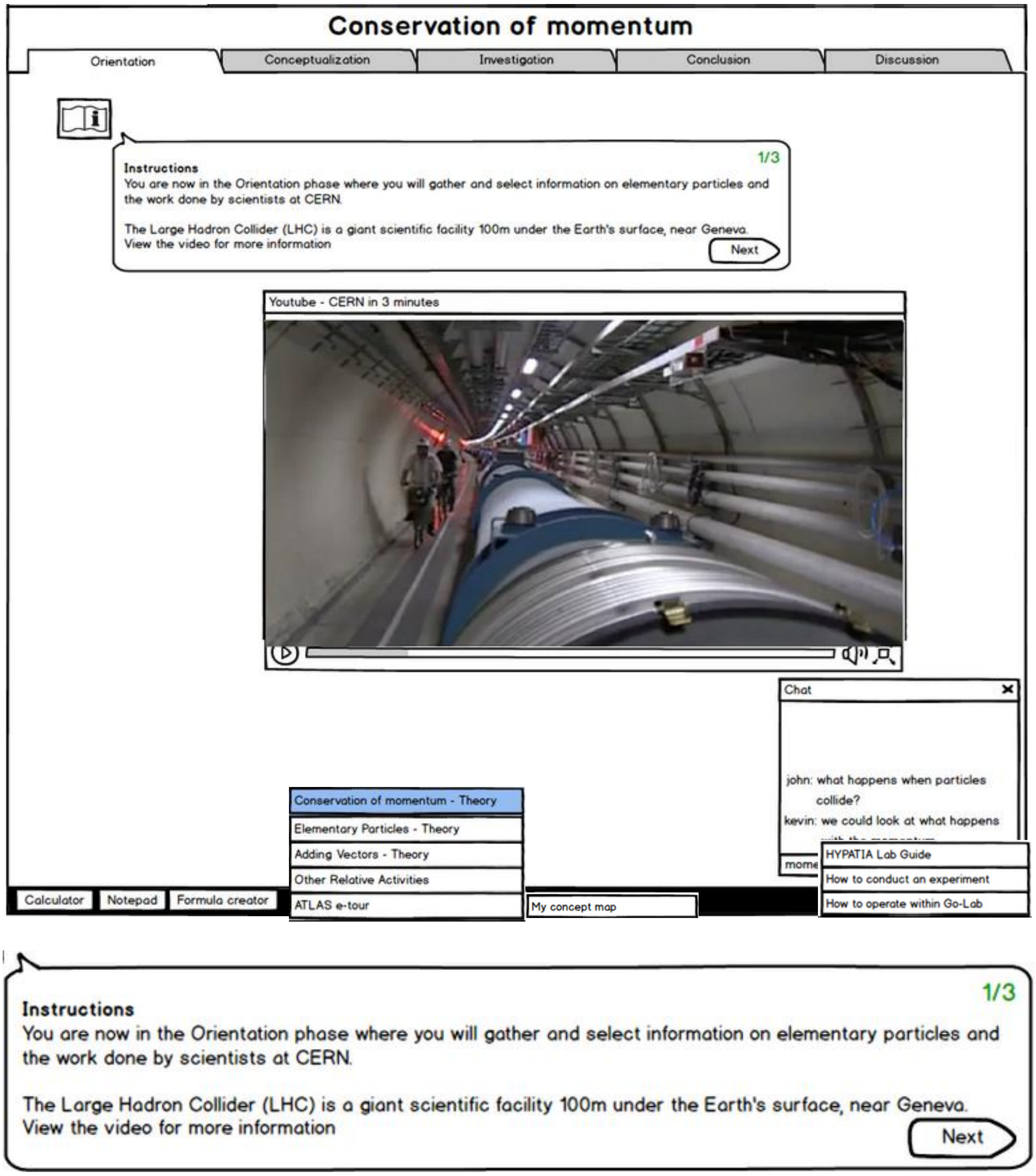


Figure 23. First page of the Orientation phase

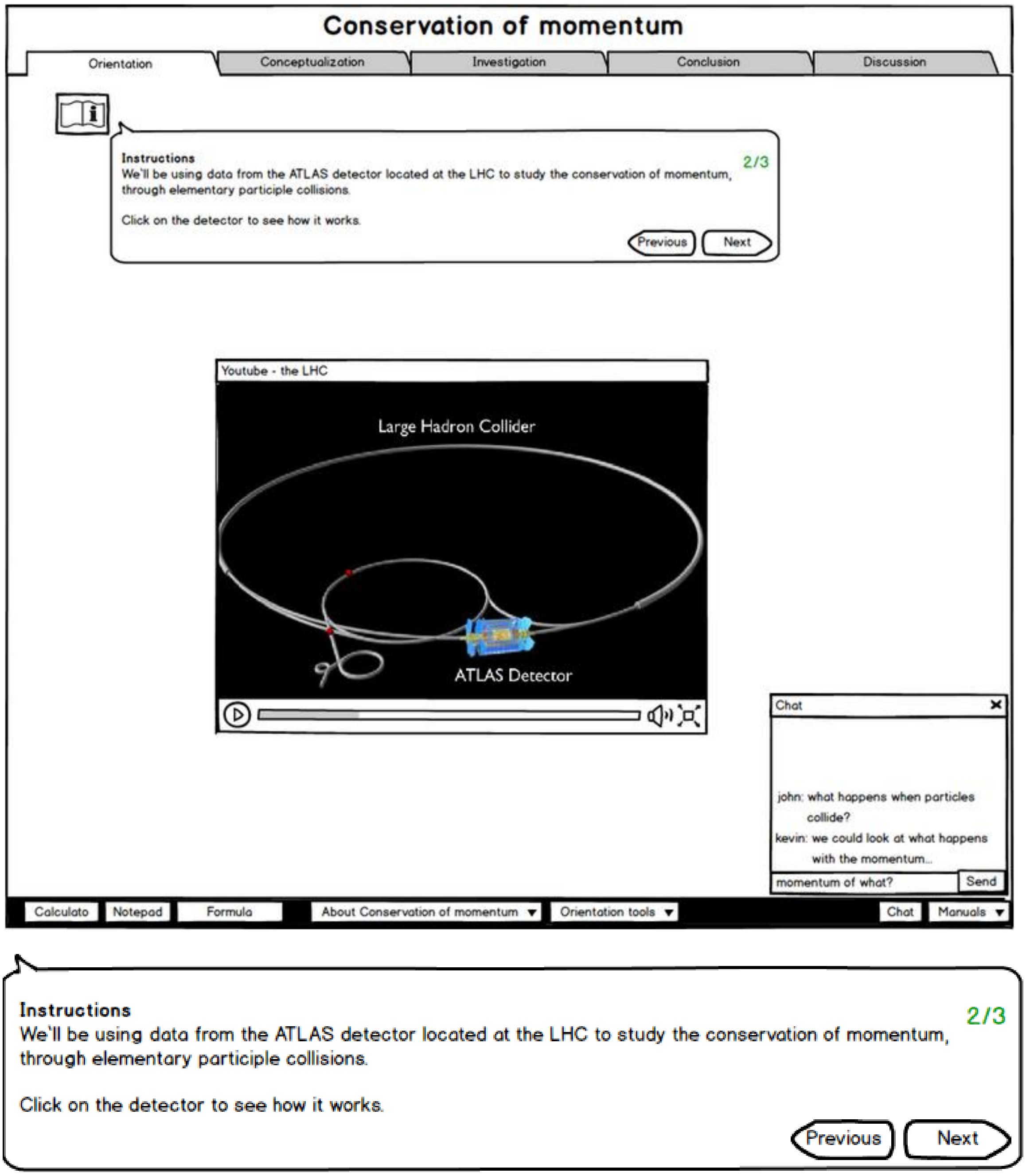


Figure 24. Second page of the Orientation phase

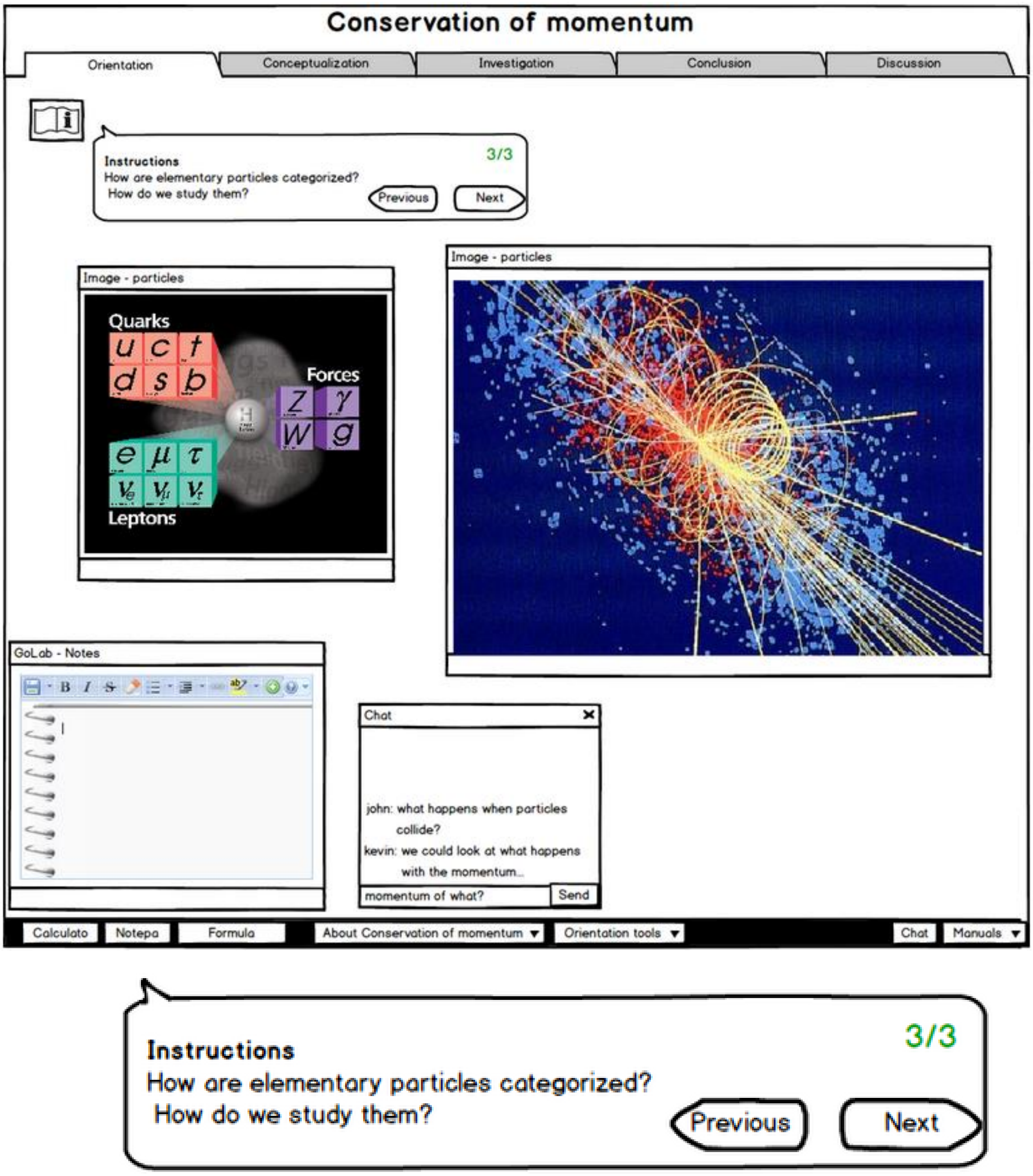


Figure 25. Third page of the Orientation phase

5.6.2 Conceptualisation

After finishing the Orientation phase, students move on the *Conceptualisation* phase. In this phase students are asked to create a concept map which allows them to understand which physical quantities are involved in their investigation and how they are connected to each other. Then, students can use the “Hypothesis” tool in order to make their hypotheses focusing on the questions displayed in the “Instructions” box. Both, the “My concept map” tool and the “Hypothesis” tool can be found at the “*Conceptualisation* tools” section of the generic tools menu at the bottom of the page. The main hypothesis students have to make is on the matter whether the conservation of momentum is valid during particle collisions and if it can be applied to all planes.

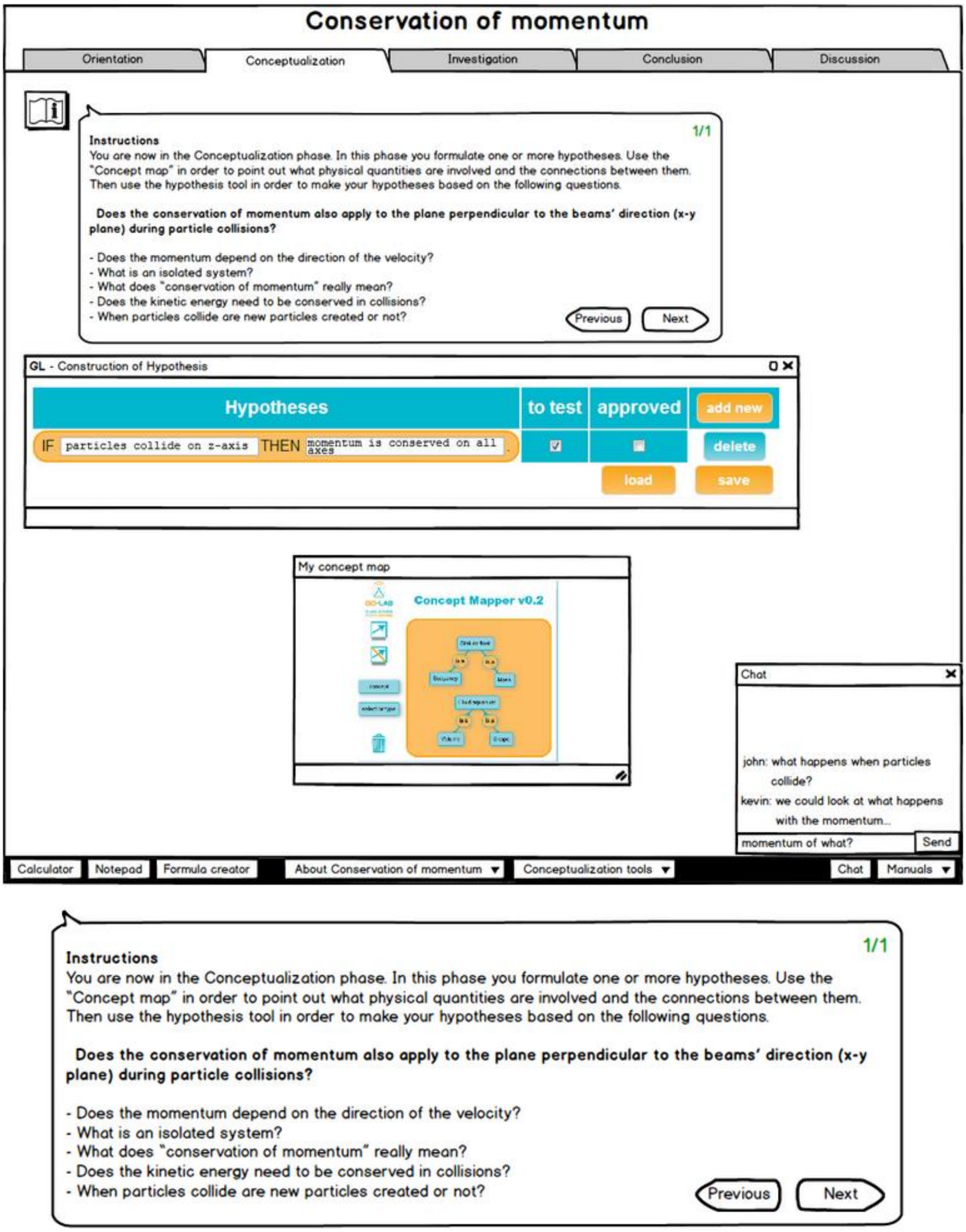


Figure 26. Conceptualisation phase

5.6.3 Investigation

As mentioned above, the main objective of laboratory is to calculate the conservation of momentum after a particle collision in the ATLAS detector and investigate if the conservation of momentum principle is valid. To do that, students will first use real data from the ATLAS detector provided by the lab in order to calculate the momentum of each particle. Then, they will add the vectors of each particle's momentum and calculate the total momentum. These actions are taking place in the *Investigation* phase which precedes the *Conceptualisation* phase.

This phase is comprised of four steps. In the first step students get acquainted with the lab. They learn how to identify a particle based on the track it has left on the ATLAS detector. Students may see the tracks in the representation of the ATLAS detector in the HYPATIA lab.

In the second step, students use the data provided by the lab, they note down the tracks that interest them and they attempt to identify the particles the tracks belong to. In order to select their data they use the "Result Table" tool which can be found in the "Investigation tools" in the bottom menu.

In the third step, students use the data they have selected to calculate the total momentum after the collision. To do that, they use the "Result Table" to record their findings and a calculator (included in the generic tools menu). A set of heuristics is also displayed in this step which provides students with tips on how to carry out the investigation.

In the last step, students finish their investigation be completing the calculation of the total momentum. They do that by drawing and adding vectors. Heuristics are available in this part as well.

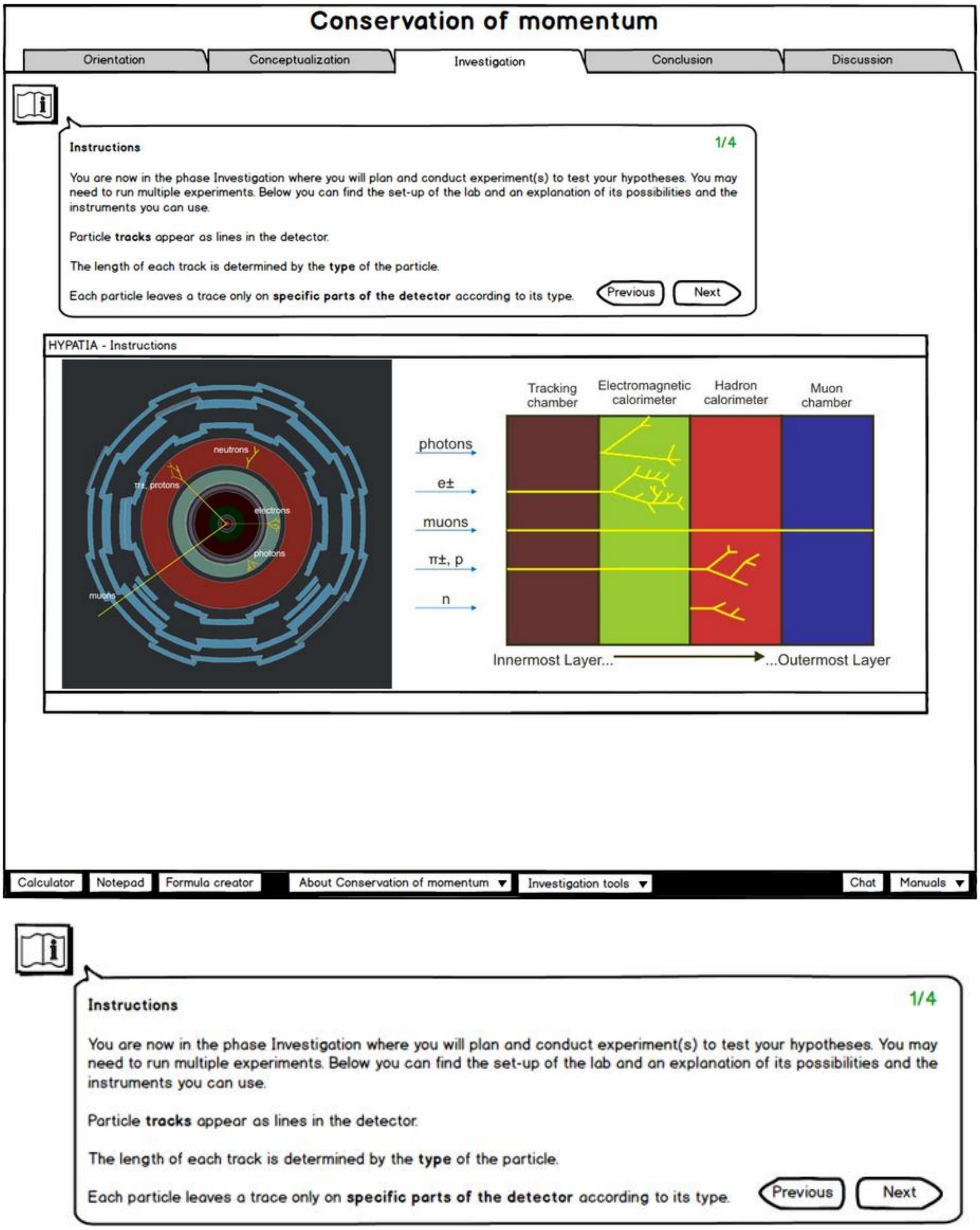


Figure 27. First page of the Investigation phase

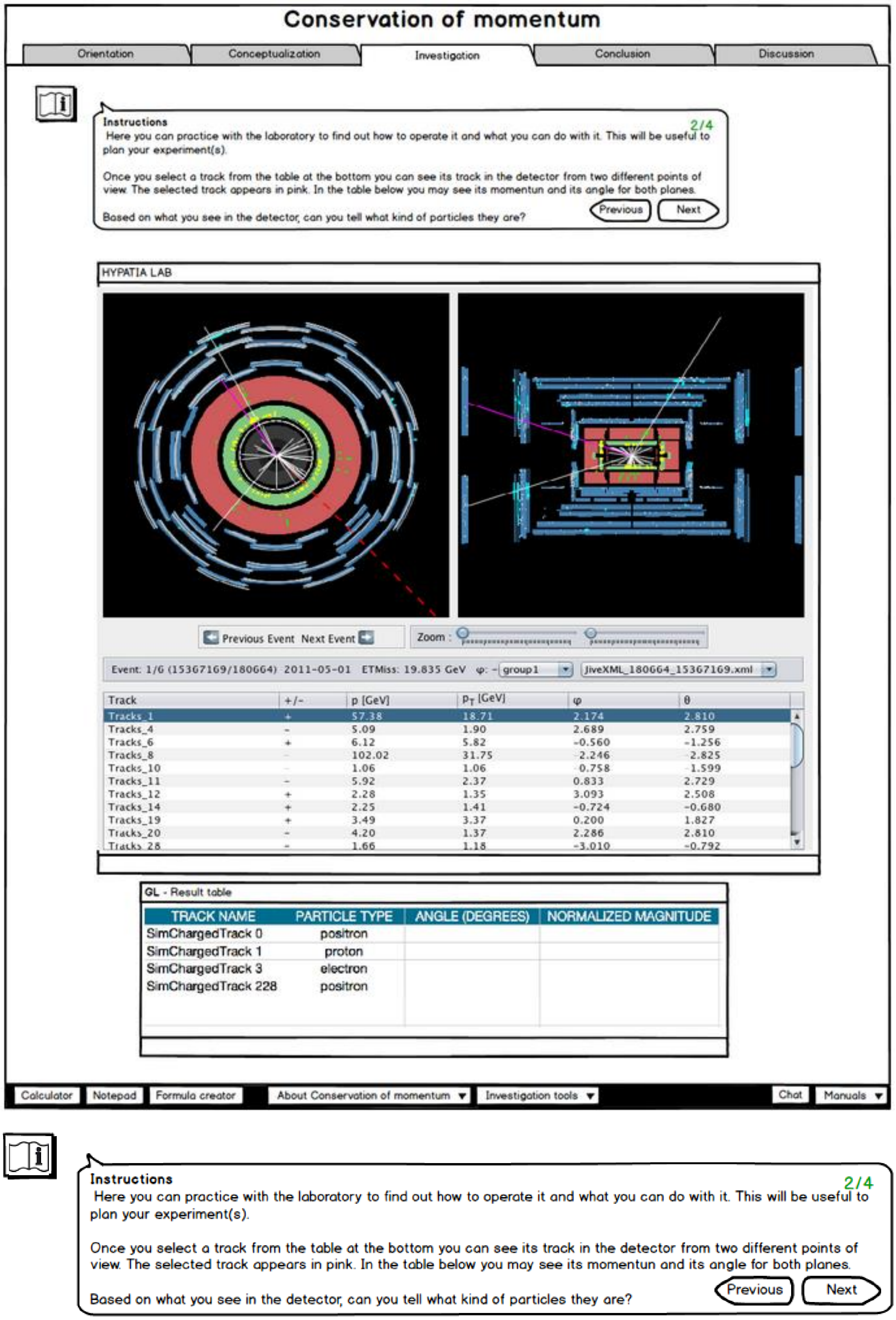


Figure 28. Second page of the Investigation phase

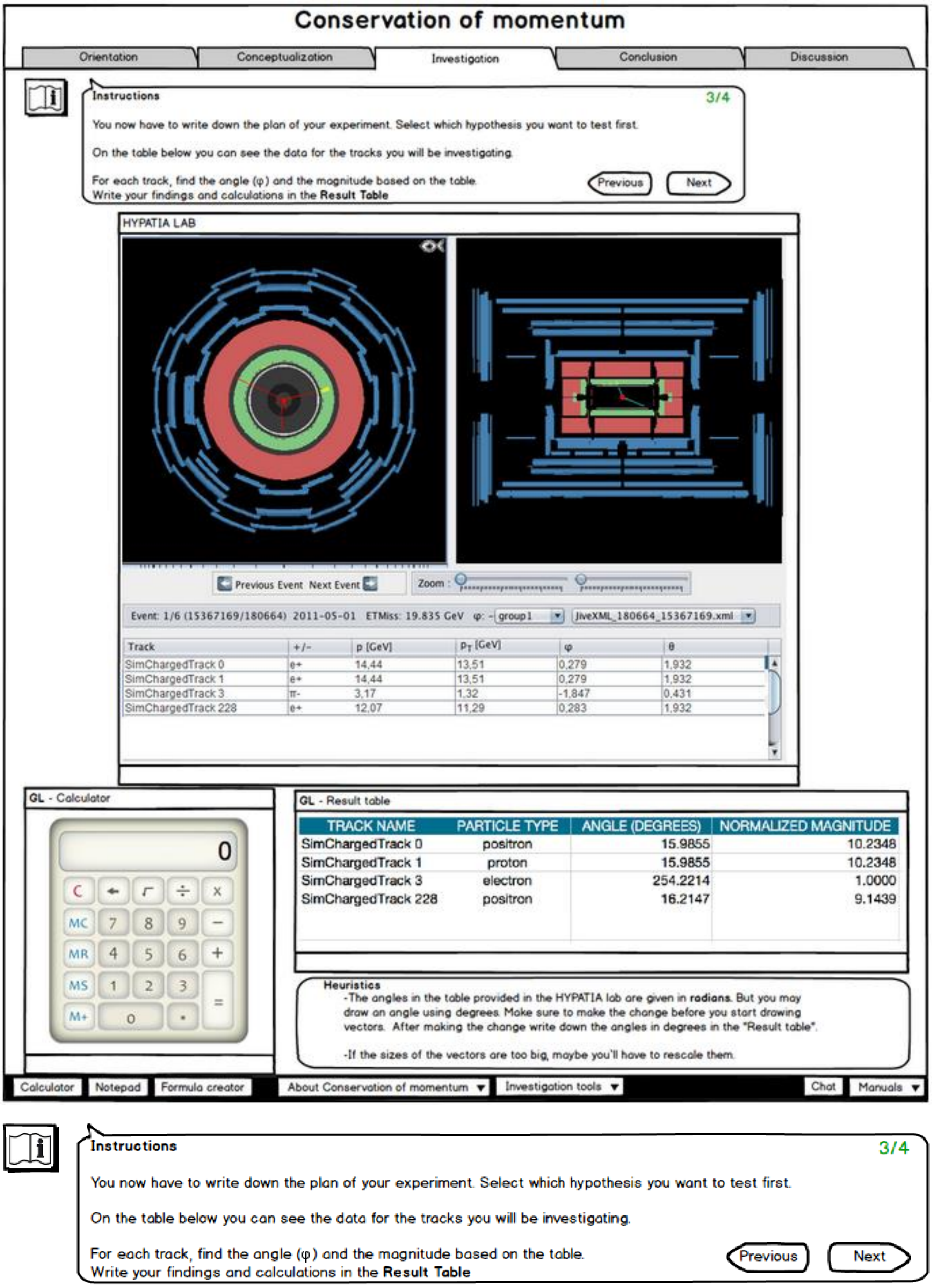


Figure 29. Third page of the Investigation phase

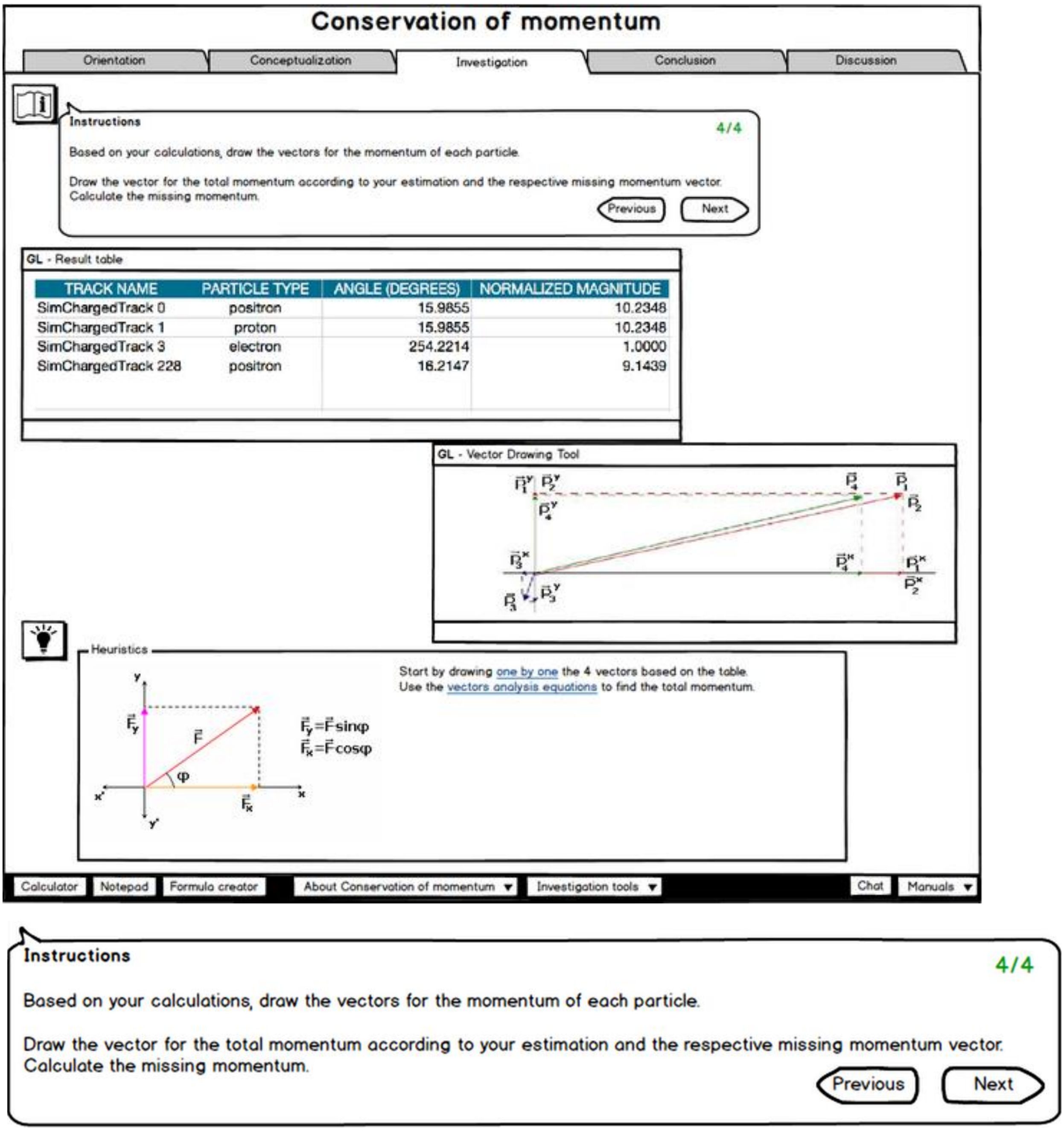


Figure 30. Fourth page of the Investigation phase

5.6.4 Conclusion

In the *Conclusion* phase, students use their findings to draw conclusions. To facilitate them in this process the “My Conclusions” tool is available in the “Conclusion tools” part of the menu at the bottom. This tool includes questions which aim to help students draw their conclusions. Students are also asked to compare their conclusions to their hypotheses made in the *Conceptualisation* phase.

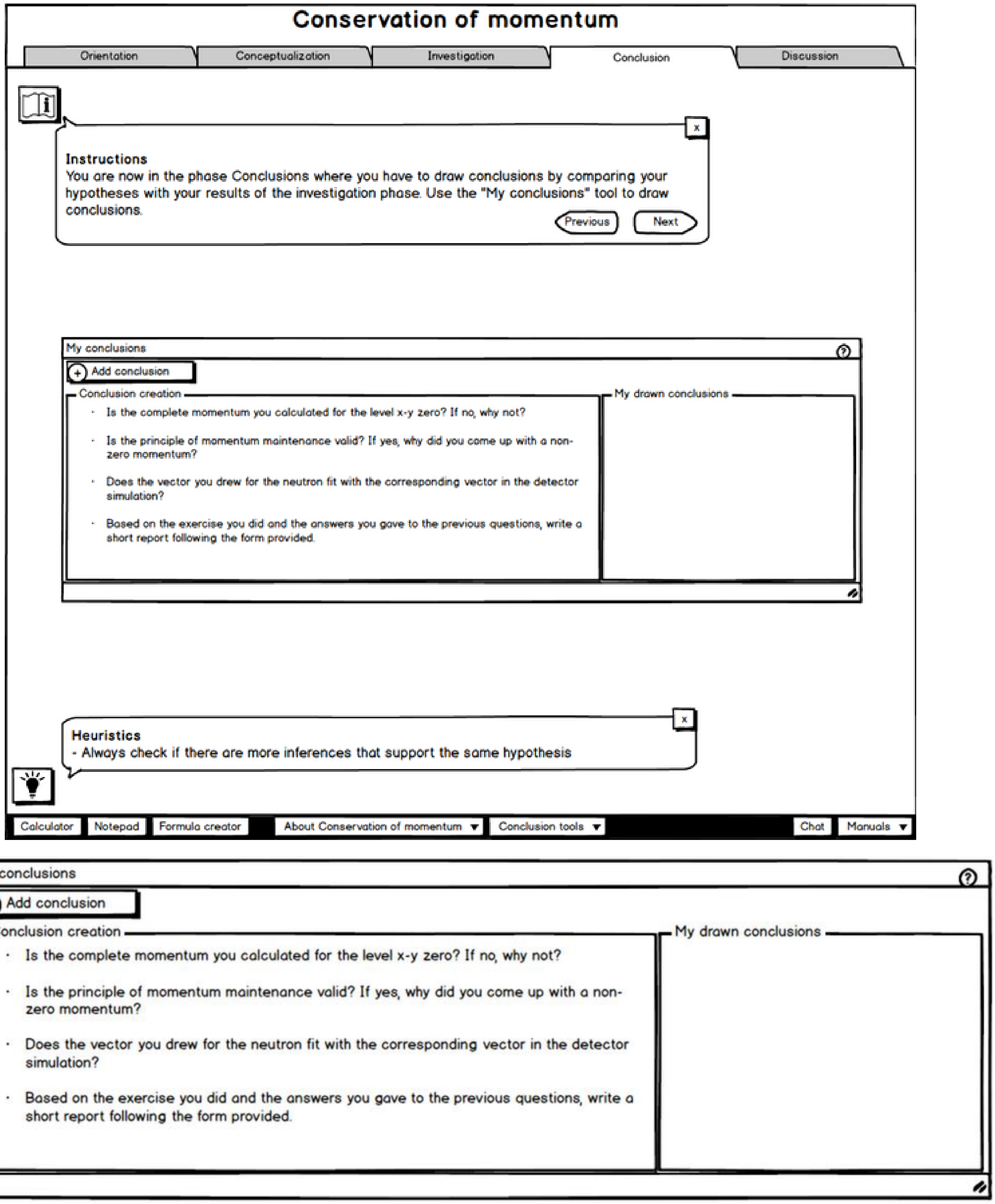


Figure 31. Conclusion phase

5.6.5 Discussion

The last phase of the activity is the *Discussion* phase. Here students may have a look at everything they have done throughout the exercise. At this stage students discuss their findings and the inquiry process they have carried out. They can use the “My report” tool to compose a report about their activity. This report may contain all the steps of the exercise, from stating the problem at hand and the original hypothesis to the final conclusions that have been drawn by the students.

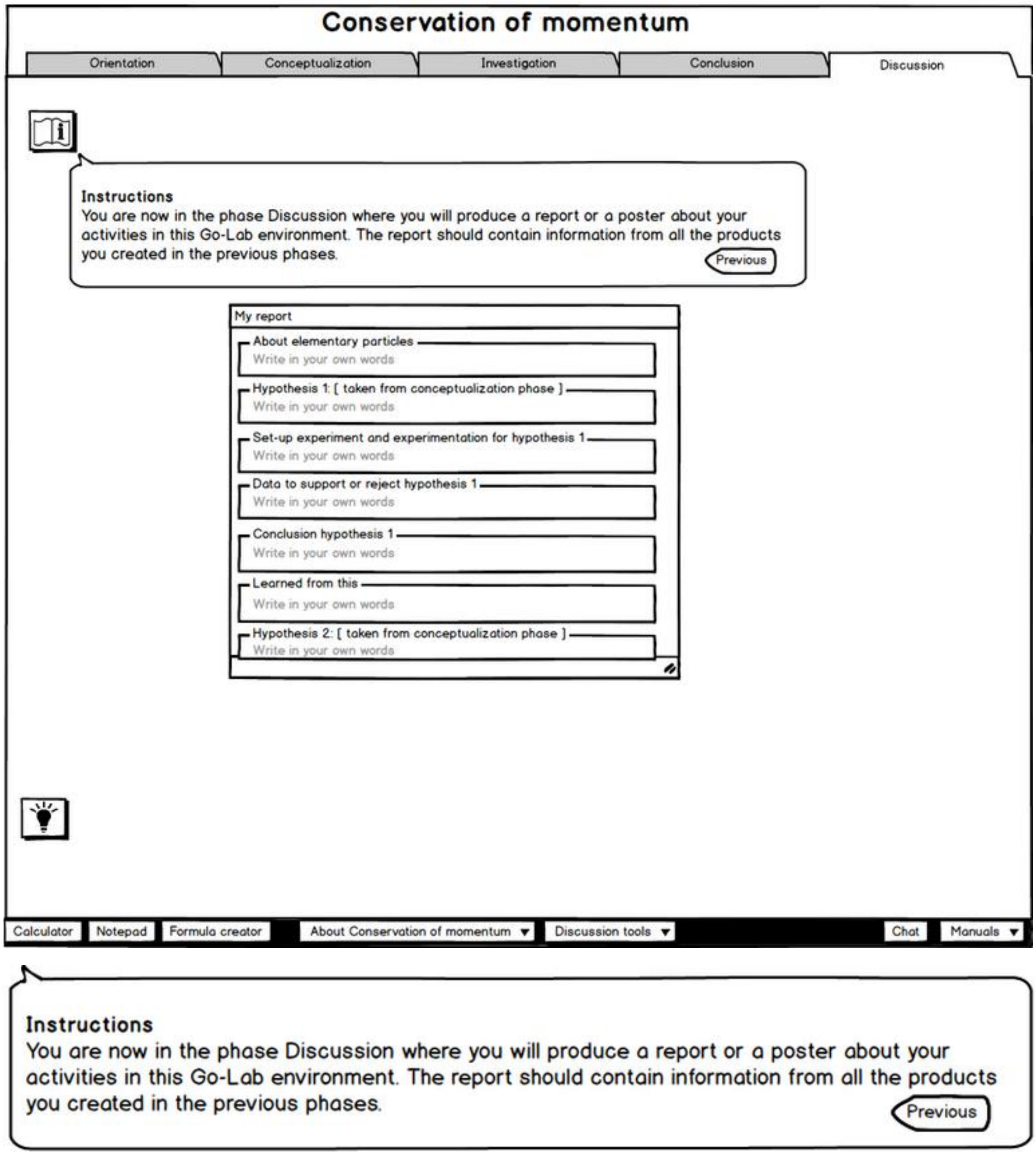


Figure 32. Discussion phase

6 Conclusion and next steps

The specifications as presented in the deliverable are not final. However, they give a solid starting point for working with teachers and students in participatory design sessions to collect reactions from users on the suggested ideas. One of the next actions in the project is to create a set of concrete questions that these participatory design activities need to answer. If needed, variations of the mock-ups will be created to investigate the reactions of users to different variants of the learning environment.

One issue that is central to our mock-ups is the generality of the guidance (prompts/assignments, heuristics etc.). In any specific teaching situation guidance that is domain specific for the online lab at hand gives the students the best help we can think of. As Go-Lab develops and when the project will approach its final stage it is foreseen that a large set of online labs is included meaning that it will also be necessary that this guidance is present in a domain generic way so that labs that are not edited by a lab-owner, teacher, or designer will have a minimum level of guidance. An editor who enters domain specific guidance may decide to combine this specific guidance with the generic guidance or may omit the generic guidance and solely rely on the domain specific support.

In the presented mock-ups the flow through the learning environment is very open, e.g., students can move freely between phases. In the final version of the system/environment we will also provide an opportunity for editors/authors to put restrictions on the flow of activities over and within the different phases of the inquiry cycle. These restrictions may be lifted when students reach a level when they can handle this freedom. This is an example of adaptation that will also affect the other forms of guidance. Guidance will be present or absent or take a specific form depending on the behaviour of the students and the interpretations made of that behaviour by using techniques from learning analytics (de Jong & Anjewierden, Submitted).

The specifications presented here form a basis for the first prototype of the Go-Lab learning environment with regard to both the general architecture of the system and the guidance that will be presented to learners. Specifications of the Go-Lab portal, where teachers can find adequate online labs and of the authoring/editing facilities that will be offered will be presented Go-Lab deliverable D5.2.

7 References

Alessi, S. M. (1995). *Dynamic vs. Static fidelity in a procedural simulation.* Paper presented at the American Educational Research Association, San Francisco, CA.

Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology, 103*, 1-18. doi: 10.1037/a0021017

Anastopoulou, S., Kerwalla, L., Littleton, K., Ainsworth, S., Twiner, A., & Conole, G. (2009). *Facilitating the expression of learner voices in the participatory design of technology to support inquiry learning*. Paper presented at the CAL 2009 Learning in Digital Worlds, March 2009, Brighton, UK. http://oro.open.ac.uk/22307/

Arnott-Hill, E., Hastings, P., & Allbritton, D. (2012). Intelligent tutoring in a non-traditional college classroom setting. *International Journal of Applied Psychology, 2*, 1-7. doi: 10.5923/j.ijap.20120202.01

Azevedo, R., Cromley, J. G., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology, 29*, 344-370.

Balamuralithara, B., & Woods, P. C. (2009). Virtual laboratories in engineering education: The simulation lab and remote lab. *Computer Applications in Engineering Education, 17*, 108-118. doi: 10.1002/cae.20186

Banerjee, A. (2010). Teaching science using guided inquiry as the central theme: A professional development model for high school science teachers. *Science Educator, 19*, 1-9.

Bell, T., Urhahne, D., Schanze, S., & Ploetzner, R. (2010). Collaborative inquiry learning: Models, tools, and challenges. *International Journal of Science Education, 32*, 349-377. doi: 10.1080/09500690802582241

Bevevino, M. M., Dengel, J., & Adams, K. (1999). Constructivist theory in the classroom internalizing: Concepts through inquiry learning. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 72*, 275-278. doi: 10.1080/00098659909599406

BGulLe. (May 20, 2013). The animal landlord software Retrieved January 24, 2012, from http://www.letus.org/bguile/animallandlord/AnimalLandlord_software.html

Biesinger, K., & Crippen, K. (2010). The effects of feedback protocol on self-regulated learning in a web-based worked example learning environment. *Computers & Education, 55*, 1470-1482. doi: 10.1016/j.compedu.2010.06.013

Bowman, C. D. D. (2012). Student use of animated pedagogical agents in a middle school science inquiry program. *British Journal of Educational Technology, 43*, 359-375.

Bruce, B. C., & Bishop, A. P. (2002). Using the web to support inquiry-based literacy development. *Journal of Adolescent & Adult Literacy, 45*, 706.

Bruce, B. C., & Casey, L. (2012). The practice of inquiry: A pedagogical 'sweet spot'for digital literacy? *Computers in the Schools, 29*, 191-206.

Buckley, B. C., Gobert, J. D., & Horwitz, P. (2006). *Using log files to track students' model-based inquiry.* Paper presented at the Proceedings of the 7th international conference on Learning sciences, Bloomington, IN.

Buckley, B. C., Gobert, J. D., Horwitz, P., & O'Dwyer, L. (2010). Looking inside the black box: Assessments and decision-making in biologica. *International Journal of Learning Technology, 5*, 166-190.

Butler, K. A., & Lumpe, A. (2008). Student use of scaffolding software: Relationships with motivation and conceptual understanding. *Journal of Science Education and Technology, 17*, 427-436. doi: 10.1007/s10956-008-9111-9

Campbell, J. O., Bourne, J. R., Mosterman, P. J., & Brodersen, A. J. (2002). The effectiveness of learning simulations for electronic laboratories. *Journal of Engineering Education, 91*, 81-87. doi: 10.1002/j.2168-9830.2002.tb00675.x

Chang, K. E., Chen, Y. L., Lin, H. Y., & Sung, Y. T. (2008). Effects of learning support in simulation-based physics learning. *Computers & Education, 51*, 1486-1498. doi: 10.1016/j.compedu.2008.01.007

Chini, J. J., Madsen, A., Gire, E., Rebello, N. S., & Puntambekar, S. (2012). Exploration of factors that affect the comparative effectiveness of physical and virtual manipulatives in an undergraduate laboratory. *Physical Review Special Topics - Physics Education Research, 8*, 010113. doi: 10.1103/PhysRevSTPER.8.010113

Chuang, C., Jou, M., Lin, Y., & Lu, C. (2013). Development of a situated spectrum analyzer learning platform for enhancing student technical skills. *Interactive Learning Environments*, 1-12. doi: 10.1080/10494820.2013.765896

Community of Informatics Initiative, C. Inquiry based learning cycle http://www.inquiry.uiuc.edu/.

Conole, G., Scanlon, E., Littleton, K., Kerawalla, L., & Mulholland, P. (2010). Personal inquiry: Innovations in participatory design and models for inquiry learning. *Educational Media International, 47*, 277-292.

Cooper, M., & Ferreira, J. M. M. (2009). Remote laboratories extending access to science and engineering curricular. *IEEE Transactions on Learning Technologies, 2*, 342-353.

Corlu, M. A., & Corlu, M. S. (2012). Scientific inquiry based professional development models in teacher education. *Educational Sciences: Theory and Practice, 12*, 514-521.

Crippen, K. J., & Earl, B. L. (2007). The impact of web-based worked examples and self-explanation on performance, problem solving, and self-efficacy. *Computers & Education, 49*, 809-821. doi: 10.1016/j.compedu.2005.11.018

de Jong, T. (2006a). Computer simulations - technological advances in inquiry learning. *Science, 312*, 532-533. doi: 10.1126/science.1127750

de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Dealing with complexity in learning environments* (pp. 107-128). London: Elsevier Science Publishers.

de Jong, T., & Anjewierden, A. (Submitted). Educational data mining. In J. M. Spector (Ed.), *Encyclopedia of educational technology*: Sage.

de Jong, T., & Lazonder, A. W. (in press). The guided discovery principle in multimedia learning. In R. E. Mayer, J. J. G. van Merriënboer, W. Schnotz & J. Elen (Eds.), *The Cambridge handbook of multimedia learning* (second ed.). Cambridge: Cambridge University Press.

de Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340*, 305-308. doi: 10.1126/science.1230579

de Jong, T., Martin, E., Zamarro, J.-M., Esquembre, F., Swaak, J., & van Joolingen, W. R. (1999). The integration of computer simulation and learning support; an example from the physics domain of collisions. *Journal of Research in Science Teaching, 36*, 597-615.

de Jong, T., & Njoo, M. (1992). Learning and instruction with computer simulations: Learning processes involved. In E. de Corte, M. Linn, H. Mandl & L. Verschaffel (Eds.), *Computer-based learning environments and problem solving* (pp. 411-429). Berlin, Germany: Springer-Verlag.

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*, 179-202. doi: 10.3102/00346543068002179

de Jong, T., van Joolingen, W. R., Savelsbergh, E., Lazonder, A., Wilhelm, P., & Ootes, S. (2002). Co-Lab specifications. Part 1 - theoretical background *Collaborative laboratories for Europe (Project number IST-2000-25035)*. Enschede, NL: University of Twente.

Demetriadis, S. N., Papadopoulos, P. M., Stamelos, I. G., & Fischer, F. (2008). The effect of scaffolding students' context-generating cognitive activity in technology-enhanced case-based learning. *Computers & Education, 51*, 939-954. doi: 10.1016/j.compedu.2007.09.012

Deslauriers, L., & Wieman, C. E. (2011). Learning and retention of quantum concepts with different teaching methods. *Physical Review Special Topics - Physics Education Research, 7*, 010101. doi: 10.1103/PhysRevSTPER.7.010101

Dunbar, K. (1993). Concept discovery in a scientific domain. *Cognitive Science, 17*, 397-434. doi: 10.1207/s15516709cog1703_3

Dunbar, K. (2000). How scientists think in the real world: Implications for science education. *Journal of Applied Developmental Psychology, 21*, 49-58. doi: 10.1016/S0193-3973(99)00050-7

Eckhardt, M., Urhahne, D., Conrad, O., & Harms, U. (2013). How effective is instructional support for learning with computer simulations? *Instructional Science, 41*, 105-124. doi: 10.1007/s11251-012-9220-y

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences, 8*, 391-450.

Etkina, E., Karelina, A., Ruibal-Villasenor, M., Rosengrant, D., Jordan, R., & Hmelo-Silver, C. E. (2010). Design and reflection help students develop scientific abilities: Learning in introductory physics laboratories. *Journal of the Learning Sciences, 19*, 54-98.

Eysink, T. H. S., de Jong, T., Berthold, K., Kollöffel, B., Opfermann, M., & Wouters, P. (2009). Learner performance in multimedia learning arrangements: An analysis across instructional approaches. *American Educational Research Journal, 46*, 1107-1149. doi: 10.3102/0002831209340235

Feisel, L. D., & Rosa, A. J. (2005). The role of the laboratory in undergraduate engineering education. *Journal of Engineering Education, 94*, 121-130.

Fretz, E. B., Wu, H., Zhang, B. H., Davis, E. A., Krajcik, J. S., & Soloway, E. (2002). An investigation of software scaffolds supporting modeling practices. *Research in Science Education, 32*, 567-589. doi: 10.1023/a:1022400817926

Friedman, D. B., Crews, T. B., Caicedo, J. M., Besley, J. C., Weinberg, J., & Freeman, M. L. (2010). An exploration into inquiry-based learning by a multidisciplinary group of higher education faculty. *Higher Education, 59*, 765-783.

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching. *Review of Educational Research, 82*, 300-329. doi: 10.3102/0034654312457206

Garcia-Zubia, J., & Alves, G. R. (Eds.). (2012). *Using remote labs in education*. Duesto (Spain): University of Deusto

Gijlers, H., & de Jong, T. (2005). The relation between prior knowledge and students' collaborative discovery learning processes. *Journal of Research in Science Teaching, 42*, 264-282. doi: 10.1002/tea.20056

Gilbert, A. (2009). Utilizing science philosophy statements to facilitate k-3 teacher candidates' development of inquiry-based science practice. *Early Childhood Education Journal, 36*, 431-438.

Glaser, R., Raghavan, K., & Schauble, L. (1988). *Voltaville, a discovery environment to explore the laws of dc circuits.* Paper presented at the Proceedings of the ITS 1988, Montreal: University of Montreal.

Glaser, R., Schauble, L., Raghavan, K., & Zeitz, C. (1992). Scientific reasoning across different domains. In E. d. Corte, M. Linn, H. Mandl & L. Verschaffel (Eds.), *Computer-based* *learning environments and problem solving* (pp. 345-373). Berlin, Germany: Springer-Verlag.

Gomes, L., & Bogosyan, S. (2009). Current trends in remote laboratories. *IEEE Transactions on Industrial Electronics, 56*, 4744- 4756.

Graesser, A. C., Wiley, J., Goldman, S. R., O'Reilly, T., Jeon, M., & McDaniel, B. (2007). Seek web tutor: Fostering a critical stance while exploring the causes of volcanic eruption. *Metacognition and Learning, 2*, 89-105. doi: 10.1007/s11409-007-9013-x

Gunawardena, C. N., Ortegano-Layne, L., Carabajal, K., Frechette, C., Lindemann, K., & Jennings, B. (2006). New model, new strategies: Instructional design for building online wisdom communities. *Distance Education, 27*, 217-232. doi: 10.1080/01587910600789613

Gutwill, J. P., & Allen, S. (2012). Deepening students' scientific inquiry skills during a science museum field trip. *Journal of the Learning Sciences, 21*, 130-181. doi: 10.1080/10508406.2011.555938

Hagemans, M. G., van der Meij, H., & de Jong, T. (2013). The effects of a concept map-based support tool on simulation-based inquiry learning. *Journal of Educational Psychology, 105*, 1-24. doi: 10.1037/a0029433

Han, I., & Black, J. B. (2011). Incorporating haptic feedback in a simulation for learning physics. *Computers & Education, 57*, 2281-2290. doi: 10.1016/j.compedu.2011.06.012

Hand, B., Wallace, C. W., & Yang, E. M. (2004). Using a science writing heuristic to enhance learning outcomes from laboratory activities in seventhβ€• grade science: Quantitative and qualitative aspects. *International Journal of Science Education, 26*, 131-149. doi: 10.1080/0950069032000070252

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and clark (2006). *Educational Psychologist, 42*, 99-107. doi: 10.1080/00461520701263368

Hoan Cho, Y., & Jonassen, D. H. (2012). Learning by self-explaining casual diagrams in high-school biology. *Asia Pacific Education Review, 13*, 171-184.

Jaakkola, T., & Nurmi, S. (2008). Fostering elementary school students' understanding of simple electricity by combining simulation and laboratory activities. *Journal of Computer Assisted Learning, 24*, 271-283. doi: 10.1111/j.1365-2729.2007.00259.x

Jackson, S., Stratford, S. J., Krajcik, J., & Soloway, E. (1996). Making dynamic modeling accessible to pre-college science students. *Interactive Learning Environments, 4*, 233-257.

Justice, C., Warry, W., Cuneo, C. I., Inglis, S., Miller, S., Rice, J., & Sammon, S. (2001). A grammar for inquiry: Linking goals and methods in a collaboratively taught social sciences inquiry course. *The Alan Blizzard Award*.

Keys, C. W. (2000). Investigating the thinking processes of eighth grade writers during the composition of a scientific laboratory report. *Journal of Research in Science Teaching, 37*, 676-690. doi: 10.1002/1098-2736(200009)37:7<676::AID-TEA4>3.0.CO;2-6

Keys, C. W., Hand, B., Prain, V., & Collins, S. (1999). Using the science writing heuristic as a tool for learning from laboratory investigations in secondary science. *Journal of Research in Science Teaching, 36*, 1065-1084. doi: 10.1002/(SICI)1098-2736(199912)36:10<1065::AID-TEA2>3.0.CO;2-I

Kim, H. J., & Pedersen, S. (2011). Advancing young adolescents' hypothesis-development performance in a computer-supported and problem-based learning environment. *Computers & Education, 57*, 1780-1789. doi: 10.1016/j.compedu.2011.03.014

Klahr, D., & Dunbar, K. (1988). Dual space search during scientific reasoning. *Cognitive Science, 12*, 1-48.

Klahr, D., Fay, A. L., & Dunbar, K. (1993). Heuristics for scientific experimentation: A developmental study. *Cognitive Psychology, 25*, 11-146. doi: 10.1006/cogp.1993.1003

Kolloffel, B., & de Jong, T. (in press). Conceptual understanding of electrical circuits in secondary vocational engineering education: Combining traditional instruction with inquiry learning in a virtual lab. *Journal of Engineering Education*.

Krajcik, J. S. (Producer). (n.d.). Model-it. Retrieved from http://www.edu-design-principles.org/dp/viewFeatureDetail.php?feKey=273

Kuhn, D., & Dean, J. (2008). Scaffolded development of inquiry skills in academically disadvantaged middle-school students. *Journal of Psychology of Science and Technology, 1*, 36-50.

Kuhn, D., & Pease, M. (2008). What needs to develop in the development of inquiry skills? *Cognition and Instruction, 26*, 512-559. doi: 10.1080/07370000802391745

Kulkarni, D., & Simon, H. A. (1988). The processes of scientific discovery: The strategy of experimentation. *Cognitive Science, 12*, 139-175. doi: 10.1207/s15516709cog1202_1

Kunsting, J., Wirth, J., & Paas, F. (2011). The goal specificity effect on strategy use and instructional efficiency during computer-based scientific discovery learning. *Computers & Education, 56*, 668-679. doi: 10.1016/j.compedu.2010.10.009

Kyza, E., Michael, G., & Constantinou, C. (2007). *The rationale, design, and implementation of a web-based inquiry learning environment.* Paper presented at the Contemporary Perspectives on New Technologies in Science and Education, Proceedings of the Eighth International Conference on Computer Based Learning in Science, Crete, Greece.

Lajoie, S. P., Lavigne, N. C., Guerrera, C., & Munsie, S. D. (2001). Constructing knowledge in the context of bioworld. *Instructional Science, 29*, 155-186.

Langley, P. (1981). Data-driven discovery of physical laws. *Cognitive Science, 5*, 31-54. doi: 10.1111/j.1551-6708.1981.tb00869.x

Larrotta, C. (2007). Inquiry in the adult classroom: An ESL literacy experience. *Adult Learning, 18*, 25-29.

Lee, H., Lim, K., & Grabowski, B. L. (2010). Improving self-regulation, learning strategy use, and achievement with metacognitive feedback. *Educational Technology Research and Development, 58*, 629-648. doi: 10.1007/s11423-010-9153-6

Lewis, E. L., Stern, J. L., & Linn, M. C. (1993). The effect of computer simulations on introductory thermodynamics understanding. *Educational Technology, 33*, 45-58.

Lim, B. (2004). Challenges and issues in designing inquiry on the web. *British Journal of Educational Technology, 35*, 627-643. doi: 10.1111/j.0007-1013.2004.00419.x

Lin, X. D., & Lehman, J. D. (1999). Supporting learning of variable control in a computer-based biology environment: Effects of prompting college students to reflect on their own thinking. *Journal of Research in Science Teaching, 36*, 837-858.

Llewellyn, D. (2002). *Inquire within: Implementing inquiry-based science standards.* Thousand Oaks, CA.: Corwin Press.

Löhner, S., van Joolingen, W. R., & Savelsbergh, E. R. (2003). The effect of external representation on constructing computer models of complex phenomena. *Instructional Science, 31*, 395-418.

Luchini, K., Quintana, C., & Soloway, E. (2003). *Pocket picomap: A case study in designing and assessing a handheld concept mapping tool for learners*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Ft. Lauderdale, Florida, USA.

MacGregor, S. K., & Lou, Y. (2004). Web-based learning: How task scaffolding and web site design support knowledge acquisition. *Journal of Research on Technology in Education, 37*, 161-175.

Mäeots, M., Pedaste, M., & Sarapuu, T. (2008, July 1-5). *Transforming students' inquiry skills with computer-based simulations.* Paper presented at the 8th IEEE International Confernce on Advanced Learning Technologies, Santander, Spain.

Manlove, S., Lazonder, A. W., & de Jong, T. (2007). Software scaffolds to promote regulation during scientific inquiry learning. *Metacognition & Learning, 2*, 141-155. doi: 10.1007/s11409-007-9012-y

Manlove, S., Lazonder, A. W., & de Jong, T. (2009). Trends and issues of regulative support use during inquiry learning: Patterns from three studies. *Computers in Human Behavior, 25*, 795-803. doi: 10.1016/j.chb.2008.07.010

Marschner, J., Thillmann, H., Wirth, J., & Leutner, D. (2012). How can the use of strategies for experimentation be fostered? *Zeitschrift Fur Erziehungswissenschaft, 15*, 77-93. doi: 10.1007/s11618-012-0260-5

Marshall, J. A., & Young, E. S. (2006). Preservice teachers' theory development in physical and simulated environments. *Journal of Research in Science Teaching, 43*, 907-937. doi: 10.1002/tea.20124

Martinez, G., Naranjo, F. L., Perez, A. L., Suero, M. I., & Pardo, P. J. (2011). Comparative study of the effectiveness of three learning environments: Hyper-realistic virtual simulations, traditional schematic simulations and traditional laboratory. *Physical Review Special Topics-Physics Education Research, 7*. doi: 10.1103/PhysRevSTPER.7.020111

McElhaney, K. W., & Linn, M. C. (2011). Investigations of a complex, realistic task: Intentional, unsystematic, and exhaustive experimenters. *Journal of Research in Science Teaching, 48*, 745-770. doi: 10.1002/tea.20423

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *Journal of the Learning Sciences, 15*, 153-191. doi: 10.1207/s15327809jls1502_1

Meyerson, P., & Secules, T. (2001). Inquiry cycles can make social studies meaningful—learning about the controversy in Kosovo. *The Social Studies, 92*, 267-271. doi: 10.1080/00377990109604014

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction - what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*, 474-496. doi: 10.1002/tea.20347

Molenaar, I., van Boxtel, C. A. M., & Sleegers, P. J. C. (2010). The effects of scaffolding metacognitive activities in small groups. *Computers in Human Behavior, 26*, 1727-1738. doi: 10.1016/j.chb.2010.06.022

Moos, D. C., & Azevedo, R. (2008). Exploring the fluctuation of motivation and use of self-regulatory processes during learning with hypermedia. *Instructional Science, 36*, 203-231. doi: 10.1007/s11251-007-9028-3

Moreno, R., Mayer, R. E., Spires, H. A., & Lester, J. C. (2001). The case for social agency in computer-based teaching: Do students learn more deeply when they interact with animated pedagogical agents? *Cognition and Instruction, 19*, 177-213.

Mulder, Y. G., Lazonder, A. W., & de Jong, T. (2011). Comparing two types of model progression in an inquiry learning environment with modelling facilities. *Learning and Instruction, 21*, 614-624. doi: 10.1016/j.learninstruc.2011.01.003

National Research Council. (1996). *National science education standards*. Washington, D.C.: National Academy Press.

National Research Council. (2006). *America's lab report: Investigations in high school science*. Washington, DC: National Academy Press.

Njoo, M., & de Jong, T. (1993). Exploratory learning with a computer simulation for control theory: Learning processes and instructional support. *Journal of Research in Science Teaching, 30*, 821-844. doi: 10.1002/tea.3660300803

Olympiou, G., & Zacharia, Z. C. (2012). Blending physical and virtual manipulatives: An effort to improve students' conceptual understanding through science laboratory experimentation. *Science Education, 96*, 21-47. doi: 10.1002/sce.20463

Olympiou, G., Zacharias, Z., & de Jong, T. (2013). Making the invisible visible: Enhancing students' conceptual understanding by introducing representations of abstract objects in a simulation. *Instructional Science, 41*, 575-596. doi: 10.1007/s11251-012-9245-2

Oshima, J., Oshima, R., Murayama, I., Inagaki, S., Takenaka, M., Yamamoto, T., . . . Nakayama, H. (2006). Knowledge-building activity structures in japanese elementary science pedagogy. *International Journal of Computer-Supported Collaborative Learning, 1*, 229-246. doi: 10.1007/s11412-006-8995-8

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*, 1-4.

Palincsar, A. S., Collins, K. M., Marano, N. L., & Magnusson, S. J. (2000). Investigating the engagement and learning of students with learning disabilities in guided inquiry science teaching. *Language, Speech & Hearing Services in Schools, 31*, 240-251.

Polya, G. (1945). *How to solve it .* Princeton, NJ: Princeton University Press.

Popov, O., & Tevel, I. (2007). Developing prospective physics teachers' skills of independent experimental work using outdoors approach. *Journal of Baltic Science Education, 6*, 47-57.

Puntambekar, S., & Kolodner, J. L. (2005). Toward implementing distributed scaffolding: Helping students learn science from design. *Journal of Research in Science Teaching, 42*, 185-217.

Pyatt, K., & Sims, R. (2012). Virtual and physical experimentation in inquiry-based science labs: Attitudes, performance and access. *Journal of Science Education and Technology, 21*, 133-147. doi: 10.1007/s10956-011-9291-6

Qing, L., Moorman, L., & Dyjur, P. (2010). Inquiry-based learning and e-mentoring via videoconference: A study of mathematics and science learning of Canadian rural students. *Educational Technology Research & Development, 58*, 729-753. doi: 10.1007/s11423-010-9156-3

Quinn, J., & Alessi, S. (1994). The effects of simulation complexity and hypothesis generation strategy on learning. *Journal of Research on Computing in Education, 27*, 75-91.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., . . . Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *The Journal of the Learning Sciences, 13*, 337-387. doi: 10.1207/s15327809jls1303_4

Reimann, P. (1991). Detecting functional relations in a computerized discovery environment. *Learning and Instruction, 1*, 45-65. doi: 10.1016/0959-4752(91)90018-4

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *The Journal of the Learning Sciences, 13*, 273-304.

Reiser, B. J., Tabak, I., Sandoval, W. A., Smith, B., Steinmuller, F., & Leone, T. J. (2001). Bguile: Strategic and conceptual scaffolds for scientific inquiry in biology classrooms. In S. M. Carver & D. Klahr (Eds.), *Cognition and instruction: Twenty five years of progress* (pp. 263-305). Mahwah, NJ: Lawrence Erlbaum Associates.

Rieber, L. P., & Parmley, M. W. (1995). To teach or not to teach? Comparing the use of computer-based simulations in deductive versus inductive approaches to learning with adults in science. *Journal of Educational Computing Research, 14*, 359-374.

Sao Pedro, M. A., Baker, R. S. J., Gobert, J. D., Montalvo, O., & Nakama, A. (2013). Leveraging machine-learned detectors of systematic inquiry behavior to estimate and predict transfer of inquiry skill. *User Modeling and User-Adapted Interaction, 23*, 1-39. doi: 10.1007/s11257-011-9101-0

Scanlon, E., Anastopoulou, S., Kerawalla, L., & Mulholland, P. (2011). How technology resources can be used to represent personal inquiry and support students' understanding of it across contexts. *Journal of Computer Assisted Learning, 27*, 516-529. doi: 10.1111/j.1365-2729.2011.00414.x

Schauble, L., Glaser, R., Raghavan, K., & Reiner, M. (1991). Causal models and experimentation strategies in scientific reasoning. *The Journal of the Learning Sciences, 1*, 201-238.

Schiffhauer, S., Gößling, J., Wirth, J., Bergs, M., Walpuski, M., & Sumfleth, E. (2012). *Fostering experimental skills by a combination of hands-on and computer-based learning-environments*. Paper presented at the AERA, Vacouver (Canada).

Schoenfeld, A. (1979). Can heuristics be taught? . In J. Lochhead & J. Clement (Eds.), *Cognitive process instruction* (pp. 315-338). Philadelphia: Franklin Institute Press.

Schoenfeld, A. H. (1985). *Mathematical problem solving*. New York: Academic Press.

Schunn, C. D., & Anderson, J. R. (1999). The generality/specificity of expertise in scientific reasoning. *Cognitive Science, 23*, 337-370.

Schwartz, D. L., Lin, X., Brophy, S., & Bransford, J. D. (1999). Toward the development of flexibly adaptive instructional designs. In C. M. Reigeluth (Ed.), *Instructional-design theories and models: A new paradigm of instructional theory* (Vol. 2, pp. 183-213). Mahwah, NJ.: Erlbaum.

Shute, V. J. (1993). A comparison of learning environments: All that glitters. In S. P. Lajoie & S. J. Derry (Eds.), *Computers as cognitive tools* (pp. 47-74). Hillsdale, NJ: Lawrence Erlbaum.

Shute, V. J., & Glaser, R. (1990). A large-scale evaluation of an intelligent discovery world: Smithtown. *Interactive Learning Environments, 1*, 51-77.

Slotta, J. (2004). The web-based inquiry science environment (wise): Scaffolding knowledge integration in the science classroom. In M. Linn, E. A. Davis & P. Bell (Eds.), *Internet environments for science education* (pp. 203-233). Mahwah, NJ: Lawrence Erlbaum Associates.

Smith, B. K., & Reiser, B. J. (1997). *What should a wildebeest say? Interactive nature films for high school classrooms.* Paper presented at the ACM Multimedia Seattle.

Smyrnaiou, Z., Foteini, M., & Kynigos, C. (2012). Students' constructionist game modelling activities as part of inquiry learning processes. *Electronic Journal of e-Learning, 10*, 235-248.

Spronken-Smith, R., & Kingham, S. (2009). Strengthening teaching and research links: The case of a pollution exposure inquiry project. *Journal of Geography in Higher Education, 33*, 241-253. doi: 10.1080/03098260802276813

Stahl, E., & Bromme, R. (2009). Not everybody needs help to seek help: Surprising effects of metacognitive instructions to foster help-seeking in an online-learning environment. *Computers & Education, 53*, 1020-1028. doi: 10.1016/j.compedu.2008.10.004

Steed, M. (1992). Stella, a simulation construction kit: Cognitive process and educational implications. *Journal of Computers in Mathematics and Science Teaching, 11*, 39-52.

Steinke, P., & Fitch, P. (2011). Outcome assessment from the perspective of psychological science: The TAIM approach. *New Directions for Institutional Research, 2011*, 15-26. doi: 10.1002/ir.377

Suthers, D., & Jones, D. (1997). *An architecture for intelligent collaborative educational systems.* Paper presented at the 8th World Conference on Artificial Intelligence in Education, Kobe: Japan.

Swaak, J., van Joolingen, W. R., & de Jong, T. (1998). Supporting simulation-based learning; the effects of model progression and assignments on definitional and intuitive knowledge. *Learning and Instruction, 8*, 235-253. doi: 10.1016/S0959-4752(98)00018-8

Tatar, N. (2012). Inquiry-based science laboratories: An analysis of pre-service teachers' beliefs about learning science through inquiry and their performances. *Journal of Baltic Science Education, 11*, 248-266.

Thillmann, H., Künsting, J., Wirth, J., & Leutner, D. (2009). Is it merely a question of "what" to prompt or also "when" to prompt? *Zeitschrift für Pädagogische Psychologie, 23*, 105-115. doi: 10.1024/1010-0652.23.2.105

Toth, E. E., Ludvico, L. R., & Morrow, B. L. (2012). Blended inquiry with hands-on and virtual laboratories: The role of perceptual features during knowledge construction. *Interactive Learning Environments*, 1-17. doi: 10.1080/10494820.2012.693102

Toth, E. E., Morrow, B., & Ludvico, L. (2009). Designing blended inquiry learning in a laboratory context: A study of incorporating hands-on and virtual laboratories. *Innovative Higher Education, 33*, 333-344.

Toth, E. E., Suthers, D. D., & Lesgold, A. M. (2002). "Mapping to know": The effects of representational guidance and reflective assessment on scientific inquiry. *Science Education, 86*, 264-286.

Tschirgi, J. E. (1980). Sensible reasoning: A hypothesis about hypothesis. *Child Development, 51*, 1-10.

Valanides, N., & Angeli, C. (2008). Distributed cognition in a sixth-grade classroom: An attempt to overcome alternative conceptions about light and color. *Journal of Research on Technology in Education, 40*, 309-336.

van Joolingen, W. R. (1998). Cognitive tools for discovery learning. *International Journal of Artificial Intelligence in Education (IJAIED), 10*, 385-397.

van Joolingen, W. R., & de Jong, T. (1991). Supporting hypothesis generation by learners exploring an interactive computer simulation. *Instructional Science, 20*, 389-404. doi: 10.1007/BF00116355

van Joolingen, W. R., & de Jong, T. (2003). Simquest: Authoring educational simulations. In T. Murray, S. Blessing & S. Ainsworth (Eds.), *Authoring tools for advanced technology educational software: Toward cost-effective production of adaptive, interactive, and intelligent educational software* (pp. 1-31). Dordrecht: Kluwer Academic Publishers.

van Joolingen, W. R., de Jong, T., & Dimitrakopoulou, A. (2007). Issues in computer supported inquiry learning in science. *Journal of Computer Assisted Learning*, 111-119. doi: 10.1111/j.1365-2729.2006.00216.x

van Joolingen, W. R., de Jong, T., Lazonder, A. W., Savelsbergh, E., & Manlove, S. (2005). Co-Lab: Research and development of an on-line learning environment for collaborative scientific discovery learning. *Computers in Human Behavior, 21*, 671-688. doi: 10.1016/j.chb.2004.10.039

van Joolingen, W. R., & Zacharia, Z. C. (2009). Developments in inquiry learning. In N. Balacheff, S. Ludvigsen, T. de Jong, A. Lazonder & S. Barnes (Eds.), *Technology-enhanced learning* (pp. 21-37): Springer Netherlands.

Veermans, K. H. (2003). *Intelligent support for discovery learning.* PhD, University of Twente, Enschede.

Veermans, K. H., de Jong, T., & van Joolingen, W. R. (2000). Promoting self directed learning in simulation based discovery learning environments through intelligent support. *Interactive Learning Environments, 8*, 229-255. doi: 10.1076/1049-4820(200012)8:3;1-D;FT229

Veermans, K. H., van Joolingen, W. R., & de Jong, T. (2006). Using heuristics to facilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*, 341-361. doi: 10.1080/09500690500277615

Waldrop, M. M. (2013). The virtual lab. *Nature, 499*, 268-270 doi: 10.1038/499268a

Wall, K., Higgins, S., Glasner, E., Mahmout, U., & Gormally, J. (2009). Teacher enquiry as a tool for professional development: Investigating pupils' effective talk while learning. *The Australian Educational Researcher, 36*, 93-117. doi: 10.1007/bf03216901

Wecker, C., Kohnle, C., & Fischer, F. (2007). Computer literacy and inquiry learning: When geeks learn less. *Journal of Computer Assisted Learning, 23*, 133-144. doi: 10.1111/j.1365-2729.2006.00218.x

White, B. Y., & Frederiksen, J. (2005). A theoretical framework and approach for fostering metacognitive development *Educational Psychologist, 40*, 211-223.

White, B. Y., Frederiksen, J., Frederiksen, T., Eslinger, E., Loper, S., & Collins, A. (2002, October 23-26). *Inquiry island: Affordances of a multi-agent environment for scientific inquiry and reflective learning.* Paper presented at the Fifth International Conference of the Learning Sciences (ICLS), Seattle, WA.

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction, 16*, 3-118. doi: 10.1207/s1532690xci1601_2

White, B. Y., Shimoda, T. A., & Frederiksen, J. R. (1999). Enabling students to construct theories of collaborative inquiry and reflective learning: Computer support for metacognitive development. *International Journal of Artificial Intelligence in Education, 10*, 151-182.

Wichmann, A., & Leutner, D. (2009). Inquiry learning multilevel support with respect to inquiry, explanations and regulation during an inquiry cycle. *Zeitschrift Fur Padagogische Psychologie, 23*, 117-127. doi: 10.1024/1010-0652.23.2.117

Wilhelm, J. A., & Walters, K. L. (2006). Pre-service mathematics teachers become full participants in inquiry investigations. *International Journal of Mathematical Education in Science and Technology, 37*, 793-804. doi: 10.1080/00207390600723635

Wirth, J., Künsting, J., & Leutner, D. (2009). The impact of goal specificity and goal type on learning outcome and cognitive load. *Computers in Human Behavior, 25*, 299-305. doi: 10.1016/j.chb.2008.12.004

Woolf, B. P., Reid, J., Stillings, N., Bruno, M., Murray, D., Reese, P., . . . Rath, K. (2002). A general platform for inquiry learning. In S. Cerri, G. Gouardères & F. Paraguaçu (Eds.), *Intelligent tutoring systems* (Vol. 2363, pp. 681-697): Springer Berlin Heidelberg.

Wu, H. K., Hsu, Y. S., & Hwang, F. K. (2010). Designing a technology-enhanced learning environment to support scientific modeling. *Turkish Online Journal of Educational Technology, 9*, 58-65.

Yaman, M., Nerdel, C., & Bayrhuber, H. (2008). The effects of instructional support and learner interests when learning using computer simulations. *Computers & Education, 51*, 1784-1794. doi: 10.1016/j.compedu.2008.05.009

Youngquist, J., & Pataray-Ching, J. (2004). Revisiting "play": Analyzing and articulating acts of inquiry. *Early Childhood Education Journal, 31*, 171-178. doi: 10.1023/B:ECEJ.0000012135.73710.0c

Zacharia, Z. C. (2007). Comparing and combining real and virtual experimentation: An effort to enhance students' conceptual understanding of electric circuits. *Journal of Computer Assisted Learning, 23*, 120-132. doi: 10.1111/j.1365-2729.2006.00215.x

Zacharia, Z. C., Olympiou, G., & Papaevripidou, M. (2008). Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature. *Journal of Research in Science Teaching, 45*, 1021-1035. doi: 10.1002/tea.20260

Zhang, J., Chen, Q., Sun, Y., & Reid, D. J. (2004). Triple scheme of learning support design for scientific discovery learning based on computer simulation: Experimental research. *Journal of Computer Assisted Learning, 20*, 269-282. doi: 10.1111/j.1365-2729.2004.00062.x

Zhang, M., & Quintana, C. (2012). Scaffolding strategies for supporting middle school students' online inquiry processes. *Computers & Education, 58*, 181-196. doi: 10.1016/j.compedu.2011.07.016

Zumbach, J. (2009). The role of graphical and text based argumentation tools in hypermedia learning. *Computers in Human Behavior, 25*, 811-817. doi: 10.1016/j.chb.2008.07.005

Appendix 1. Articles describing inquiry phases

Reference	Information gathered from the papers[3]	Domain covered (name of the domain)	List of inquiry phases[4]			
			List	based on theoretical / empirical information	validity of the results (present / absent)	reliability of the results (present /absent)
Bruce and Casey (2012)	1	N/A	Ask, Investigate, Create, Discuss, Reflect (Bruce & Davidson, 1999; Bruce and Bishop (2002); Community of Informatics Initiative ())	Theoretical	N	N
Meyerson and Secules (2001)	1	Social studies	Anchor, Generate, Research, Debate, Offer Solution	Theoretical	N	N
Larrotta (2007)	1	Inquiry in the Adult Classroom	Observe, Wonder, Explain, Generate Theory	Theoretical	N	N
Conole, et al. (2010)	1	Healthy eating	Find My Topic, Decide My Inquiry Question Or Hypothesis, Plan My Methods, Equipment And Actions, Collect My Evidence, Analyse And Represent My Evidence, My Conclusions, Share And Discuss My Inquiry (Anastopoulou et al., 2009)	Theoretical	N	N
Valanides and Angeli (2008)	1		Conduct Observation, Recording And Organizing Data, Discussing With Others, Drawing Conclusions, Reasoning With Evidence About A Phenomenon	Theoretical	N	Y
Spronken-Smith and Kingham (2009)	1	Geography	Developing A Question, Determining What Needs To Be Known, Identifying Resources, Gathering Data, Assessing Data, Synthesising, Communicating New Understandings, Evaluating Success (Justice, et al., 2001, p. 19)	Theoretical	N	N
Youngquist and Pataray-Ching (2004)	1	Early Childhood Classroom	Observation, Initial Inquiry Question, Sign System Exploration, Analysis, Transmediation, Refinement, Celebration, New/Further Inquiries (adapted from Short And Harste, with Burke's, 1996)	Theoretical	N	N
Gilbert (2009)	1,2	Early Childhood	5 E Inquiry Cycle: Engage, Explore, Explain, Elaborate, Evaluate (Llewellyn (2002); Boddy, Watson, Aubusson, 2003)	Theoretical	N	N

[3] 1 = descriptions of inquiry phases; 2 = descriptions of inquiry path-ways and/or cycles
[4] If the inquiry cycle used came from another source, this original reference is indicated. These original references are not included in the list of references of the Deliverable.

Wilhelm and Walters (2006)	1,2	Mathematics Science	Llewelyn's Inquiry Model: Introducing A Topic, Assessing Prior Knowledge, Providing Exploration, Raising And Revising Questions, Brainstorming Solutions, Carrying Out A Plan, Collecting Data, Organizing Data, Finding Relationships And Drawing Conclusions, Communicating Results, Comparing New Knowledge To Prior Knowledge, Applying Knowledge To New Situations, Stating A New Question To Investigate (Llewellyn, 2002)	Empirical	N	N
Lim (2004)	1,2	Designing inquiries on the web	Ask, Plan, Explore, Construct, Reflect	Theoretical	N	N
Kuhn and Dean (2008)	1	Educationally disadvantaged, low-achieving middle-school students	Intent (Identifying The Question To Be Asked), Analysis (Designing An Investigation, And Interpreting Data), Inference (Drawing Conclusions), Argument (Entering Claims Into Scientific Discourse) (Kuhn, 2001, 2002, 2005)	Theoretical	N	N
Wecker, Kohnle, and Fischer (2007)	1	computer literacy	Hypothesis Generation, Experiment Design, Data Interpretation (de Jong & van Joolingen, 1998; Schwartz, Lin, Brophy, & Bransford, 1999; van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005)	Theoretical	N	N
White and Frederiksen (2005)	1,2	Mathematics	Question, Hypothesize, Investigate, Analyze, Model, Evaluate (White & Frederiksen, 1998); Eslinger, White, Frederiksen & Brobst, 2008)	Theoretical	N	N
van Joolingen, de Jong, and Dimitrakopoulou (2007)	1		Orientation, Hypothesis Generation, Experimentation, Conclusion, Evaluation (De Jong 2006)	Theoretical	N	N
Wall, Higgins, Glasner, Mahmout, and Gormally (2009)	1,2		Cycle1: Define Problem, Needs Assessment, Hypothesise Ideas, Develop Action Plan, Implement Plan, Evaluate Action, Decisions (Reflect, Explain, Understand Action) Cycle 2: Redefine Problem, Needs Assessment, New Hypothesis, Revise Action Plan, Implement Revised Plan, Evaluate Action, Decisions (Reflect, Explain, Understand Action) (Adapted From Kemmis & Mctaggarst, 1988)	Theoretical	N	N
Gunawardena et al. (2006)	1	Instructional design model	Learning Challenge (I.E., A Case, Problem, Or An Issue), Initial Exploration, Resources, Reflection, Preservation	Theoretical	N	N
Bevevino, Dengel, and Adams (1999)	1		Exploration, Discussion And Presentation Of New Content,	Theoretical	N	N

			Application And Expansion			
Etkina et al. (2010)	1	Physics	Observation, Find Patterns, Devise Explanations Or Mechanisms For The Patterns, Test The Explanations, Predict The Outcomes Of New Experiments, Apply New Knowledge To Solve Practical Problems (Etkina And Van Heuvelen, 2007)	Theoretical	N	N
(Palincsar, Collins, Marano, & Magnusson, 2000)	1	Learning Disabilities	Engage, Investigate, Explain, Report	Theoretical	N	N
(Popov & Tevel, 2007)	1	Physics	Question, Predict, Experiment, Model, Apply (White And Frederiksen, 2000)	Theoretical	N	N
(Steinke & Fitch, 2011)	1		Theory, Generate Testable Hypotheses, Collect And Analyze Data, Refine Theory (Kantowitz, Roediger, And Elmes, 2009)	Theoretical	N	N
(Smyrnaiou, Foteini, & Kynigos, 2012)	1		Orientation, Hypothesis Generation, Experimentation, Conclusion (De Jong and Van Joolingen, 2008)	Theoretical	N	N
(Zhang & Quintana, 2012)	1	Online inquiry, middle school	Online Inquiry: Generating A Scientific Question (Driving Question), Searching For Information On The Web, Evaluating And Making Sense Of Online Information, Integrating Different Pieces Of Information To Answer The Driving Question (Quintana, Zhang, & Krajcik, 2005)	Theoretical		
(Tatar, 2012)	1	Science laboratories	Ask Questions, Design Studies, Collect And Interpret Data, Draw Conclusions (NRC, 1996)	Theoretical	N	N
(Bell, Urhahne, Schanze, & Ploetzner, 2010)	1,2	Collaborative inquiry learning; Inquiry models	Orientation/Question, Hypothesis Generation, Planning, Investigation, Analysis/Interpretation, Model, Conclusion/Evaluation, Communication, Prediction	Theoretical (meta-analysis)	Y	Y
(Banerjee, 2010)	1	Inquiry model	Learner Investigates Scientifically Oriented Questions, Learner Gives Priority To Evidence In Responding To Questions, Learner Formulates Explanations From Evidence, Learner Connects Explanations To Scientific Knowledge, Learner Communicates And Justifies Explanations	Theoretical	N	N
(Qing, Moorman, & Dyjur, 2010)	1,2	Mathematics	Ask, Investigate, Create, Discuss, Reflect (Community Informatics Initiative, 2009)	Theoretical	N	N
(Friedman et al., 2010)		Higher Education	Ask, Investigate, Create, Discuss, Reflect (Community Informatics Initiative, 2009)	Theoretical	N	N
(Scanlon, et al., 2011)	1	Technology	Orientation, Set Up Inquiry Question, Plan Question, Conduct	Theoretical	N	N

			Investigation, Analyse Evidence, Draw Conclusions, Present Inquiry, Evaluate Inquiry (e.g White et al., 1999)			
(Gutwill & Allen, 2012)	1		Asking Questions, Making Predictions, Designing Experiments, Analyzing Data, Reasoning With Models, Drawing Conclusions, And Communicating Results (e.g., Minstrell & Van Zee, 2000; White & Frederiksen, 1998)	Theoretical	-	-
(Corlu & Corlu, 2012)	1	Physic teachers	Identifying The Problem, Analysing, Setting Hypotheses, Generating A Synthesis, Problem Solving And Developing A Course/Experiment	Theoretical	-	-
(Kuhn & Pease, 2008)	1	Middle-school students	Identification Of A Question Or Questions, Design Of An Investigation To Address Them, Examination And Analysis Of Empirical Data, Drawing Inferences And Conclusions And Justifying Them (Klahr, 2000; NRC, 1996), Identifying A Question, Accessing Data Of Their Choice To Address The Question, Analyzing These Data To Identify Patterns And Make Inferences, Drawing Conclusions And Making Judgments Based On Them	Theoretical	-	-

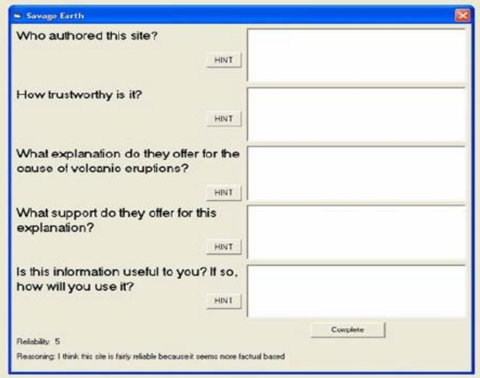
Appendix 2: Types of Guidance

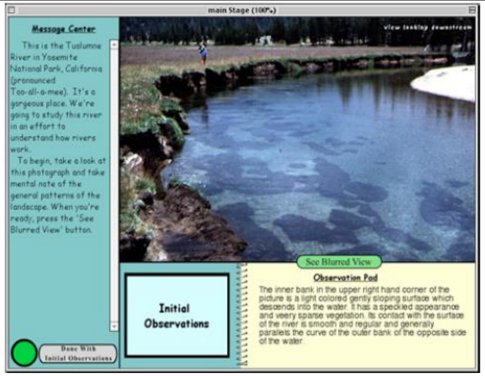
Types of Guidance

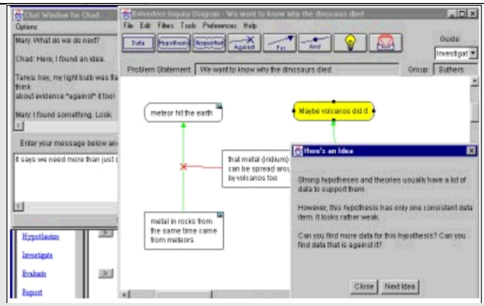
Process Constraints

Process	Guidance	Description (as described in the cited papers)	Findings (as described in the cited papers)	References
Orientation	Hint button – SEEK tutor	This facility contains "suggestions on how to effectively guide students' search" (on the Google™ search engine page). … The purpose is "to provide hints that are relevant to the planning phase of self-regulated learning" (Graesser, et al., 2007, p. 93).	"The presence of the SEEK Tutor did not increase the depth of inspecting reliable Websites, the ability to differentiate reliable versus unreliable sites, learning gains on a true–false statement verification task, or the quality of essays on the causes of the volcanic eruption. … SEEK Tutor did lead to more expressions of critical stance in the essay compared with the Navigation condition" (Graesser, et al., 2007, p. 98).	Graesser A., Wiley J., Goldman S., O'Reilly T., Jeon M. & McDaniel B. (2007). SEEK Web tutor: fostering a critical stance while Exploration the causes of volcanic eruption. *Metacognition and Learning 2,* 89–105.
	On-line ratings (pop-up windows) – SEEK tutor	"The on-line ratings asked students to evaluate the expected reliability of the information in a site by providing a rating and a rationale for their rating. The on-line rating window appears after the students view a particular Web site for 20 s. The students are		

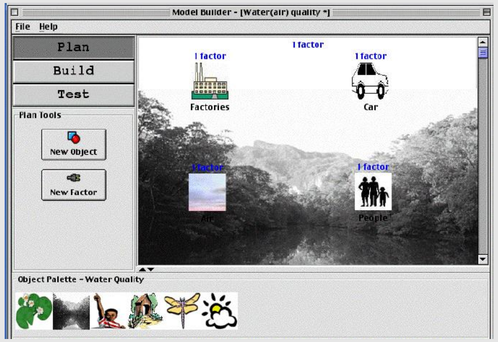
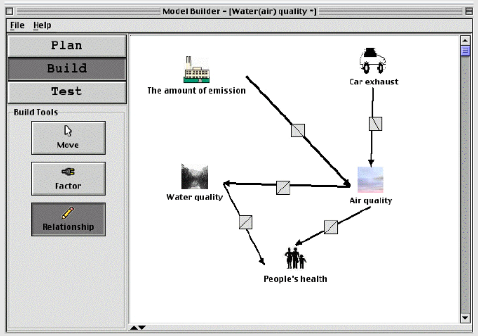
		asked to rate the site on reliability using a 6-point scale, where 6 is the most reliable. … The purpose of this facility was to encourage the metacognitive monitoring phase in self-regulated learning, particularly with respect to evaluating the quality of the Web site when they first encounter a site" (Graesser, et al., 2007, p. 94).		
	Note taking interface with questions and hints – SEEK tutor	When the reader exits a site a pop up window appears with five questions about the reliability of the site. "Each question had a Hint button that could be pressed to evoke spoken hints to guide the learners on answering each question. … The note-taking facility promotes the reflection phase of self-regulated learning by encouraging the learner to think about each of the five core aspects of critical stance and also to articulate verbally the reasons for their ratings" (Graesser, et al., 2007, p. 94).		

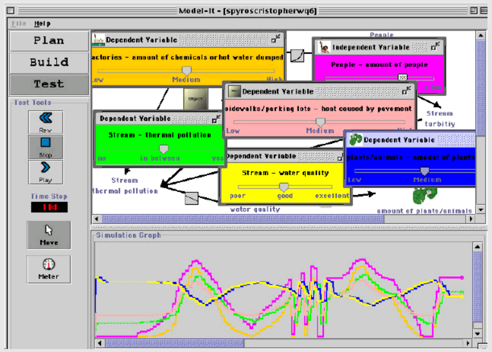
		 Note-taking facility (Graesser, et al., 2007)		
Conceptualisation (Question)	Tuolumne River Module – Support for Observation phase	“During the *Observation* phase, students organize their discussion around three questions: What do we know? What do we think we know?... What more we need to know? ... The software automatically recalls comments…” (Woolf et al., 2002, p. 6). The tools created for this phase are *Observation Pad* and *Identify focus of attention*.	No definite conclusions could be drawn for the effectiveness of this guidance.	Woolf, B., Reid, J., Stillings, N., Bruno, M., Murray, D., Reese, P., Peterfreund, A., & Rath, K. A general platform for inquiry learning. *Proceedings of the International Conference on Intelligent Tutoring Systems,* Biarritz, France, June, 2002. Retrieved from http://link.springer.com/chapter/10.1007%2F3-540-47987-2_69?LI=true

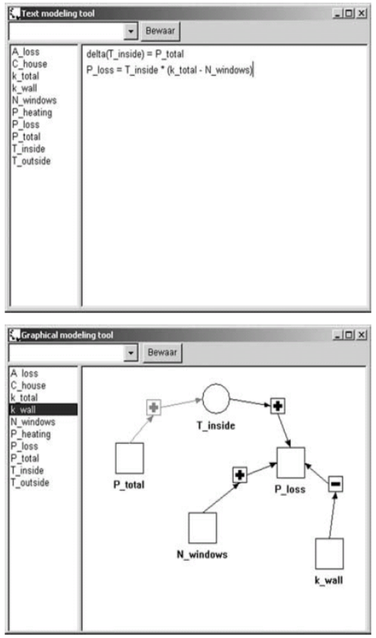
		 Observation Pad (Woolf, et al., 2002, p. 1).		
Conceptualisation-Investigation	Belvedere inquiry diagram	"In Belvedere, students work with realistic problems, collect data, set hypotheses etc. A so-called "inquiry diagram" is available to 'explore' the domain under study. This inquiry diagram is a kind of concept mapping tool dedicated to scientific inquiry. The diagram has pre-defined concepts such as "hypothesis" and "data," and also has pre-defined links to connect hypotheses and data. These links indicate whether the data support or conflict with a hypothesis." (de Jong, 2006b, p. 112).	"The inquiry diagram from Belvedere is useful not only for linking data and theory (thus supporting the process of 'conclusion') but is also intended to be used both in the *Orientation* phase when the main variables of the domain are entered in the diagram and in the hypothesis phase when relations are made more specific. Toth et al. (2002) report positive effects on "reasoning scores" for students using the Belvedere inquiry diagram as compared to students who used simple prose to express their view on the domain." (de Jong, 2006b, p. 112).	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier. Toth, E. E., Suthers, D. D., & Lesgold, A. M. (2002). "Mapping to know": The effects of representational guidance and reflective assessment on scientific inquiry. *Science Education, 86*, 264-286.

		 Belvedere inquiry diagram (Suthers & Jones, 1997)		Suthers, D. & Jones, D. (August, 1997). *An architecture for intelligent collaborative educational systems*. Paper presented at 8th World Conference on Artificial Intelligence in Education, Kobe: Japan
Investigation (Exploration-Experimentation)	Model progression	"The simulation model is presented in separated parts in which learners gain control over an increasing number of variables." (de Jong et al., 1999, p. 598) - "present different views on the domain to the learners by using more than one simulation model in the learning environment - use models that gradually increase from simple to complex, zoom in on parts of the model - present different representations of the model These support learners on the regulative aspects of the learning process, by demarcating different models, structuring the environment, and presenting an overview." (Veermans, 2003, p. 28).	"Model progression can lead to higher performance by learners (Alessi, 1995; Rieber & Parmley, 1995)" … "Quinn & Alessi (1994) argue otherwise. Model progression does not always help learners and so it is better to present to the learners the simulation on its full complexity all at once (Quinn & Alessi, 1994)." (de Jong, et al., 1999, p. 598) De Jong et al. (1999) found that the model progression didn't have an effect on students' intuitive knowledge.	Veermans, K. H. (2003). Intelligent support for discovery learning. Ph.D. thesis, University of Twente. de Jong, T., Martin, E., Zamaro, J. M., Esquembre, F., Swaak, J., & van Joolingen, W. R. (1999). The integration of computer simulation and learning support: An example from physics domain on collisions. *Journal of Research in Science Teaching, 36*(5), 597-615. Alessi, S.M. (1995, April). Dynamic vs. static fidelity in a procedural simulation.

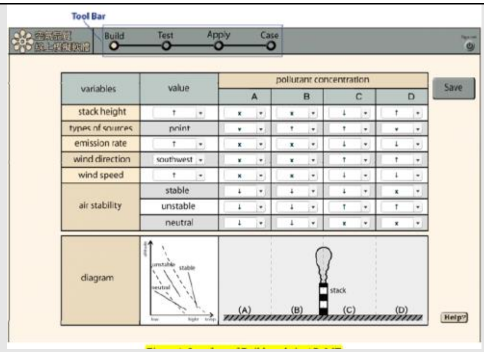
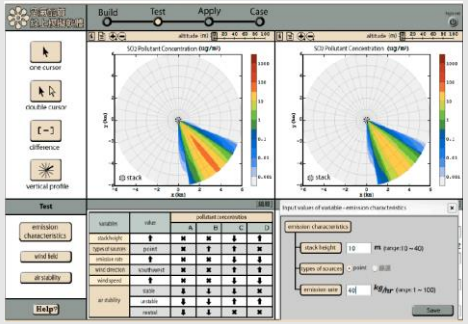
				Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA. Rieber, L.P., & Parmley, M.W. (1995). To teach or not to teach? Comparing the use of computer-based simulations in deductive versus inductive approaches to learning with adults in science. *Journal of Educational Computing Research, 14*, 359–374. Quinn, J., & Alessi, S. (1994). The effects of simulation complexity and hypothesis generation strategy on learning. *Journal of Research on Computing in Education, 27*, 75–91.
Investigation (Exploration-Experimentation-Data Interpretation)	Process map (Model-It software)	"The process map (Figure 1) breaks the modelling process into three modes, to allow the learners to master the modelling process in steps and to reduce the complexity of the modelling task. … For example, as the learner is starting the model, in	"…seventh grade students were able to use the intentionally designed process map to follow the initial sequence of modelling modes and use the modes opportunistically thereafter" (Fretz, et al., 2002, p.	Fretz, E. B, Wu, H. K., Zhang, B., Davis, E. A., Krajcik, J. S., & Soloway, E. (2002). An investigation of software scaffolds supporting modeling practices.

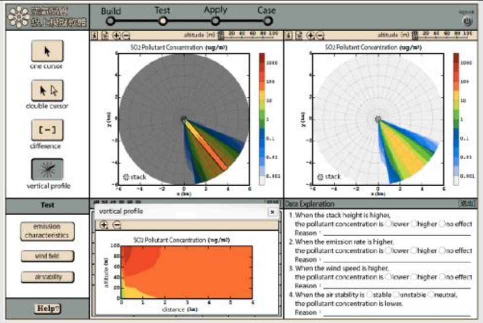
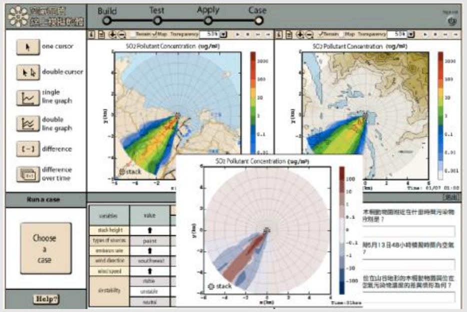
		plan mode, they have tools to create objects and variables, but not for creating relationships or testing. This ensures that the modelling task does not initially overwhelm the learners, and is intended to make it possible for the learners to shift between modes easily as their experience and skill increase" (Fretz, et al., 2002, pp. 571-572).  Plan mode (Krajcik, n.d.)  	579). "Learners did succeed in creating models" and "the general progression from planning to testing also shows that this scaffold succeeded in helping learners master the task of creating a model" (Fretz, et al., 2002, p. 583).	*Research in Science Education, 32*, 567-589. Krajcik, J. (nd). Model-It. Retrieved January 24, 2012, from *http://www.edu-design-principles.org/dp/viewFeatureDetail.php?feKey=273*

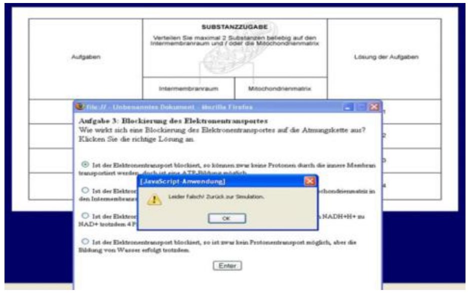
		Build mode (Krajcik, n.d.)  Test mode (Krajcik, n.d.)		
Investigation	Textual/Graphical modeling representation (SimQuest modeling tool)	"…*textual modeling representation*…uses text as primary representation. The information is externalized in the form of a list, the modeling language is quantitative, the primary model entities are variables and relations and the learner as to specify the exact from of complex relations…(in the) *graphical representation*…the primary representation is graphical, the structure of the model is visualized in a diagram, the modeling language is qualitative (or semi-quantitative), the primary model entities are the variables and complex relations are handled by the system…" (Löhner, van Joolingen, & Savelsbergh, 2003, p. 403).	"Students working with the graphical representation seemed to be making more use of the representation as an external working memory…In the textual representation this function was not used as much…For the graphical representation we found a negative correlation between the size of the search space and the modeling result... (while) for the textual representation we do not find this correlation…In the textual representation, students often begin with the same kind of reasoning…The graphical representation seems to invite more Investigation with the model…The different representations seem to	Löhner, S., van Joolingen, R.W., & Savelsbergh, R.E. (2003). The effect of external representation on constructing computer models of complex phenomena. *Instructional Science, 31*, 395-418.

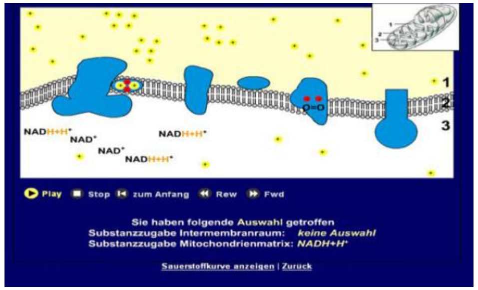
		 Textual modeling representation (top) and graphical modeling representation (bottom). (Löhner, et al., 2003, p. 404)	support different phases in the modeling process. The graphical representation leads the students to switching quickly from one relation to the next, and trying out every idea that comes up…In the text representation this kind of modeling is virtually impossible…Both forms of representation have their own particular role in the modeling process. Therefore, learners would need a mixed representation providing both benefits of easy Investigation and expression power." (Löhner, et al., 2003, pp. 414-416).	
Investigation (Exploration-Experimentation-Data Interpretation)	Air Pollution Modeling Tool (APoMT)	"APoMT decomposes the modeling processes into four modes: Build…, Test…, Apply, and Case…Two common features are embedded in every mode: Tool Bar and Help. The Tool Bar…provides a visual organizer that allows students to have access to functionality… (the Help feature) serves a role of expert guidance to help learners use the tool, understand the purposes of each mode, and apply	"…an implementation study…shows positive results (Wu, 2010)…The results indicated a significant improvement in conceptual understandings. In addition, students performed better on modeling abilities, such as planning, identifying variables, and testing models. These findings suggest that combining APoMT with well-designed learning lessons could	Wu, H.-K., Hsu, Y.-S., & Hwang, F.-K. (2010). Designing a technology-enhanced learning environment to support scientific modeling. *The Turkish Online Journal of Educational Technology, 9*(4), 58-64. Wu, H.-K. (2009).

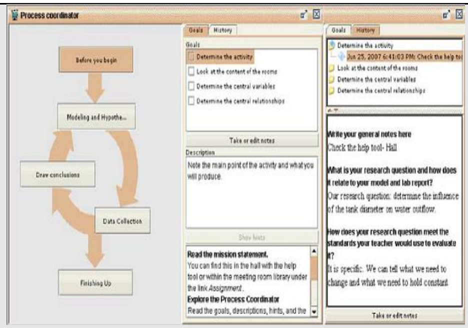
		science content to modeling…" (Wu, Hsu, & Hwang, 2010, p. 60). "In the build mode, the tool provides a Variable Table… (and) allows students to make prediction about relationships between variables and reveals students' own models before they collect simulated results…in test mode…,students could examine their models and test their hypotheses…Apply mode is also designed for students to manipulate variables, to visualize simulated results, and to describe their findings…(and) allows students to manipulate all variables at once and is designed to support a more sophisticated modeling process…In this mode (Case mode), students are asked to generalize their conclusions, apply their models and concepts learned to different case…" (Wu, et al., 2010, pp. 62-63).	effectively support students' development of conceptual understandings and modeling abilities." (Wu, Hsu, & Hwang, 2010, pp. 63-64).	Modeling a complex system: Using novice-expert analysis for developing an effective technology-enhanced learning environment. *International Journal of Science Education, 32*(2), 195-219.

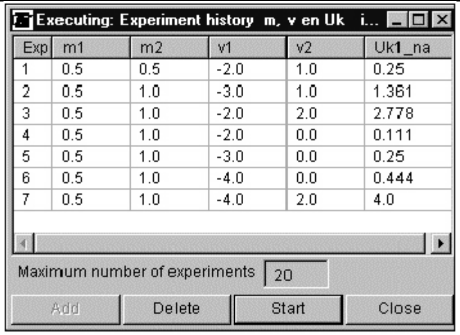
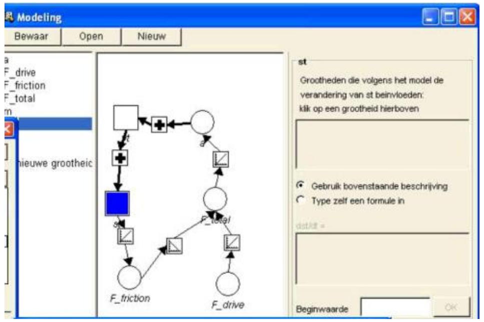
		 Build mode (Wu, et al., 2010, p. 60)  Test mode (Wu, et al., 2010, p. 61)		

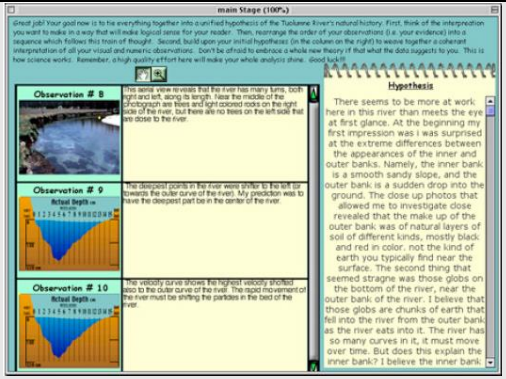
		 Test mode (Wu, et al., 2010, p. 62)  Case mode (Wu, et al., 2010, p. 63)		
Applies in multiple phases of the inquiry cycle	Instructional support (problem-solving tasks – feedback/worked-out examples)	“Problem-solving tasks consist of a task definition and answer choices…provided either in a yes/no or multiple choice format. After solving the problem independently, the learner gets feedback…either provides an explanation on why the given answer is false, and why a different choice would have been true, or is a request, instructing the learner	“Simulations incorporating worked-out examples have the potential to positively influence the learner’s situational-subject-interest in highly complex subject-matters. For learners with low individual subject-interest, both kinds of instructional support…were conductive to fostering gains in factual knowledge. When deeper understanding is	Yaman, M., Nerdel, C., & Bayrhuber, H. (2008). The effects of instructional support and learner interests when learning using computer simulations. Computer & Education, 51(4), 1784-1794.

		to review certain contents …Worked-out examples …consist of a task definition, a number of solution steps, and the final solution. They aim to support the learner's ability to solve a problem step by step…" (Yaman, Nerdel, & Bayrhuber, 2008, p. 1785).  "Simulation with problem-solving tasks: Pop-up window solution…" (Yaman, et al., 2008, p. 1788)  "Simulation with worked-out examples: Pop-up window with a step-by-step solution of the task with	concerned, worked-out examples are of particular benefit for learners with high individual subject-interest." (Yaman, et al., 2008, p. 1793). Crippen and Earl (2007), also found that "…a worked example with a tailored self-explanation prompt improves student performance, well-structured problem skill, and motivation" (p. 818).	Crippen, J.K., & Earl, L.B. (2007). The impact of web-based worked example and self-explanation on performance, problem solving, and self-efficacy. Computers & Education, 49(3), 809-821.

		reference to the simulation" (Yaman, et al., 2008, p. 1789).  "Simulation with worked-out examples. Exemplary pop-up window with a simulation" (Yaman, et al., 2008, p. 1789).		
Applies in multiple phases of the inquiry cycle	Process Coordinator/regulative support tool (in Co-Lab inquiry learning environment)	"This tool contained a process model, a preset goal hierarchy, and goal descriptions which outlined the phases students should process in performing their inquiry…Each goal came with one or more hints…proposed strategies for goal attainment…a note taking form" with self-explanation prompts and reason justification prompts and cues "reminded students to take notes…appeared as pop-ups in the environment" (Manlove, Lazonder, & de Jong, 2007, pp. 146-147).	Students who had access to the "full" version of the Process Coordinator tool, used the tool more often and wrote better lap reports than students who had access to an "empty" version of the tool. Surprisingly, the use of the "fully" versioned tool did not lead to the construction of better domain models. (Manlove, et al., 2007) Similar findings are reported in the study of Manlove, Lazonder and de Jong (2009) who also found that the Process Coordinator was effective in promoting goal viewing.	Manlove, S., Lazonder, W.A., & de Jong, T. (2007). Software scaffolds to promote regulation during scientific inquiry learning. *Metacognition and Learning, 2*(2), 141-155. Manlove, S., Lazonder, W.A., & de Jong, T. (2009). Trends and issues of regulative support use during inquiry learning: Patterns from three studies. *Computers in*

		 Process Coordinator (Manlove, et al., 2007, p. 146)		*Human Behavior, 25*(4), 795-803.
Performance Dashboard				
Investigation (Exploration-Experimentation)	Monitoring tool - SIMQUEST	"They can store experiments in the tool, which then presents the values of the variables in a table format. They can later replay experiments if they want to see them once more, or sort variables to compare different experiments" (Veermans, 2003, pp. 30-31).	"It supports the learners in monitoring their experiments with the simulation" (Veermans, 2003, p. 30). "At the specific level, a notebook facility for storing experiments (Reimann, 1991; Shute & Glaser, 1990) provides support for monitoring these experiments. In a similar vein, notebook facilities for hypotheses provide support for monitoring progress in the exploration of the domain on a higher level." (Veermans, 2003, p.	Veermans, K. H. (2003). Intelligent support for discovery learning. Ph.D. thesis, University of Twente. van Joolingen, W.R., & de Jong, T. (2003). SimQuest, authoring educational simulations. In: T. Murray, S. Blessing, S. Ainsworth: *Authoring Tools for Advanced Technology Learning Environments: Toward*

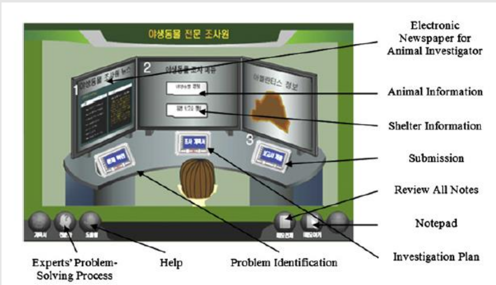
		 (Veermans, 2003, p. 58)  Monitoring tool/SimQuest (van Joolingen & de Jong, 2003)	12).	*cost-effective adaptive, interactive, ans intelligent educational software.* pp. 1-31. Dordrecht: Kluwer. Reimann, P. (1991). Detecting functional relations in a computerized discovery environment. *Learning and instruction, 1*, 45-65. Shute, V. J., & Glaser, R. (1990). A large-scale evaluation of an intelligent discovery world: Smithtown. *Interactive Learning Environments*, *1*, 51-77.
Conclusion	Tuolumne River Module – Support for Conclusion and final report phase	"In the *report* phase… the student writes the report within the context of the software, but is free to use a text processor and copy the report into the *Final Case Review Tool.*" (Woolf, et al., 2002, p. 8).	No definite conclusions could be drawn for the effectiveness of this scaffold.	Woolf, B., Reid, J., Stillings, N., Bruno, M., Murray, D., Reese, P., Peterfreund, A., & Rath, K. A general platform for inquiry learning. *Proceedings of the International Conference*

		 "During the last phase, an organized sequential review of observations and hypotheses is presented. The student can edit and re-order observations for the final report." (Woolf, et al., 2002, p. 4).		*on Intelligent Tutoring Systems,* Biarritz, France, June, 2002. Retrieved from http://link.springer.com/chapter/10.1007%2F3-540-47987-2_69?LI=true
Applies in multiple phases of the inquiry cycle	Reflective support	The reflective support "… increases learners' self-awareness of the learning processes and prompts their reflective abstraction and integration of their discoveries" (Zhang, Chen, Sun, & Reid, 2004, p. 270). "The treatment consisted of: a) showing the students their inquiry processes (goals of experiments, predictions, and conclusions); b) reflection notes that students had to fill in asking them to reflect on the experiment; and c) a fill-in form after the experiment that asks students to	"Students who received this type of evaluation support outperformed students who did not receive this support on a number of performance measures." "… reflection prompts helped students develop a better understanding of the domain but that the effect of the prompts depends on the students having a sufficient level of prior knowledge." "…reflection helps students in their understanding of the topic, but only for non interactive environments."	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier. Zhang, J., Chen, Q., Sun, Y., & Reid, D. J. (2004). Triple scheme of learning support design for

		think over the process they had gone through and the discoveries they had made." (de Jong, 2006b, p. 121).	and "…only fosters learning when it is based on correct information." (de Jong, 2006b, p. 121).	scientific discovery learning based on computer simulation: Experimental research. *Journal of Computer Assisted Learning, 20*, 269-282. Land, S. M., & Zembal-Saul, C. (2003). Scaffolding reflection and articulation of scientific explanations in a data-rich, project-based learning environment: An investigation of progress portfolio. *Educational Technology: Research & Development, 51*. Moreno, R., & Mayer, R. E. (2005). Role of guidance, reflection, and interactvity in an agent-based multimedia game. *Journal of Educational Psychology, 97*, 117-128.

Prompts

Orientation-Conceptualisation	Prompts for generating/processing information	Generating prompt: “FIND OUT whereof it depends whether ….Therefore, you best conduct experiments, in which you manipulate only ONE variable” (Thillmann, Künsting, Wirth, & Leutner, 2009, p. 108). Reminding generating prompt: “FIND OUT whereof it depends whether…” (Thillmann, et al., 2009, p. 109). Corresponding processing prompt: “MEMORIZE whereof it depends whether … Therefore you best take notes which illustrate relations between variables” (Thillmann, et al., 2009, p. 109). Reminding corresponding prompt: “MEMORIZE whereof it depends whether…” (Thillmann, et al., 2009, p. 109).	Concerning the learning outcome, presenting prompts during the learning instead of before is beneficial. Specifically “presenting prompts for generating and processing information online positively affects strategy use, and thus learning outcome.” (Thillmann, et al., 2009, p. 113).	Thillmann, H., Kunsting J., Wirth J., & Leutner D. (2009). Is it merely a question of ‘what’ to prompt or also ‘when’ to prompt? The role of point of presentation time of prompts in self-regulated learning. Zeitschrift Fur Padagogische Psychologie, 23, 105–115.
Conceptualisation (Question-Hypothesis)	Metacognitive scaffolds in Animal investigator	Reflection prompts for hypothesis development: questions, for example “(1) What was the problem you were asked to solve?, (2) Why do you think the current clue is important? ...” (Kim	“…metacognitive scaffolds enhance learners’ hypothesis-development performance…students…performed significantly better on developing hypotheses…” (Kim & Pedersen,	Kim, J.H., & Pedersen, S. (2011). Advancing young adolescents’ hypothesis-development performance in a computer-supported

		& Pedersen, 2011, p. 1784). Expert self-Question process: “self-questions the emphasized repeating the hypothesis-development process: (1) What is this animal’s problem? (2) What do I need to know? (3)What can be a possible solution?...” (Kim & Pedersen, 2011, p. 1784). Paper-and-pencil self-checklist: statements for example “(1) I asked myself the questions in the expert question list; I found a clue from the animal information;…” ?...” (Kim & Pedersen, 2011, p. 1784).  	2011, p. 1786).	and problem-based learning environment. Computers & Education, 57, 1780-1789.

		 Animal Investigator (Kim & Pedersen, 2011, p. 1783)		
Conceptualisation-Investigation	Reason-justification/rule-based/emotion-focused prompts	"…the reason-justification prompts were expected to help students develop an understanding of their own strategies and procedures… (for example) 'What is your plan for solving the problem?' 'How are you deciding what to do next?' and 'How did you decide that you have enough data to make conclusions?' The rule-based prompts were used to help students understand the nature of the problem-solving tasks at hand… (for example) 'What variables are you testing?' 'What conclusions can you draw from your experiments?' and 'What were the experiments you did that led you to the solution?' Emotion-focused prompts were used to enhance students' understanding of their own emotional state… (for	"…prompting students to explicitly justify their own thoughts enhanced their ability to solve a far transfer problem involving control of variables…helped them organize their thoughts and resolve problems…plan and monitor the design activities they engaged in…prompts focusing on rules and emotions did not enhance students' ability to solve the far transfer problems…" (Lin & Lehman, 1999, pp. 853-854).	Lin, X., & Lehman, D.J. (1999). Supporting learning of variable control in a computer-based biology environment: Effects of prompting college students to reflect on their own thinking. Journal of research in science teaching, 36(7), 837-858.

		example) 'How are you feeling right now in dealing with this problem?' 'How are you feeling right now?' and 'How are you feeling right now compared to when you got started?'" (Lin & Lehman, 1999, p. 841).		
Investigation (Exploration-Experimentation)	Experiment prompting	"The acquisition of the background-knowledge by the learner is tested using an online evaluation … in which a minimum threshold of 80 points must be reached before conducting the experiment in order to ensure that the learner has acquired sufficient background-knowledge. … During the experiment, learners put interactive components and all he/she needed in the simulation area, the system displays prompts (particularly about 'varying one thing at a time') that help the learner to perform the experiments. When conducting the experiment, the learner can use the mouse to click or drag components to observe relationships between and changes to each component. The learner can adjust the original hypothesis based on the concepts discovered in the experiment and input the final conclusion in the conclusion panel located at the lower-right of the screen. …When	"The learning performance was better when using experiment prompting and a hypotheses menu than when using step guidance" (Chang, et al., 2008, p. 1496).	Chang K.E., Chen Y.L., Lin H.Y. & Sung Y.T. (2008). Effects of learning support in simulation-based physics learning. Computers & Education 51, 1486–1498.

<table>
<tr>
<td></td>
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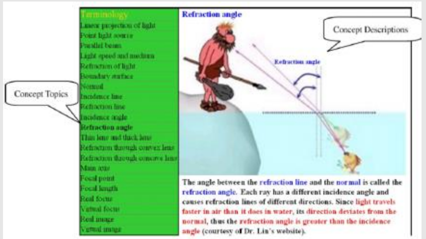
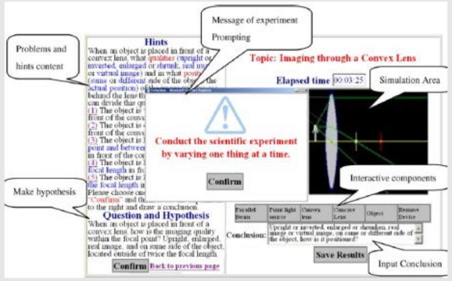
<td>Exploration the simulation, a learner can check the learning-process records at any time, which serves as a notebook that keeps track of his/her problems and hypotheses, the operational steps in the simulation exploration, conclusions drawn, and elapsed time. The learner can review his/her entire learning process and use them as the basis for future activities” (Chang, et al., 2008, pp. 1489-1490).
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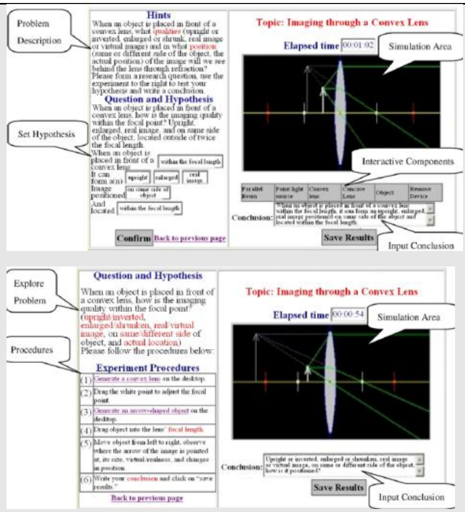
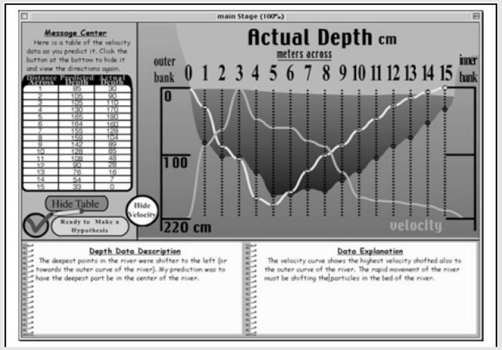
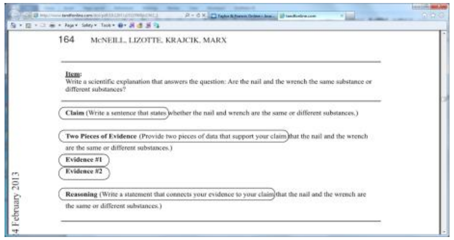
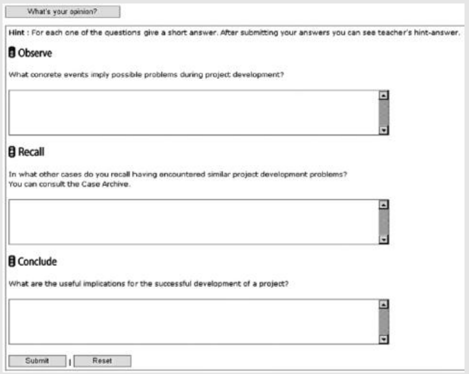
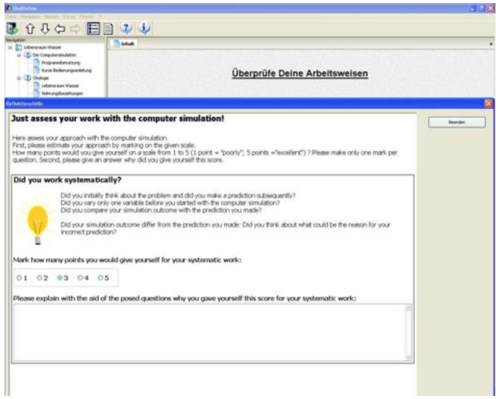
		 Experiment prompting (Chang, et al., 2008).		
Investigation (Experimentation)	Prompts for Experimentations	“Lin and Lehman (1999) provided students with prompts that aimed to stimulate reflection on the strategies that were used for Experimentations with an emphasis on the control of variables strategies (e.g., "How did you decide that you have enough data to make conclusions") (Lin & Lehman, 1999, p. 841).” (de Jong, 2006b, p. 117).	“These prompts helped students to understand experiment design principles and resulted in better transfer compared to a group of students who received different types of prompts (Lin & Lehman, 1999, p. 841). (de Jong, 2006b, p. 117). 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, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), Handling complexity in learning environments: Theory and research (pp. 107- 128). London: Elsevier. Lin, X., & Lehman, J. D. (1999). Supporting learning of variable control in a computer-based biology

				environment: Effects of prompting college students to reflect on their own thinking. Journal of Research in Science Teaching, 36, 837-858.
Investigation (Data Interpretation)	Tuolumne River Module – Support for Design and data collection phase	“In the design and data collection phase, students request data to confirm or refute their hypotheses.” (Woolf, et al., 2002, p. 7). The tools designed for this phase was Slider bars and Sticky notes. Also a tutor checks consistency of data using prompts and ask general questions like ‘What do you want to do now?’ in order to identify the focus of attention.  Slider bar (Woolf, et al., 2002, p. 4).	No definite conclusions could be drawn for the effectiveness of this guidance.	Woolf, B., Reid, J., Stillings, N., Bruno, M., Murray, D., Reese, P., Peterfreund, A., & Rath, K. A general platform for inquiry learning. Proceedings of the International Conference on Intelligent Tutoring Systems, Biarritz, France, June, 2002. Retrieved from http://link.springer.com/chapter/10.1007%2F3-540-47987-2_69?LI=true
Investigation (Experimentation)	Design diaries in a Learning By Design	“Design Diaries are ‘a paper-and-pencil-based’ tool with pages associated with each of the activities	“…students were better able to articulate and use the science they were being exposed to…”	(Puntambekar & Kolodner, 2005)Puntambekar, S., &

	approach	of the design process…Each page had prompts…" (Puntambekar & Kolodner, 2005). "…macro-prompts, designed to help students reason about the phase of design that they were working on. …micro-prompts, designed to help students carry out the activities within each design phase. Both the macro- and micro-prompts encouraged students to reason about the purposes of their designs right from the start …the diaries also include metacognitive prompts…designed to help students to monitor their learning by encouraged them go back to what they had already written in the diaries, and by helping them understand the cyclical nature of design." (Puntambekar & Kolodner, 2005, p. 202). Additionally, they had "pages for students to write specification" and "pages to help them hypothesize about how their models would work when they tested them and whether their predictions came true…" (Puntambekar & Kolodner, 2005, p. 202).	(Puntambekar & Kolodner, 2005). "… students showed a deeper understanding of the usefulness and applicability of the science they were learning." (Puntambekar & Kolodner, 2005, p. 210)	Kolodner, L.J. (2005). Toward implementing distributed scaffolding: Helping students learn science from design. Journal of Research in Science Teaching, 42 (2), 185-217.

Investigation (Experimentation)	Assignments	The core of the collection of assignments offered to the learner is formed by the investigation assignments. These assignments prompt the learner to start an inquiry on the relationship between two given variables. (Swaak, et al., 1998, p. 240).	In addition, assignments suggested ways for the learners to extract knowledge from the simulation environment by supporting them with discerning relevant variables, interpreting the results of experiments, and setting goals for the learners.(Swaak, et al., 1998, p. 249)	Swaak, J., van Joolingen, W.R., & de Jong, T. (1998). Supporting simulation-based learning; the effects of model progression and assignments on definitional and intuitive knowledge. Learning and Instruction, 8, 235-253.
Conclusion	Prompts for writing scientific explanations	Students are guided to write scientific explanations following the structure claim-evidence-reasoning. In each of the three elements they are provided with related prompts. (McNeill, et al., 2006)  164 McNEILL, LIZOTTE, KRAJCIK, MARX Item: Write a scientific explanation that answers the question: Are the nail and the wrench the same substance or different substances? **Claim** (Write a sentence that states whether the nail and wrench are the same or different substances.) **Two Pieces of Evidence** (Provide two pieces of data that support your claim that the nail and the wrench are the same or different substances.) **Evidence #1** **Evidence #2** **Reasoning** (Write a statement that connects your evidence to your claim that the nail and the wrench are the same or different substances.) 4 February 2013 (McNeill, et al., 2006, p. 164)	Fading was more successful than continuous support (McNeill, et al., 2006).	McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. Journal of the Learning Sciences, 15, 153-191.
Conclusion	Questions prompts (eCase environment)	Below, three questions prompts are defined: "('observe prompt'), asking learners to identify important case-specific information…and their effect on the	"…explicitly asking questions to activate students' context-generating cognitive processes can have positive effect on learning from cases…	Demetriadis, N.S., Papadopoulos, M.P., Stamelos, G.I., & Fischer, F. (2008). The effect of scaffolding students'

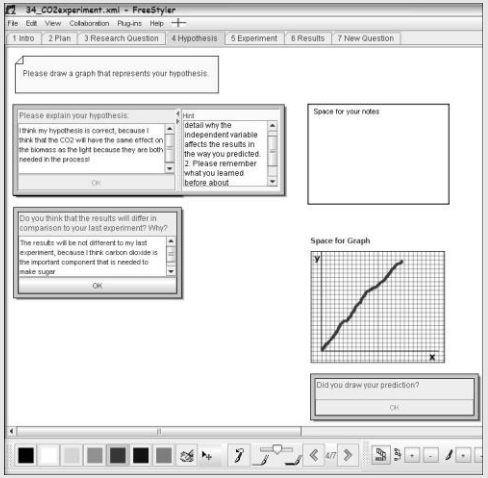
		situation…(‘recall prompt’), asking learners to link information from step (a) to similar/relevant information encountered in other cases… (‘conclude prompt’), asking learners to do some reasoning based also on results from previous steps, preferably reaching useful conclusions regarding the professional practice in the field.” (Demetriadis, Papadopoulos, Stamelos, & Fischer, 2008, p. 942)  Questions prompts in the eCase environment (Demetriadis, et al., 2008) (Demetriadis et al, 2008, p. 947).	…the impact of question prompts during the study of advice-cases was significant, resulting in deeper domain knowledge understanding and potential for knowledge transfer in novel problem situations. …students…processed information and integrated it in their cognitive schemata more efficiently while articulating their understanding in the form of answers to the questions prompts.” (Demetriadis, et al., 2008, p. 950)	context-generating cognitive activity in technology-enhanced case-based learning. Computer & Education, 51(), 939-954.
Discussion (Reflection)	Prompts for self-reflection	Students had to grade their inquiry process and describe why they had given this grade (Eckhardt, et al., 2013).	This improved the acquisition of conceptual knowledge (Eckhardt, et al., 2013).	Eckhardt, M., Urhahne, D., Conrad, O., & Harms, U. (2013). How effective is instructional support for

		 (Eckhardt, et al., 2013, p. 114).		learning with computer simulations? Instructional Science, 41, 105-124. doi: 10.1007/s11251-012-9220-y
Discussion (Reflection)	Hints	"… 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 non-dynamic, not adapted feedback on their conclusions, the group with adaptive feedback did not score better on a 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, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), Handling complexity in learning environments: Theory and research (pp. 107- 128). London: Elsevier. Veermans, K. H., de Jong, T., & van Joolingen, W. R. (2000). Promoting self directed learning in simulation based discovery learning environments through

				intelligent support. Interactive Learning Environments, 8, 229-255.
Applies in multiple phases of the inquiry cycle	Generative learning strategy prompts	"Generative learning strategy prompts asking participants to highlight important sentences in the instructional script (e.g., ''Highlight one or more sentences that you think are important in this section.''), and then prompted them to summarize or organize their understanding in the provided note-taking field" (Lee, Lim, & Grabowski, 2010, pp. 633-634)	"Generative learning strategy prompts with metacognitive feedback improved learners' self-regulation and use of generative strategies and, accordingly, their learning performance. In contrast, generative learning strategy prompts without metacognitive feedback improved only learners' use of generative strategies" (Lee, et al., 2010, p. 643).	Lee H.W., Lim K.Y. & Grabowski B. (2010). Improving self-regulation, learning strategy use, and achievement with metacognitive feedback. *Educational Technology Research and Development 58*, 629–648.
	Metacognitive feedback	"If a participant selected an incorrect answer, the following feedback appeared: 'Incorrect! Now would be a good time to ask yourself if you have learned all the important information. If you haven't, it would be a good idea to return to the previous page to revise your highlighting or note'." (Lee, et al., 2010, p. 634)".		
Applies in multiple phases of the inquiry cycle	Prompts - Checking our Understanding	"…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).	No definite conclusions could be drawn for the effectiveness of this guidance.	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp.

				107- 128). London: Elsevier. Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., et al. (2004). A scaffolding design framework for software to support science inquiry. *The Journal of the Learning Sciences, 13*, 337-387.
Applies in multiple phases of the inquiry cycle	Strategic prompts/general advices and graphic advance organizer (as metacognitive support)	Strategic prompts are “an instruction with general advices for the task that were presented in a short list….ask them to (a) take their time to read and understand… (b) to activate the help functions… (c) to reflect … (d) to get an overview about… (e) to judge how sure they were…(f) to act thoughtfully…” (Stahl & Bromme, 2009, p. 1024). The graphical advance organizer “help students to activate their prior knowledge… to become aware of the kind of knowledge that is relevant for the task and their gaps of knowledge.” (Stahl & Bromme, 2009, pp. 1022-1023).	No benefits were found on students’ performance and knowledge from the use of metacognitive support (Stahl & Bromme, 2009).	Stahl, E., & Bromme, R. (2009). Not everybody needs help to seek help: surprising effects of metacognitive instructions to foster help-seeking in an online-learning environment. Computers & Education, 53, 1020–1028.

<table>
<tr><td>Applies in multiple phases of the inquiry cycle</td><td>Prompts for students</td><td>Explanations prompts help student how to conduct appropriate experiments. Regulation prompts help students to regulate their thoughts when formulating explanation during an inquiry cycle (Wichmann & Leutner, 2009).



Free Styler learning environment with regulation prmpts (Wichmann, et al., 2009, p. 121)</td><td>More extensive prompts asking students to perform certain tasks worked better than simple prompts. Students supported with explanation and regulation prompts significantly outperformed students with explanation prompts and students with basic inquiry support on a knowledge and application test (Wichmann & Leutner, 2009).</td><td>Wichmann, A., & Leutner, D. (2009). Inquiry learning multilevel support with respect to inquiry, explanations and regulation during an inquiry cycle. Zeitschrift Fur Padagogische Psychologie, 23, 117-127. doi: 10.1024/1010-0652.23.2.117</td></tr>
<tr><td colspan="5">Heuristics</td></tr>
<tr><td>Conceptualisation
(Question, Hypothesis)</td><td>Simplify problem</td><td>“Simplify the problem, or try to solve part of the problem (Polya, 1945; Schoenfeld, 1985)”</td><td>No definite conclusions could be drawn for the effectiveness of this guidance.</td><td>Veermans, K., van Joolingen, W., & de Jong, T. (2006). Use of</td></tr>
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		(Veermans, et al., 2006, p. 344).		heuristics to facilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*(4), 341-361. Polya, G. (1945). *How to solve it.* Princeton, NJ: Princeton University Press. Schoenfeld, A. (1985). *Mathematical problem solving.* New York: Academies Press.
Conceptualisation (Hypothesis)	Identify hypothesis	"Generate a small amount of data and examine for a candidate rule or relation (Glaser, Schauble, Raghavan, & Zeitz, 1992)" (Veermans, et al., 2006, p. 344).	No definite conclusions could be drawn for the effectiveness of this guidance.	Veermans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to facilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*(4), 341-361.

				Glaser, R., Schauble, L., Raghavan, K., & Zeitz, C. (1992). Scientific reasoning across different domains. In E. D. Corte, M. Linn, H. Mandl, & L. Verschaffel (Eds.), *Computer-based learning environments and problem solving* (pp. 345–373). Berlin: Springer-Verlag.
Conceptualisation (Hypothesis)	Slightly modified hypothesis	"Address slightly modified problems: Weaken or strengthen conditions slightly in reformulating hypotheses (Glaser, et al., 1992)" (Veermans, et al., 2006, p. 344).	No definite conclusions could be drawn for the effectiveness of this guidance.	Veermans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to facilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*(4), 341-361. Glaser, R., Schauble, L., Raghavan, K., & Zeitz, C. (1992). Scientific reasoning across different domains. In E. D. Corte, M. Linn, H. Mandl, & L. Verschaffel (Eds.), *Computer-based learning*

				environments and problem solving (pp. 345–373). Berlin: Springer-Verlag.
Conceptualisation (Question, Hypothesis)	Set expectations	"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 & Simon, 1988; Langley, 1981)" (Veermans, et al., 2006, p. 344).	No definite conclusions could be drawn for the effectiveness of this guidance.	Veermans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to fecilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*(4), 341-361. Kulkarni, D., & Simon, H. A. (1988). The processes of scientific discovery: The strategy of experimentation. *Cognitive Science, 12*(2), 139-175. Langley, P. (1981). Data-Driven Discovery of Physical Laws. *Cognitive Science, 5*(1), 31-54.
Conceprualization (Hypotheses) –	HOTAT	HOTAT – hold one thing at a time CA – change all	"Subjects (overall)…did not appear to be sensitive to the fact that with	Tschirgi, J.E. (1980). Sencible reasonig: A

Investigtion (Experimentation)		(Tschirgi, 1980)	only two variables to manipulate a proof using a HOTAT strategy is logically equivalent to one using a VOTAT…" (Tschirgi, 1980, pp. 8-9).	hypothesis about hypotheses. *Child Development,* 51, 1-10.
Investigation (Exploration, Experimentation)	VOTAT (Controlling Variables Stradegy-CVS)	"If not varying a variable, then pick the same value as used in the previous experiment (Glaser, et al., 1992; Klahr & Dunbar, 1988; Schunn & 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, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to fecilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*(4), 341-361. Glaser, R., Schauble, L., Raghavan, K., & Zeitz, C. (1992). Scientific reasoning across different domains. In E. D. Corte, M. Linn, H. Mandl, & L. Verschaffel (Eds.), *Computer-based learning environments and problem solving* (pp. 345–373). Berlin: Springer-Verlag. Klahr, D., & Dunbar, K.

				(1988). Dual space search during scientific reasoning. *Cognitive Science, 12*(1), 1-48. Schunn, C. D., & Anderson, J. R. (1999). The generality/specificity of expertise in scientific reasoning. *Cognitive Science, 23*(3), 337-370. Tschirgi, J.E. (1980). Sencible reasonig: A hypothesis about hypotheses. *Child Development,* 51, 1-10.
Investigation (Experimentation)	Simple values	"Choose special cases, set any parameter to 1,2,3 (Schoenfeld, 1979)" (Veermans, et al., 2006).	No definite conclusions could be drawn for the effectiveness of this guidance.	Veermans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to fecilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*(4), 341-361. Schoenfeld, A. (1979). Can heuristics be taught? In J. Lochhead & J.

				Clement (Eds.), *Cognitive process instruction* (pp. 315–338). Philadelphia: Franklin Institute Press.
Investigation (Experimentation)	Equal increments	"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 & 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 & Anderson, 1999, p. 23).	Veermans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to fecilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*(4), 341-361. Schunn, C. D., & Anderson, J. R. (1999). The generality/specificity of expertise in scientific reasoning. *Cognitive Science, 23*(3), 337-370.
Investigation (Data interpretation)	Confirm hypothesis	"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).	No definite conclusions could be drawn for the effectiveness of this guidance.	Veermans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to fecilitate scientific discovery learning in a simulation learning environment in a physics domain.

				International Journal of Science Education, 28(4), 341-361. Glaser, R., Schauble, L., Raghavan, K., & Zeitz, C. (1992). Scientific reasoning across different domains. In E. D. Corte, M. Linn, H. Mandl, & L. Verschaffel (Eds.), *Computer-based learning environments and problem solving* (pp. 345–373). Berlin: Springer-Verlag.
Investigation (Experimentation)	Extreme values	"Try some extreme values to see there are limits on the proposed relationship (Schunn & Anderson, 1999)" (Veermans, et al., 2006, p. 344).	"Overall, most participants were able to avoid such unfortunate outcomes, but only the Experts were able to avoid them entirely" (Schunn & Anderson, 1999, p. 23).	Veermans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to fecilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*(4), 341-361. Schunn, C. D., & Anderson, J. R. (1999).

				The generality/specificity of expertise in scientific reasoning. *Cognitive Science, 23*(3), 337-370.
Investigation (Data interpretation)	Make a graph	“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).	No definite conclusions could be drawn for the effectiveness of this guidance.	Veermans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to fecilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*(4), 341-361. Polya, G. (1945). *How to solve it.* Princeton, NJ: Princeton University Press.
Investigation (Exploration-Experimentation-Data Interpretation)	Heuristics for experimentation	Students received heuristics for explanation that were either fixed, either adaptive to the learning behavior, either adaptive with an explanation why they were given (Marschner et al., 2012).	Only the adaptive with an explanation heuristics influenced experimentation behavior but there were no differences in knowledge between the three groups (Marschner et al., 2012	Marschner, J., Thillmann, H., Wirth, J., & Leutner, D. (2012). How can the use of strategies for experimentation be fostered? Zeitschrift Fur Erziehungswissenschaft, 15, 77-93. doi: 10.1007/s11618-012-0260-5

Investigation (Experimentation)	Plausibility heuristic	"Use the plausibility of a hypothesis to choose experimental strategy." (Klahr, Fay, & Dunbar, 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, D., Fay, A., & Dunbar, K. (1993). Heuristics for specific experimentation: A developmental study. *Cognitive Psychology,* 25, 111-146.
Investigation (Experimentation)	Focusing 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, D., Fay, A., & Dunbar, K. (1993). Heuristics for specific experimentation: A developmental study. *Cognitive Psychology,* 25, 111-146.
Investigation (Experimentation)	Observing 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. 135).	Klahr, D., Fay, A., & Dunbar, K. (1993). Heuristics for specific experimentation: A developmental study. *Cognitive Psychology,* 25, 111-146.
Investigation (Experimentation)	Designing heuristic	"Design experiments giving characteristics 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, D., Fay, A., & Dunbar, K. (1993). Heuristics for specific experimentation: A developmental study. *Cognitive Psychology,* 25, 111-146.

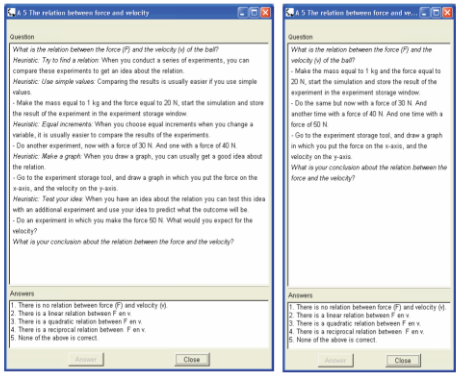
Investigation (Exploration-Experimentation-Data Interpretation)	Step guidance	"The learner can follow the steps and conduct the experiment in the simulation area … whilst observing the changes in each graphic component. The learner can modify the original hypothesis based on the observations and input the final conclusion in the conclusion panel. The learner can review his/her entire learning process records and use them as the basis for future activities" (Chang, et al., 2008, p. 1491).	"Providing guidance on the experimental procedures limits the freedom of learners to explore due to them having to follow the given steps, which impairs the learning results" (Chang, et al., 2008, p. 1496).	Chang K.E., Chen Y.L., Lin H.Y. & Sung Y.T. (2008). Effects of learning support in simulation-based physics learning. *Computers & Education 51*, 1486–1498.
Investigation (Exploration, Experimentation, Data Interpretation)	Unexpected findings	"…a useful strategy in science is to 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 discovery the causes of the unexpected finding* (Dunbar, 1993, 2000; Kulkarni & Simon, 1988)" (Dunbar, 2000, p. 52)	No definite conclusions could be drawn for the effectiveness of this guidance.	Dunbar, K. (2000). How scientists think in the real world: Implications for science education. *Journal of Applied Developmental Psychology, 21*(1), 49-58. Dunbar, K. (1993). Concept discovery in a scientific domain. *Cognitive Science, 17,* 397-434. Kulkarni, D., & Simon, H. A. (1988). The processes of scientific discovery: The strategy of

				experimentation. *Cognitive Science, 12*(2), 139-175.
Conclusions	Present evidence	"If you state a conclusion about a certain hypothesis present evidence to support that conclusion (Schoenfeld, 1985)" (Veermans, et al., 2006, p. 344).	No definite conclusions could be drawn for the effectiveness of this guidance.	Veermans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to fecilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*(4), 341-361. Schoenfeld, A. (1985). *Mathematical problem solving.* New York: Academies Press.
Discussion (Reflection)	Keep track	"Keep records of what you are doing (Klahr & Dunbar, 1988; Kulkarni & Simon, 1988; Schauble, Glaser, Raghavan, & Reiner, 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, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to facilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*(4), 341-361.

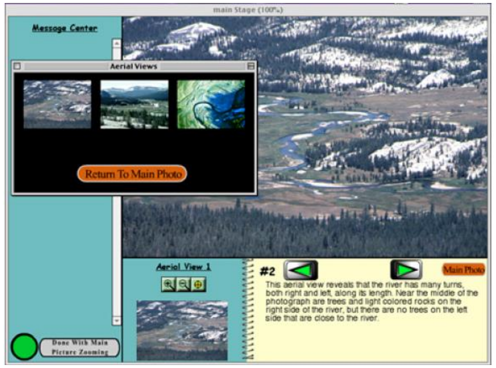
				Klahr, D., & Dunbar, K. (1988). Dual Space Search During Scientific Reasoning. *Cognitive Science, 12*(1), 1-48. Kulkarni, D., & Simon, H. A. (1988). The processes of scientific discovery: The strategy of experimentation. *Cognitive Science, 12*(2), 139-175. Schauble, L., Glaser, R., Raghavan, K., & Reiner, M. (1991). Causal Models and Experimentation Strategies in Scientific Reasoning. *Journal of the Learning Sciences, 1*(2), 201-238.
Discussion (Communication)	Science Writing Heuristic (SWH)	"The SWH is a tool for promoting thinking, negotiating meaning, and writing about science laboratory activities." (Hand, Wallace, & Yang, 2004, p. 131).	"…*(The)* use of the SWH by students has resulted in improved understanding of science concepts, Metacognition, and the nature of science (Keys, 2000; Keys, Hand, Prain, & Collins, 1999)" (Hand, et	Hand, B. (2004). Using a Science Writing Heuristic to enhance learning outcomes from laboratory activities in seventh-grade science: quantitative and qualitative aspects.

		Student Template 1. Beginning Ideas --What are my questions? 2. Tests-- What did I do? 3. Observations-- What did I see? 4. Claims -- What can I claim? 5. Evidence-- How do I know? Why am I making these claims? 6. Reading -- How do my ideas compare with other ideas? 7. Reflection – How have my ideas changed? The Science Writing Heuristic student template (Hand, et al., 2004, p. 132).	al., 2004, p. 131). “Students who engage with using the a SWH and then complete a writing task as a mean of summarizing their work outperformed students who used the normal ‘cookbook’ approach to laboratory work…The writing activities including the SWH and textbook explanation task are successful interventions for increasing both conceptual knowledge and metacognition of science understanding.” (Hand, et al., 2004, p. 148).	*International Journal of Science Education, 26*(2), 131-149. Keys, C.W. (2000). Investigating the thinking processes of eight writers during the composition of a scientific laboratory report. *Journal of Research in Science Teaching, 37*, 676-690. Keys, C.W., Hand, B., Prain, V., & Collins, S. (1999). Using the science writing heuristic as tool for learning from laboratory investigations in secondary science. *Journal of Research in Science Teaching, 36*, 1065-1084.
Applies in multiple phases of the inquiry cycle	Planning of the inquiry process	“The planning of the inquiry process can be supported by making the different steps (*Orientation*, creating a hypothesis, etc.) clear for the students. This gives the student an overview of different steps in the process and helps in planning what to	It helps students proceed through tasks by providing structure. (de Jong, 2006b)	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp.

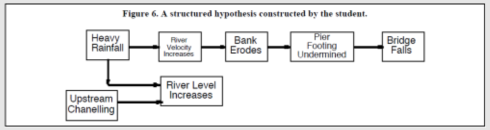
		do. Reiser (2004) mentioned the structuring of the task by the learner as one of the main functions of cognitive scaffolds. By structuring a task, the learner is informed of the necessary elements of a task; the operating space of learners is also constrained, making planning and monitoring more feasible processes (de Jong & van Joolingen, 1998). More specific process support can then be given within each of these steps.” (de Jong, 2006b, pp. 118-119).		107- 128). London: Elsevier. Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *The Journal of the Learning Sciences, 13*, 273-304. de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*, 179-202.
Applies in multiple phases of the inquiry cycle	Heuristics (explicit/implicit condition)	“…in the implicit condition the student only receives guidelines derived from the heuristics. The students are told the steps that have to be taken in order to obtain enough information to reach a conclusion on the assignment goal. In the explicit condition these step/guidelines are accompanied by the heuristic that they were derived from…the implicit condition presents	“…a considerable gain, …, on both definitional and intuitive knowledge from pre- to post-test for the students in both conditions… offering explicit heuristics may be especially beneficial for the weaker students…There is some evidence indicating that the explicit heuristics triggered more self-regulation in students.” (Veermans, et al., 2006,	Veermans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to facilitate scientific discovery learning in a simulation learning environment in a physics domain. International Journal of Science Education, 28(4),

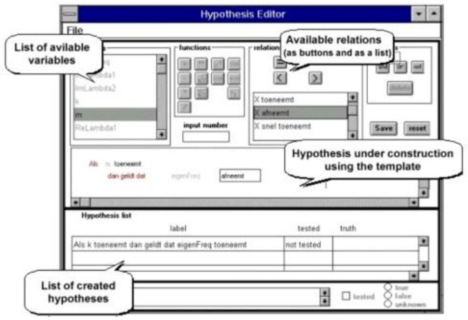
		only feedback that could be derived from a heuristic, the explicit condition presents information about the heuristic itself as well. In both learning environments heuristics are faded gradually…" (Veermans, et al., 2006, p. 349).  "Example of an assignment in two versions. On the left version that was used within the learning environment with explicit heuristics, on the right, the same assignment in the version for the implicit heuristics environment" (Veermans, et al., 2006, p. 347).	pp. 358-359)	341-361.
Applies in multiple phases of the inquiry cycle	Heuristics	According to Veermans (2003) heuristic is: "A rule of thumb, simplification, or educated guess that reduces or limits the search for solutions in domains that are difficult	"With respect to the heuristics, no firm conclusions can be stated. There is slight evidence that the explicit heuristics triggered more self regulation, which would mean that	Veermans, K. H. (2003). Intelligent support for discovery learning. Ph.D. thesis, University of Twente.

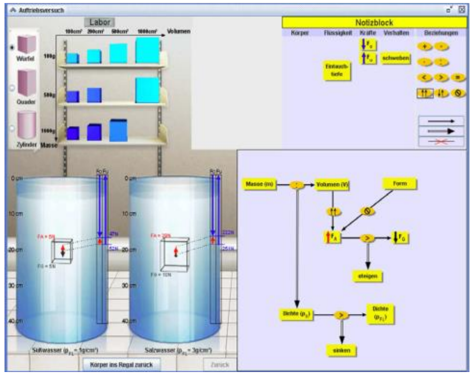
		and poorly understood … They can serve as a means to make a decision about a problem without the need for a complete and exhaustive analysis of the problem and the context". Additionally, they can "even be used without a complete understanding of the origins of the heuristic". (Veermans, 2003, p. 23) "They can be used to introduce the formal view on scientific discovery before presenting the formal logic behind this view. … They can provide guidance to learners during these experiences, and provide a basic informal structure that can later be transformed into a formal structure." (Veermans, 2003, p. 24) "Productive heuristics can be included in the expert model, not as a prescriptive model of correct behaviour (that is used to correct a learner) but as a descriptive model of good practice. They can be used to provide the learner with advice, triggering reflection on the learner's own practice" … "Heuristics provide the possibility to support problem solving, or discovery learning, while at the same time highlighting this	the heuristics are incorporated in already existing knowledge structures." (Veermans, 2003, p. 100)	

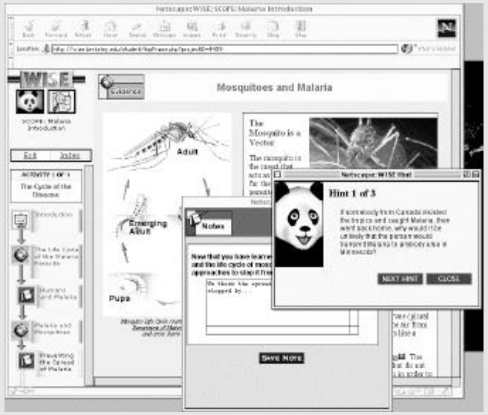
		uncertainty. The characteristics of heuristics make them well suited to support learners in discovery learning" (Veermans, 2003, p. 25).		
Scaffolds				
Orientation	Tuolumne River Module – Support for Orientation phase	For the *Orientation phase* the *Fuzzy View tool* presents the initial photo and students are guided to observe carefully in order to find out if there is something notable or unusual. The *Photo Gallery Zoom-in tool* provides functions like enlargement and movement to other views.  (Woolf, et al., 2002, p. 2)	No definite conclusions could be drawn for the effectiveness of this guidance.	Woolf, B., Reid, J., Stillings, N., Bruno, M., Murray, D., Reese, P., Peterfreund, A., & Rath, K. A general platform for inquiry learning. *Proceedings of the International Conference on Intelligent Tutoring Systems,* Biarritz, France, June, 2002. Retrieved from http://link.springer.com/chapter/10.1007%2F3-540-47987-2_69?LI=true
Orientation	Artemis – internet based	"The software is a graphical interface that connects students to a library of	"…there is a positive relationship between the students use of the	Butler, A. K., & Lumpe A. (2008). Student use of

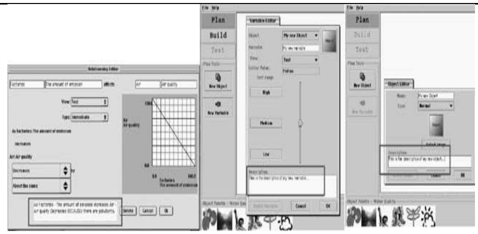
	software program	websites…to search and sort science information related to project-based investigation." (Butler & Lumpe, 2008, p. 428) Artemis software contains search, saving and viewing, maintenance, organizational and collaborative scaffolding features. With the Artemis software students can conduct web searches, view abstracts of websites, visit actual websites, save and retrieve search results, edit or delete information, develop and organize folders and share information (Butler & Lumpe, 2008).  The Artemis software (Butler & Lumpe, 2008, p. 429)	saving/viewing features and the students' perception of how interesting, how important, and how useful the task is…between the use of the searching features and the students' perception of their ability to accomplish a task as well as their confidence in their skills to perform that task…between the student use of the collaborative features and the students' ability to perform high cognitive tasks…between the students use of the maintenance features and students' conceptual understanding" (Butler & Lumpe, 2008, p. 434). But "…it cannot be determined if the positive relationship is due to the influence of the software or if students with higher conceptual understanding and motivation tend to use particular software features." (Butler & Lumpe, 2008, p. 434),	scaffolding software: Relationships with motivation and conceptual understanding. *Journal of Science Education and Technology, 17*(5), 427-436.
Orientation	Concept-map template	"…a form of a concept map template used in guiding the learners and design features of Websites that students used when gathering	"The findings indicated that concept mapping templates enhanced students' free recall and application of acquired knowledge."	MacGregor S.K. & Lou Y. (2004) Web-based learning: how task scaffolding and web site

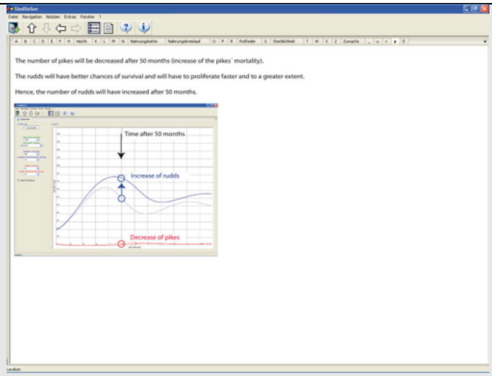
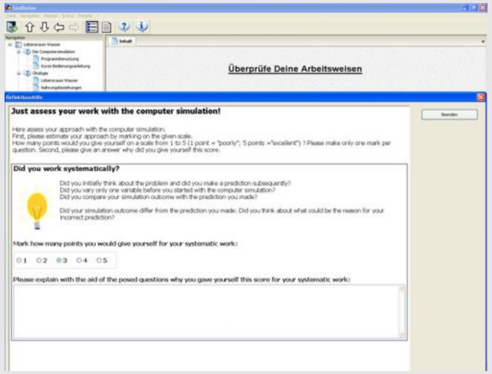
		relevant information for completing their WebQuest tasks.” (MacGregor & Lou, 2004, p. 164) “The template provided a framework that specified how the learner was to make connections from the information they acquired with their study guide to the major relevant concepts… The concept mapping template was then used as a design mechanism for their slide show presentation.” (MacGregor & Lou, 2004, p. 168)	(MacGregor & Lou, 2004, p. 161) “… conceptual scaffolds in the form of a study guide and a concept mapping template supported students as they were engaged in learner-centred resource-based learning. Providing a study guide that identified what information to extract and a concept map that provided cues for organizing and synthesizing their information were helpful in keeping students on task and facilitated higher-order learning. The concept map template was effective in guiding students’ synthesizing and organizing the information they gathered for their target purpose and audience.” (MacGregor & Lou, 2004, p. 172)	design support knowledge acquisition. *Journal of Research on Technology in Education* 37(2), 161–175.
Conceptualisation (Hypothesis)	Tuolumne River Module – Support for Hypotheses phase	“In the *hypotheses* phase, students suggest hypotheses and ask for data” using the *Hypotheses Pad* and *Structures Hypothesis tool*. (Woolf, et al., 2002, p. 7).  Figure 6. A structured hypothesis constructed by the student.	No definite conclusions could be drawn for the effectiveness of this guidance.	Woolf, B., Reid, J., Stillings, N., Bruno, M., Murray, D., Reese, P., Peterfreund, A., & Rath, K. A general platform for inquiry learning. *Proceedings of the International Conference on Intelligent Tutoring Systems,* Biarritz, France, June, 2002. Retrieved

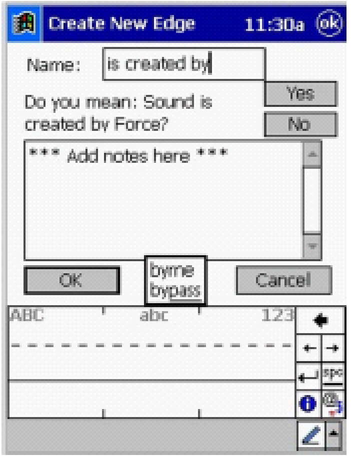
		(Woolf, et al., 2002, p. 7).		from http://link.springer.com/chapter/10.1007%2F3-540-47987-2_69?LI=true
Conceptualisation (Hypothesis)	Hypothesis scratchpad	“A scaffold that allows students to compose hypotheses from separate elements such as variables, relations, and conditions” … “It exists in the SimQuest context (van Joolingen & de Jong, 2003). In this version, learners can compose hypotheses by filling in if-then statements and by selecting variables and relations to fill in the slots. For each hypothesis, they can indicate whether it was tested or not, or whether the data confirmed the hypothesis” (de Jong, 2006b, p. 113).  Hypothesis scratchpad (van Joolingen, 1998)	“The hypothesis scratchpad appeared to be quite complex for learners to use (van Joolingen & de Jong, 2003).” (de Jong, 2006b, p. 113). In Wirth, et al. (2009) the scratchpad per se was not subject under study.	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier. van Joolingen, W. R., & de Jong, T. (2003). SimQuest: Authoring educational simulations. In T. Murray, S. Blessing & S. Ainsworth (Eds.), *Authoring tools for advanced technology educational software: Toward cost-effective production of adaptive, interactive, and intelligent educational software* (pp. 1-31). Dordrecht: Kluwer Academic Publishers.

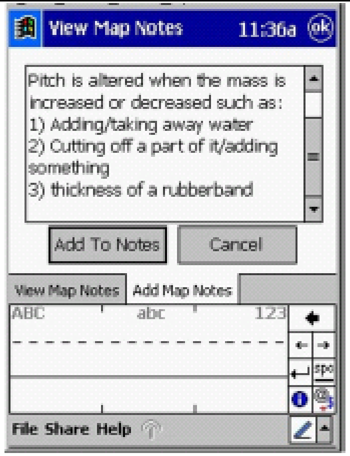
		In Wirth, Künsting, & Leutner (2009) “the scratch pad allowed students to make notes in terms of constructing a specific kind of concept-map.” (p. 301).  Hypothesis scratchpad (Wirth, et al., 2009, p. 301)		van Joolingen, W. (1998). Cognitive tools for discovery learning. *International journal of Artificial Intelligence in Education, 10*, 385-397. Wirth, J., Künsting, J., & Leutner, D. (2009). The impact of goal specificity and goal type on learning outcome and cognitive load. *Computers in Human Behavior*, 25, 299-305. doi: 10.1016/j.chb.2008.12.004
Conceptualisation (Hypothesis)	Prediction	“Learners were supported in stating predictions by providing them with semi-structured sentences in which they can fill in slots. This is done, for example, in WISE (Slotta, 2004). Students receive sheets with sentences concerning predictions. Learners fill in the dots on these sheets to generate a verifiable prediction. An example of such a sentence is: “with an earthquake of 5 on the Richter scale, the building at	Lewis et al. (1993) showed that scaffolding prediction led to stating correct predictions (correct in the sense of their structure and not necessarily in terms of their content). The prediction phase needs support. (de Jong, 2006b). No results in the Slotta (2004) study.	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier. Slotta, J. (2004). The web-based inquiry

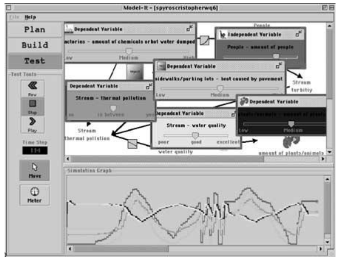
		my school would … because ….” (Slotta, 2004).” (de Jong, 2006b, p. 117).  Pop-up note and hints windows (Slotta, 2004)		science environment (WISE): Scaffolding knowledge integration in the science classroom. In M. Linn, E. A. Davis & P. Bell (Eds.), *Internet environments for science education* (pp. 203-233). Mahwah (NJ): Lawrence Erlbaum Associates. Lewis, E. L., Stern, J. L., & Linn, M. C. (1993). The effect of computer simulations on introductory thermodynamics understanding. *Educational Technology, 33*, 45-58.
Conceptualisation (Question - Hypothesis)	Articulation box (Model-It software)	“The articulation text boxes are designed to encourage learners to articulate their reasoning when creating objects, variables, and relationships. … The relationship editor also has a partly filled out sentence in the box, in the form of ‘as X increases Y increases/decreases, because’. . .” (Fretz, et al., 2002, p. 572).	“The scaffold makes their thinking visible to each other, as well as the researcher, and fosters the use of modelling practices and more specifically, leads them to improve their model. …students using modelling practices like synthesising and explaining, by making connections and justifying arguments. By sharing these explanations, and coming to a	Fretz, E. B, Wu, H. K., Zhang, B., Davis, E. A., Krajcik, J. S., & Soloway, E. (2002). An investigation of software scaffolds supporting modeling practices. *Research in Science Education, 32*, 567-589.

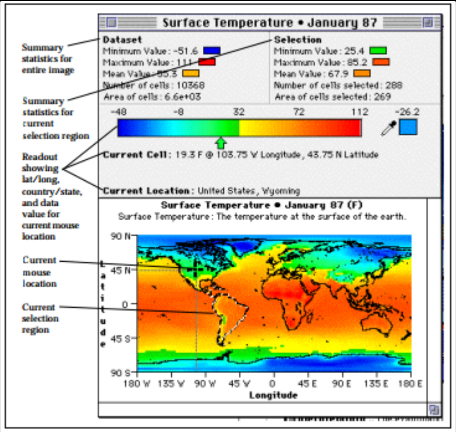
		 Articulation box (Fretz, et al., 2002)	common understanding, students discover errors in their understanding and/or their models" (Fretz, et al., 2002, p. 581).	
Conceptualisation-Investigation	Experimental design tool (SimBioSee)	In this tool students have to make a prediction, similar to the hypo scratchpad, and then see if the simulation gives the same data. Support for data interpretation: "Learners requested to describe and to interpret their own simulation outcome… (and) a description and biological interpretation of the simulation outcome after conducting an experiment appeared on the computer screen." (Eckhardt, Urhahne, Conrad, & Harms, 2013, p. 112)	"The best learning outcomes were found for the learners who received either only instructional support for data interpretation or only instructional support for self-regulation…A combination of instructional support for data interpretation and self-regulation did not lead to higher knowledge gains than supporting the learners with only one of these interventions." (Eckhardt, et al., 2013, p. 119)	Eckhardt, M., Urhahne, D., Conrad, O., & Harms, U. (2013). How effective is instructional support for learning with computer simulations? Instructional Science, 41, 105-124.

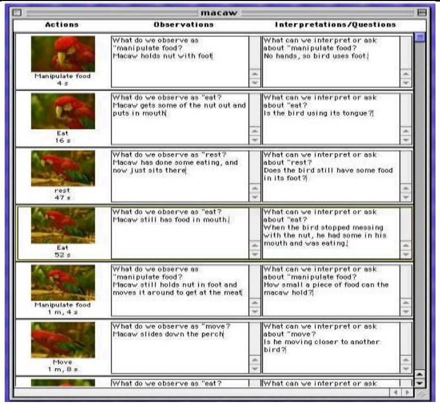
		 (Eckhardt, et al., 2013, p. 113) Support for self-regulation: “…a reflective assessment tool integrated into the computer program…(and) learners were prompted to justify their assessments in written form.” (Eckhardt, et al., 2013, p. 112)  (Eckhardt, et al., 2013, p. 114)		

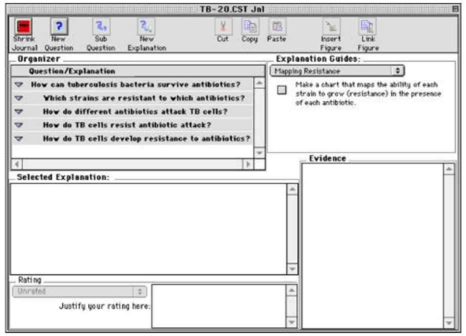
Conceptualisation-Investigation	Pocket PiCoMap	"…a scaffolded tool to support students in using handheld Pocket PC computers to create concept maps…(with) visible tools and scaffolds…to support students' primary task within this activity space." (Luchini, Quintana, & Soloway, 2003, p. 324). The scaffolds included were concept colors, link scaffold, concept, link and map notes, and text map.  Link Scaffold (Luchini, et al., 2003, p. 323)	"While students can create substantive concept maps using Pocket PiCoMap, they are more likely to create maps that are difficult to read and that contain orphan nodes." (Luchini, et al., 2003, p. 327).	Luchini, K., Quintana, C., & Soloway, E. (2003, April). Pocket PiCoMap: A case study in designing assessing a handheld concept mapping tool for learners. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 321-328). ACM.

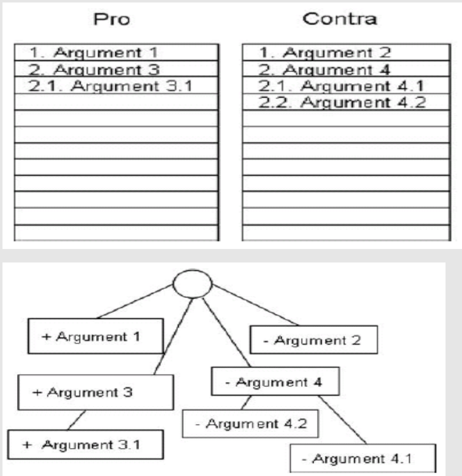
		 Map notes scaffold (Luchini, et al., 2003, p. 324).		
Investigation (Data Interpretation)	Tools for data interpretation	Tools that support the performance of curve fitting, or they can be used for drawing graphs (Veermans, 2003).	No definite conclusions could be drawn for the effectiveness of this guidance.	Veermans, K. H. (2003). Intelligent support for discovery learning. Ph.D. thesis, University of Twente.
Investigation (Exploration-Experimentation)	Dynamic testing scaffold (Model-It software)	“The dynamic testing scaffold (Figure 3) allows learners to interact with the model in real time, manipulating meters and observing changes on graph representations of meter values. This scaffold removes the burden of repeatedly entering discrete values in equations, and instead this visual and dynamic scaffold allows the simultaneous observation of multiple values as elements of the model	Students have rich discussions “about model content and structure when they manipulate the model in test mode”. … “The dynamic test mode scaffold encourages the use of evaluating practices like interpreting results, identifying anomalies, and proposing solutions” (Fretz, et al., 2002, p. 583).	Fretz, E. B, Wu, H. K., Zhang, B., Davis, E. A., Krajcik, J. S., & Soloway, E. (2002). An investigation of software scaffolds supporting modeling practices. *Research in Science Education, 32*, 567-589.

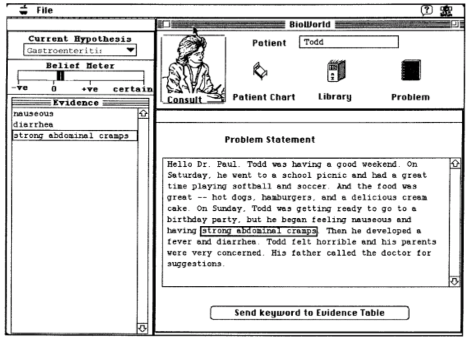
		interact. … This scaffold can help the learner detect errors in the model's function, encouraging a cycle of debugging and improvement" (Fretz, et al., 2002, p. 573).  Dynamic testing scaffold (Fretz, et al., 2002)		
Investigation (Data Interpretation)	Data interpretation - Worldwatcher	"Worldwatcher is a software that contains real data sets acquired by NASA. These data are temperature measurements from all over the world. Worldwatcher visualizes this data with the intention of helping learners understand the complexity of the data"… and "…provide opportunities to see the data from different angles. Learners can re-group data, compare data from different sources (e.g., compare temperatures in different months), and create overviews, etc. (see Edelson, Gordin, & Pea, 1999)." (de Jong, 2006b, p. 118).	No definite conclusions could be drawn for the effectiveness of this guidance.	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier. Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum

		 A visualization window/Worldwatcher (Edelson, et al., 1999)		design. *Journal of the Learning Sciences, 8*, 391-450.
Investigation (Data Interpretation)	Data interpretation - BGuILE	"BGuILE software Animal Landlord (Smith & Reiser, 1997). In this software program learners have to analyse data that come from a video and they are asked questions to guide their interpretation of the data." (de Jong, 2006b, p. 118).	No definite conclusions could be drawn for the effectiveness of this guidance.	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier. Smith, B. K., & Reiser, B. J. (1997). *What should a wildebeest say? Interactive nature films for high school classrooms.* Paper presented at the

		 Window for data interpretations (BGulLe, May 20, 2013)		ACM Multimedia, Seattle. BGulLe (May 20, 2012). Retrieved January 24, 2012 from *http://www.letus.org/bguile/animallandlord/AnimalLandlord_software.html*
Conclusion	Self-explanation and meta-level feedback (description of casual diagram)	Students in the instructional condition “read an instructor-provided text explaining the casual diagram…in the self-exlanation and meta-level feedback conditions were given the self-explanation propmt. ‘Write your explanation of the diagram in regard to…Make inferences going beyond the diagram based on previous expirience or knowledge.’…in the meta-level feedback condition were asked to compare their own explanations with instructional explanations and write the differences.” (Hoan Cho & Jonassen, 2012, p. 175).	“…the meta-level feedback enhanced learning by self-explaining a casual diagram. Students who received the meta-level feedback after the self-explaining a casual diagram outperformed those in the instructional explanation condition, whereas students who self-explained a casual diagram without the meta-level feedback did not…The meta-level feedback was necessary to strengthen the effectiveness of self-explanation…(and) instructional supports are needed to elicit inferences from a casual diagram.” (Hoan Cho &	Hoan Cho, Y., & Jonassen, D.H. (2012). Learning by self-explaining casual diagrams in high-school biology. *Asia Pacific Education Review, 13*(1), 171-184.

			Jonassen, 2012, p. 180).	
Conclusion	Investigation journal	“The drawing of conclusions is often supported by linking evidence and theory. In BGuILe (Reiser, et al., 2001), a series of inquiry environments in the domain of biology, 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 in investigations.” (de Jong, 2006b, p. 117).  BGulLe/Investigation journal (nd)	It appears to work. Reiser et al. (2001) state that even their participants used two very complex collections of software tools, “they yet managed to move flawlessly between them, Exploration data in the investigation environment and periodically returning to the explanation journal to review outstanding questions, insert data, or add to the written explanation.” (Reiser, et al., 2001, p. 28).	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier. Reiser, B. J., Tabak, I., Sandoval, W. A., Smith, B., Steinmuller, F., & Leone, T. J. (2001). BGuILE: Strategic and conceptual scaffolds for scientific inquiry in biology classrooms. In S. M. Carver & D. Klahr (Eds.), *Cognition and instruction: Twenty five years of progress* (pp. 263-305). Mahwah (NJ): Lawrence Erlbaum Associates. BGulLe/Investigation journal/Explanation Constructor (nd) Retrieved January 24, 2012 from

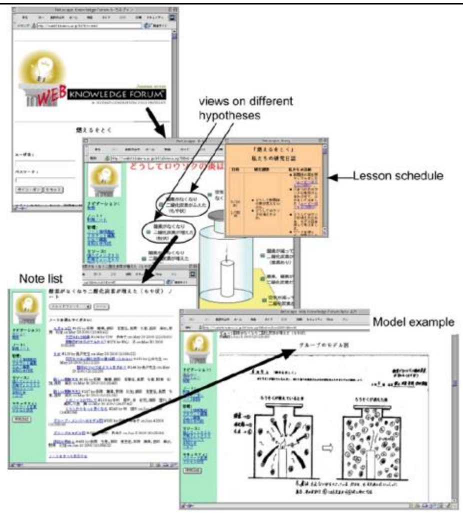
				http://www.letus.org/bguile/finches/Journal.html
Conclusion	Argumentation task – graphical mind mapping tool/text editor	The text editor tool uses “an input formula with two columns, one for pro and one for contra arguments….The complementary graphic based mind mapping tool was commercial software that allowed participants to draw notes and to connect them with arrows…to mark cards with a “+” or a “-” in order to mark a pro or a contra statement…” (Zumbach, 2009, p. 814).  The text editor tool and the graphical mind mapping tool (Zumbach, 2009, p. 814)	“Both tools of external representation of arguments revealed advantages regarding knowledge acquisition compared to a control group. While there were minor advantages of the graphical argumentation in maintaining learners’ intrinsic motivation. There were also some minor advantages of the text based argumentation editor regarding the balance of pro and contra arguments.” (Zumbach, 2009, p. 816)	Zumbach, J. (2009). The role of graphical and text based argumentation tools in hypermedia learning. *Computers & Education, 25*(4), 811-817.

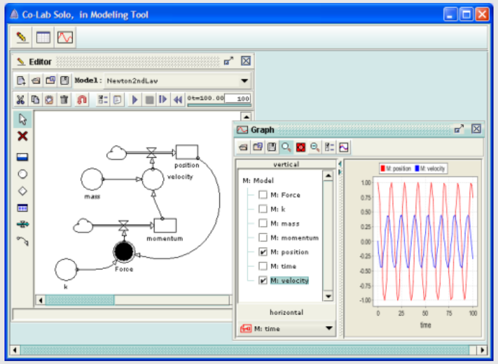
Discussion (Reflection)	Evidence palette, belief meter.	"Lajoie et al. (2001) argue that in BioWorld, learners are encouraged to reflect on their process and results by means of the so-called "evidence palette" and the "belief meter." The evidence palette (an overview of all evidence collected for a hypothesis) makes students reflect on their plans and actions, and the belief meter (a measure in which students can indicate how credible their hypothesis is, based on the evidence collected) makes them think about the data collected and screened." (de Jong, 2006b, p. 120).  Evidence palette and belief meter/ BioWorld (Lajoie, et al., 2001)	Both scaffolds appear to work. According to Lajoie et al (2001), BioWorld's students can make an assertion (or hypothesis) and support it by collecting appropriate data. "Making actions and results visible in the evidence palette facilitates reasoning by supporting memory" (Lajoie, et al., 2001, p. 161).	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier. Lajoie, S. P., Lavigne, N. C., Guerrera, C., & Munsie, S. D. (2001). Constructing knowledge in the context of Bioworld. *Instructional Science, 29*, 155-186.
Applies in multiple phases of the	Adaptive/Fixed/ No scaffolding	"In the *adaptive scaffolding* (AS) condition students were provided with an overall learning goal. They had	"As led to significant increases in students' understanding…and was more effective than providing	Azevedo, R., Cromley, G. J., & Seibert D. (2004). Does adaptive scaffolding

inquiry cycle	conditions (hypermedia learning environment - Microsoft Encrata)	access to a human tutor who provided adaptive scaffolding by helping them enact various aspects of self regulated learning (SRL), such as planning their learning, monitoring their emerging understanding,…In the *fixed scaffolding* (FS) condition, the students were given the same overall learning goal and a list of 10 domain-spesific questions. These were designed to scaffold their conceptual understanding…by providing a fixed list of sub-goals which an expert would use to learn about…In the *no scaffolding* (NS) condition, we wanted to determine whether students could learn about a complex science topic in thw absence of any scaffolding." (Azevedo, Cromley, & Seibert, 2004, p. 348).	students with either FS or NS…providing students with AS during learning can facilitate their ability to regulate their learning with hypermedia by engaging several key processes and mechanisms related to SRL such as planning, monitoring, enactment of effective strategies, and handling task difficulties and demands." (Azevedo, et al., 2004, p. 361).	facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology, 29*(3), 344-370.
Applies in multiple phases of the inquiry cycle	Guiding questions	"… higher-ordered questions…to foster students' conceptual knowledge…" (Moos & Azevedo, 2008, p. 210).	"…the provision of conceptual scaffolds, in the form of guiding question, during learning with hypermedia is positively associated with students' learning of challenging science topics…"and "…participants used, on average, more planning processes." (Moos & Azevedo, 2008, p. 223)	Moos D.C., & Azevedo R. (2008) Exploration the fluctuation of motivation and use of self-regulatory processes during learning with hypermedia. Instructional Science 36(3), 203– 231.

Applies in multiple phases of the inquiry cycle	Metacognitive scaffolding (structuring scaffolds/problematizing scaffolds)/Ontdeknet e-learning environment	“Structuring scaffolds structure metacognitive activities stimulating Metacognition on the interpersonal plane; problematizing scaffolds elicit metacognitive activities of individual student and in turn support group discussion on the interpersonal plane.” (Molenaar, van Boxtel, & Sleegers, 2010, p. 1729). Examples of the two different scaffolds: Structuring scaffold - “I am going to show you an example of how to introduce yourselves…” Problematizing scaffold – “Why are you going to introduce yourselves?” (Molenaar, et al., 2010, p. 1731)  “Structuring scaffolds in the learning environment” (Molenaar et al., 2010,	“…the triads receiving scaffolds remained to perform more metacognitive activities after the scaffolding had stopped then the triads in the control group.” (Molenaar, et al., 2010, p. 1735) “…metacognitive scaffolding of small groups in complex open learning environments is successfully in stimulating metacognitive activities and supporting the development of metacognitive skills in the triads. The form of scaffolds does not significantly influence activation of metacognitive activities on the interpersonal plane.” (Molenaar, et al., 2010, p. 1736)	Molenaar, I., van Boxtel, A.M.C., & Sleegers, J.C.P. (2010). The effects of scaffolding metacognitive activities in small groups. Computers in Human Behavior, 26(6), 1727-1738.

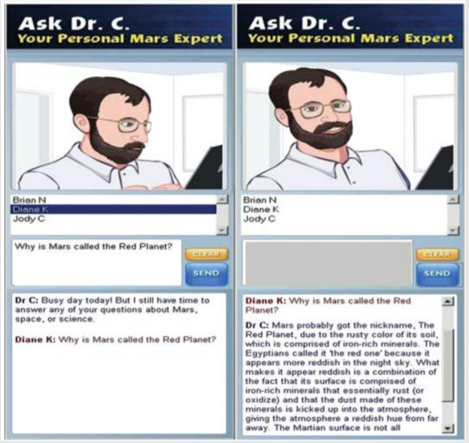
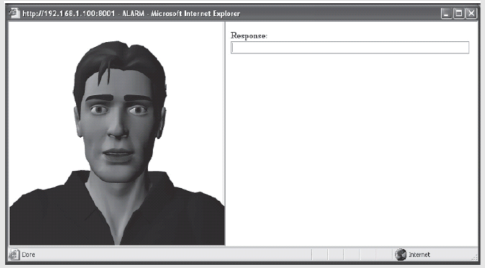
		p. 1737)  “Problematizing scaffolds in the learning environment” (Molenaar et al., 2010, p. 1737)		
Applies in multiple phases of the inquiry cycle	Web knowledge forum (software)	“…learners report their ideas and thoughts in notes…can also add pictures or movies…can add links by inputting note numbers. …notes are reported in the spaced called ‘view’…the administrator can easily order or arrange views, linking one with another or restructuring them.” (Oshima et al., 2006, p. 233).	“The blending of off- and on-line communication for student progress helped them understand what their class as a community knew and what problems or questions remained, or which groups had similar interests and important data. It facilitates more effective use of searching the database for new ideas.” (Oshima, et al., 2006, p. 245)	Oshima, J., Oshima, R., Murayama, I., Inagaki, S., Takenaka, M., Yamamoto, T., Yamaguchi, E., & Nakayama, H. (2006). Knowledge-building activity structures in Japanese elementary science pedagogy. Computer-Supported Collaborative Learning, 1(2), 229-246.

		 The interface of web Knowledge Forum (Oshima, et al., 2006, p. 234)		
Applies in multiple phases of the inquiry cycle	Co-Lab - graphical modelling tool	“In the Co-Lab system (van Joolingen, et al., 2005) the view on the domain is expressed in the form of a model. A graphical modelling tool based on system dynamics is available in Co-Lab (Steed, 1992). 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	This scaffold works. There are numerous studies supporting the use of such a modelling tool. (e.g., Löhner, et al., 2003)	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier. van Joolingen, W. R., de Jong, T., Lazonder, A. W., Savelsbergh, E., & Manlove, S. (2005). Co-

		different levels of precision: qualitative and quantitative. In Co-Lab, learners could start with specifying relations between variables in a qualitative way. They can do this by selecting a relation between variables and linking a pre-defined graphical label depicting the relation to it. The transition from qualitative to quantitative models is smooth, which makes the tool suitable for use in the *Orientation*, hypothesis, and conclusion phases…" (de Jong, 2006b, p. 112).  Graphical Modelling tool/Co-Lab (n.d.)		Lab: Research and development of an on-line learning environment for collaborative scientific discovery learning. *Computers in Human Behavior, 21*, 671-688. Steed, M. (1992). Stella, A simulation construction Kit: Cognitive Process and Educational Implications. *Journal of Computers in Mathematics and Science Teaching, 11*, 39-52. Löhner, S., van Joolingen, W. R., & Savelsbergh, E. R. (2003). The effect of external representation on constructing computer models of complex phenomena. *Instructional Science*, *31*(6), 395-418. Co-Lab Collaborative laboratories (nd). This project is funded under the European eLearning

				programme. Retrieved January 24, 2012 from *http://www.recoil.nl/ap/coils/CoLab/index.html*
Applies in multiple phases of the inquiry cycle	Machine-learned detectors	Machine-learning-based detectors were developed after student-level cross-validation to detect when students test their hypotheses, design controlled experiments and engage in planning behaviours. "Students could engage in either systematic or haphazard inquiry behaviour… students acting in a systematic manner (Buckley, Gobert, Horwitz, & O'Dwyer, 2010) collect data by designing and running controlled experiments that test their hypotheses…In contrast, students acting haphazardly …may construct experiments that do not test their hypotheses, not collect enough data to support or refute their hypotheses, design confounded experiments, fail to use the inquiry support tools to analyze their results and plan additional trials (cf. de Jong, 2006b), or collect data for the same experimental setup multiple times (Buckley, Gobert, & Horwitz, 2006; Buckley, et al., 2010)." (Sao Pedro, et al., 2013, p. 8)	No definite conclusions could be drawn for the effectiveness of this guidance.	Sao Pedro, M.A., de Baker, R.S., Gobert, J.D., Montalvo, O., & Nakama, A. (2013). Leveraging machine-learned detectors of systematic inquiry behavior to estimate and predict transfer of inquiry skill. *User Modeling and User-Adapted Interaction, 23*, 1-39. Buckley, B.C., Gobert, J.D., & Horwitz, P. Using log files to track students' model-based inquiry. In Barab, S. & Hay, K., Hickey, D. (eds.) *Proceedings of the 7th International Conference on Learning Sciences*, ICLS 2006, Bloomington, IN, pp. 57-63. Lawrence Erlbaum Associates (2006).

		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 Pedro, et al., 2013, p. 25).		Buckley, B.C., Gobert, J.D., Horwitz, P., & O'Dwyer, L. (2010). Looking inside the black box: Assesments and decision-making in BioLogica. *International Journal of Learning Technology, 5*(2), 166-190. de Jong, T. (2006a). Computer simulations - technological advances in inquiry learning. *Science, 312*(5773), 532-533.
Applies in multiple phases of the inquiry cycle	Animated pedagogical agent	"A likable cartoon figure who talks to the learner and responds to the learner's input"… "The major aspects of the social agency environment include (a) presenting a visual image of the agent's body, especially the agent's face; (b) presenting an auditory image of the agent's voice, using speech rather than on-screen text; and (c) allowing the learner to interact with the agent by providing input and receiving a contingent response" (Moreno, Mayer, Spires, &	"Students learn a computer-based lesson more deeply when it is presented in a social agency environment than when it is presented as a text and graphics source" … "Students who learn in a computer environment that entails participation between agent and learner are more actively involved in the processing of the materials of the lesson than students who learn identical materials in an environment based on a one-way	Moreno R., Mayer R., Spires H. & Lester J. (2001) The case for social agency in computer-based teaching: do students learn more deeply when they interact with animated pedagogical agents? *Cognition and Instruction 19*, 177–213. Bowman, D.D.C. (2012).

		Lester, 2001, p. 179).  Animated pedagogical agent/Dr. C (Bowman, 2012)  Animated pedagogical agent/Mr Joshua (Arnott-Hill, Hastings, & Allbritton, 2012)	transmission from computer to learner" (Moreno, et al., 2001, p. 209). When using media, "students like to learn within an agent-based environment more than from other source" (Moreno, et al., 2001, p. 209).	Student use of animated pedagogical agent in a middle school science inquiry program. *Briitsh Journal of Educational Technology, 43*(3), 359-375. Arnott-Hill, E., Hastings, P., & Allbritton, D. (2012). Intelligent tutoring in a non-traditional college classroom setting. *International Journal of Applied Psychology, 2*(1), 1-7.
Applies in multiple phases of the	Intelligent Tutoring	"The primary purpose of tutoring is to provide instruction about a certain	It supports the learners' activities in discovery learning. (Veermans,	Veermans, K. H. (2003). Intelligent support for

inquiry cycle	Systems	domain to a learner. … the tutor needs to have an idea about the learner's knowledge, the target knowledge, and an idea of how to change the learner's knowledge. This general description of tutoring also applies to computer mediated tutoring" (Veermans, 2003, p. 16). 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).	2003)	discovery learning. Ph.D. thesis, University of Twente.
Applies in multiple phases of the inquiry cycle	Smithdown	"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. A second goal of the system is to impart scientific content knowledge in microeconomics, specifically the laws of supply and demand." (Shute & Glaser, 1990, p. 51)	"Overall, the system performed as expected. Tutoring on scientific inquiry skills resulted in increase knowledge of microeconomics." (Shute & Glaser, 1990, p. 51)	Shute, V. J., & Glaser, R. (1990). A large-scale evaluation of an intelligent discovery world: Smithtown. *Interactive Learning Environments*, *1*, 51-77.

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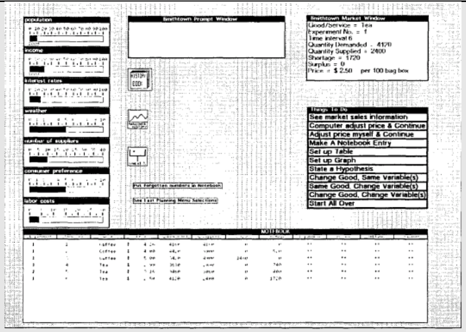
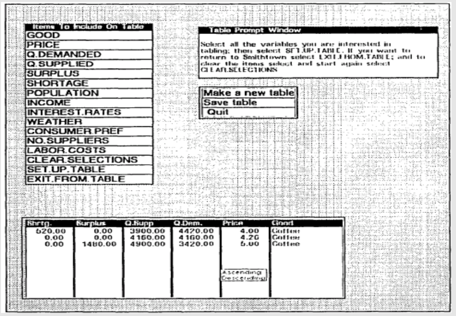


Features of Smithtown (Shute & Glaser, 1990)



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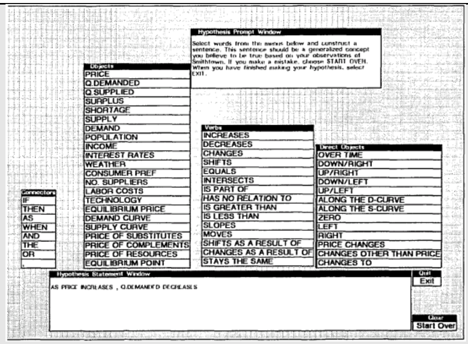
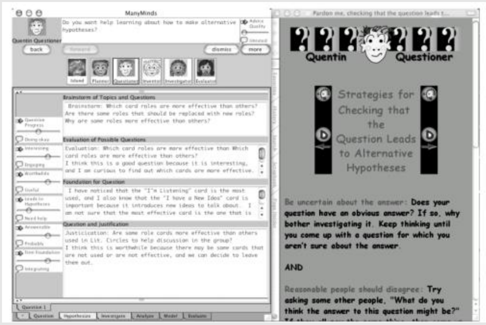
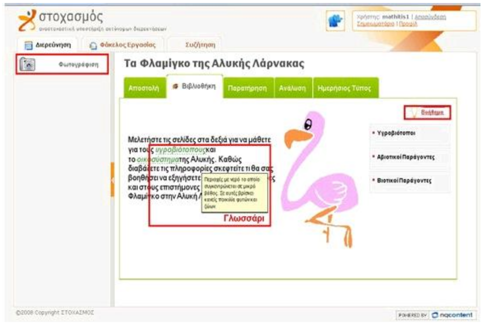
		 Hypothesis menu (Shute & Glaser, 1990)		
Applies in multiple phases of the inquiry cycle	Feedback protocol (norm-reference/self-reference feedback)	"…the norm-reference feedback group, receive feedback in relation to all other learners….the self-referenced feedback group, received feedback on cumulative quiz performance in comparison only to their own prior attempts…" (Biesinger & 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 & Crippen, 2010, p. 1479).	Biesinger, K., & Crippen, K. (2010). The effects of feedback protocol on self-regulated learning in a web-based worked example learning environment. *Computers & Education, 55*(4), 1470-1482.
Applies in multiple phases of the inquiry cycle	Thinkertools/Inquiry Island environments (It includes a fading mechanism)	"Learners have to follow the "inquiry cycle" that contained five phases: state a question, make predictions, perform experiments, formulate laws, and investigate the generality of the laws. All phases contain detail support, but during the course of working with the environment the support gradually disappears" (Veermans, 2003, p. 14).	No definite conclusions could be drawn for the effectiveness of this guidance.	Veermans, K. H. (2003). Intelligent support for discovery learning. Ph.D. thesis, University of Twente. de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J.

		Thinkertools/Inquiry Island has several advisors, each of them related to a specific part of the inquiry cycle. (de Jong, 2006b, p. 112).  Inquiry Island learning environment (White et al., 2002)		Elen & R. E. Clark (Eds.), Handling complexity in learning environments: Theory and research (pp. 107- 128). London: Elsevier. White, B., Frederiksen, J., Frederiksen, T., Eslinger, E., Loper, S., & Collins, A. (2002) Inquiry Island: Affordances of a Multi-Agent Environment for Scientific Inquiry and Reflective Learning. In P. Bell, R. Stevens & T. Satwicz (Eds). Proceedings of the Fifth International Conference of the Learning Sciences (ICLS). Mahwah, NJ: Erlbaum. 2002.
Direct Presentation of Information				
Orientation	Access to domain knowledge	Provision of “definitions of the concepts that are used in the simulation (Glaser, Raghavan, & Schauble, 1988; Shute, 1993).” (Veermans, 2003, p. 13).	No definite conclusions could be drawn for the effectiveness of this guidance.	Veermans, K. H. (2003). Intelligent support for discovery learning. Ph.D. thesis, University of Twente.

				Glaser, R., Raghavan, K., & Schauble, L. (1988). Voltaville, a discovery environment to explore the laws of dc circuits. In G. Gauthier & C. Frasson (Eds.), *Procceedings of intelligent Tutoring Systems – 88* (pp. 61-67). Montreal: University of Montreal. Shute, V. J. (1993). A comparison of learning environments: All that glitters. In S. P. Lajoie & S. J. Derry (Eds.), *Computers as cognitive tolls* (pp. 47-75). Hillesdale, NJ: Erlbaum.
Conceptualisation (Question - Hypothesis)	Issues	"… an idea of the domain is formed, variables are identified, tentative ideas of relations between variables are created, and possibly a 'rough' idea of the structure and complexity of the domain is formed. In an earlier work (de Jong et al., 2002), we have labelled these incomplete and global ideas "issues". An issue is not a full hypothesis, but a problem statement that guides subsequent	No definite conclusions could be drawn for the effectiveness of this guidance.	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier.

		experimentation." (de Jong, 2006b, p. 111)		de Jong, T., van Joolingen, W. R., Savelsbergh, E., Lazonder, A., Wilhelm, P., & Ootes, S. (2002). *Co-Lab Specifications. Part 1 - Theoretical background*. Enschede, NL: University of Twente.
Conceptualisation (Hypothesis)	Complete, pre-defined, hypotheses	"Provides students working with the SimQuest environment on a physics topic of motion with complete, pre-defined, hypotheses. This was inspired by the work of Njoo and de Jong (1993), who found that students could benefit from ready made hypotheses." (de Jong, 2006b, p. 113).	"It appears that this scaffold works. Additionally, the by Gijlers and de Jong (2005) study shows that confronting students with each other's propositions could be beneficial for learning." (de Jong, 2006b, p. 114).	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier. Njoo, M., & de Jong, T. (1993). Exploratory learning with a computer simulation for control theory: Learning processes and instructional support. *Journal of Research in Science Teaching, 30*, 821-844.

				Gijlers, H., & de Jong, T. (2005). The relation between prior knowledge and students' collaborative discovery learning processes. *Journal of Research in Science Teaching, 42*, 264-282.
Discussion (Reflection)	Argumentation palette	"Argumentation palette helps students create a justification for their conclusion. The students' conclusions are compared to an expert conclusion, which helps student reflect on their own argumentation process." (de Jong, 2006b, p. 120).	"BioWorld's explicit argumentation palette directs students to both categorize the evidence that they have posted as well as prioritize its importance." (Lajoie, et al., 2001, p. 180).	de Jong, T. (2006b). Scaffolds for scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107- 128). London: Elsevier. Lajoie, S. P., Lavigne, N. C., Guerrera, C., & Munsie, S. D. (2001). Constructing knowledge in the context of Bioworld. *Instructional Science, 29*, 155-186.
Applies in multiple phases of the inquiry cycle	Glossary - Hyperlinks (STOCHASMOS platform)	"In STOCHASMOS (Kyza, Michael, & Constantinou, 2007) a glossary is used to provide further clarification concerning terminology used	No definite conclusions could be drawn for the effectiveness of this guidance.	Joolingen, W. R., & Zacharia, Z. C. (2009). Developments in inquiry learning. *Technology-*

		throughout a mission. The aim is to ensure that the learners are provided with all the information needed to understand the mission in detail." (van Joolingen & Zacharia, 2009, p. 28).  Glossary/STOCHASMOS (Stochasmos, 2013)		*enhanced learning*, 21-37. Kyza, E., Michael, G., & Constantinou, C. (2007). The rationale, design, and implementation of a web-based inquiry learning environment. In C. Constantinou, Z. C. Zacharia & M. Papaevripidou (Eds.), *Contemporary Perspectives on New Technologies in Science and Education, Proceedings of the Eighth International Conference on Computer Based Learning in Science* (pp. 531–539). Crete, Greece: E-media. STOCHASMOS (2013). Retrieved January 24, 2012 from *http://www.stochasmos.org/nqcontent.cfm?a_id=792*

Applies in multiple phases of the inquiry cycle	Explanations	"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).	No definite conclusions could be drawn for the effectiveness of this guidance.	Veermans, K. H. (2003). Intelligent support for discovery learning. Ph.D. thesis, University of Twente.