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DEVELOPMENT ARTICLE

Using scenarios to design complex technology-enhanced learning environments

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Abstract Science Created by You (SCY) learning environments are computer-based environments in which students learn about science topics in the context of addressing a socio-scientific problem. Along their way to a solution for this problem students produce many types of intermediate products or learning objects. SCY learning environments center the entire learning process around creating, sharing, discussing, and re-using these learning objects. This instructional approach requires dedicated instructional designs, which are supplied in the form

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of what are called pedagogical scenarios. A SCY pedagogical scenario presents the learning process as an organized assembly of elementary learning processes, each associated with a specific learning object and a tool for creating this learning object. Designing a SCY learning environment is basically a two-step procedure: the first step is to select one of the available scenarios, and the second step is to define the domain content. The SCY technical infrastructure then handles the instantiation of the scenario as a SCY computer-based learning environment. In this article we describe the SCY pedagogical design scenarios and report on our experiences in designing four different SCY learning environments.

Keywords Instructional design · Open learning environments · Learning by design · Inquiry learning · Collaborative learning

Introduction

Contemporary, constructivist-based, technology-enhanced learning environments provide students with ample opportunities for inquiry and/or collaboration. In these environments, the affordances offered by technology are used directly for pedagogical purposes. *Inquiry* calls for non-linear, manipulable, and runnable content, and *collaboration* (in particular when asynchronous or online) is enabled by different communication media and the opportunity to share content. Some examples of such environments are Belvedere (Suthers et al. 1995), BioWorld (Lajoie et al. 2001), SimQuest environments (van Joolingen & de Jong 2003), Co-Lab (van Joolingen et al. 2005), WISE (Slotta 2004), Inquiry Island (White et al. 2002), Young Scientist (Mäeots et al. 2008), Genscope (Horwitz et al. 2010), and Stochasmos (Kyza et al. 2011). Evidence is accumulating that these approaches provide students with genuinely effective learning opportunities. Large scale evaluations, conceptual overviews, and meta-analyses have shown that inquiry, if scaffolded, outperforms other forms of instruction (Alfieri et al. 2011, 2011; Deslauriers & Wieman 2011; Eysink et al. 2009; Hickey et al. 2003; Linn et al. 2006; Marusić & Slisko, 2012; Plass et al. 2012; Rutten et al. 2012; Scalise et al. 2011; Smetana & Bell, in press), and the effectiveness of collaboration compared to individual learning has also been demonstrated (see e.g., Gijlers & de Jong, 2009; Kolloffel et al. 2011; Lou, 2004; Lou et al. 2001).

A third instructional approach that is aligned with the basic constructivist principles of inquiry and collaboration is *learning by design*. Here, students learn by creating products; the literature suggests that this method of learning helps specifically with the acquisition of transferable knowledge (Etkina et al. 2010; Kolodner et al. 2003; Mehalik et al. 2008). Unlike the situation for inquiry and collaboration, there is little software that specifically enables learning by design. The environments coming closest to learning by design are those that support students in making computer models of phenomena (see e.g., de Jong & van Joolingen 2007; Shen & Linn 2010; Wilensky & Reisman 2006).

The Science Created by You (SCY) project creates learning environments (called SCY 'missions') that combine all three of these instructional approaches. A central tenet of SCY missions is that students learn by creating products (design), and that in doing so they investigate learning materials (inquiry) and share and discuss their products with peers (collaboration). The main purpose of the current article is to give an outline of the design principles underlying the creation of SCY missions, in which the use of the templates or blueprints known as pedagogical scenarios is central. We begin by giving a brief sketch of what a SCY mission looks like from the student's perspective and an impression of student experiences, followed by the central part of the paper, the presentation of our design approach, and a report of our experiences in designing four different SCY missions.

SCY for students

SCY missions

SCY uses the metaphor of the student as an engineer or scientist who gathers knowledge in the course of working on a research or design project. Therefore, SCY missions are characterized by an overall research or design goal, e.g., to create a report on water quality or to create a CO_2-friendly house. Along their way to this final product students create many types of (intermediate) products. An example of such a product in the CO_2-friendly house mission is a set of hypotheses on the effects of measures that reduce CO_2 emission. We have called these products that are created in SCY missions Emerging Learning Objects (ELOs). Examples of types of ELOs include: runnable models, concept maps, data sets, hypotheses, tables, summaries, reports, and experimental procedures.

To date, four SCY missions have been developed, each of which addresses specific science content in the context of creating a particular final product. Students in the *CO_2-friendly house mission* are assigned the task of designing a CO_2-friendly house. In this mission, students must describe how domestic CO_2 emission occurs and how much of it occurs, and find out how it can be controlled. They take into account materials and how energy is supplied, and list the requirements and constraints for their house. Learning goals include knowledge of physics, such as knowledge of types of energy (potential, kinetic, thermal, chemical, electromagnetic) and of the first law of thermodynamics, as well as mathematical knowledge, such as knowing how the ratio of surface area to volume changes with the size and shape of a specific object. ELOs that need to be produced along the way include a concept map on CO_2 emission, a set of hypotheses about the energy household of a specific house, and data sets from two different simulations (a house simulation and an energy consumption simulation). The students' final product is a 3D-drawing of their house and an accompanying report that gives the rationale for their design choices.

The *ECO mission* is intended for learning about topics at the junction of biology and ecology. These topics are: (a) the influence of nutrient concentration on primary production, (b) influences of light on the level of photosynthesis, (c) relations between trophic levels in an ecosystem, and (d) the concept of pH and changes of pH in bodies of water. The selected topics enable students to encounter real-life problems (e.g., what bait to use to catch fish). Students' final products are a concept map about relations in an ecosystem and a video report that illustrates the inquiry processes that they have applied. ELOs that need to be created during the learning process are research questions and hypotheses, experimental procedures, data sets from mobile devices measuring water quality, dynamic models, and inferences from data.

In the *Healthy Pizza mission* the final product that must be designed is a healthy pizza (either in the form of a real pizza or using a simulation). Topics that students address in this mission are the nutritional value of food items in general (carbohydrates, fat, proteins, energy, vitamins, etc.) and of various pizza ingredients in particular, the classification of food products (grains, fruits, vegetables, milk, meat, and beans), and information on energy (calories) and the human digestive system. ELOs that need to be created en route to the healthy pizza include a personal health passport, a nutrition table, a map of the digestive system, and a food pyramid.

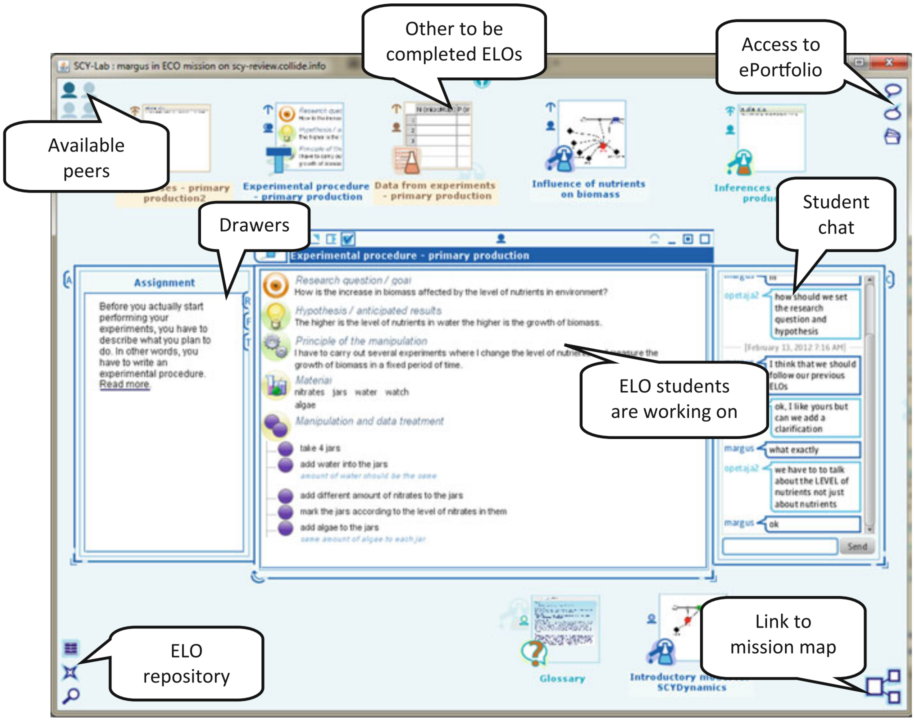
In the *forensic mission* students are engaged in an investigation to find a criminal offender. They must identify the techniques they will use to analyze DNA or ink samples, elaborate or justify their experimental procedure, carry out real experiments, and analyze their results. Students deal with concepts about DNA (universality, structure, sequence of nucleotides), biological techniques (electrophoresis gel, restriction enzymes, DNA profiling), chemistry (solution, solvent, solubility), chemical techniques (thin layer chromatography, identification and separation techniques), and mathematics (frequency, match probability). Examples of ELOs that students need to create are a concept map on techniques for chemical analyses, texts such as a definition of DNA or the justification of chromatography as a relevant technique for analysis of ink, expected results of the experiments, experimental procedures for the chemical analysis, pictures of experimental results (e.g., taken with a mobile phone), and calculations of DNA profile frequencies in the human population. The final product is a report for the attorney general that will help to solve the case.

The CO_2, ECO, and forensic missions aim for students in the 16–19 age group, while the Healthy Pizza mission is intended for a somewhat younger group of 12- to 15-year-olds. The estimated duration of a mission ranges from 16 h (ECO and Forensic missions) to 20 h (CO_2 and Healthy Pizza missions). However, there is some flexibility built into the missions that makes it possible to use them even if less lesson time is available. For example, the *ECO mission* covers four topics that can be completed independently, in about 4 h each.

The (interface) design of SCY missions

At the center of all SCY missions are the *ELOs* that students need to develop. Students are provided with dedicated *tools* for creating these ELOs, such as a modeling tool, a concept mapping tool, an experiment design tool and so forth, and are given collaboration facilities to discuss the ELOs with other students. Students have access to *resources* (internet links, background documents) that provide them with information that is helpful in creating ELOs. Finally, students are provided with four *services* that help them in their work, but do not lead directly to the production of ELOs: (1) the awareness service reports on the presence of student peers, (2) the ePortfolio service enables students to save their ELOs in a portfolio and ask for assessment, (3) the repository service enables students to save, search for, and share ELOs, and (4) the mission map helps students to navigate through the mission overall. Figure 1 shows an example of a SCY mission interface. The interface shows an ELO under development in the center. The tool for creating the ELO is integrated in the ELO; the facilities supporting the creation of the ELO are close to the ELO in ‘drawers’, extendable tabs to the left and right of the ELO. The services are located in the corners of the interface.

In the interface presented in Fig. 1, taken from the ECO mission, students are composing an ELO called ‘experimental procedure’. A number of thumbnails of other ELOs that students also need to complete are visible on the screen. The four drawers to the left of the ELO contain (1) an assignment that explains what students should do; this drawer is extended in Fig. 1 (labeled ‘Assignment’), (2) resources (e.g., texts or hyperlinks) that can help in completing the ELO, (3) a feedback request option and (4) an option for adding tags to the ELO, such as tags that may help in later searches for ELOs. Communication about an ELO under edit is closely connected to the ELO itself. As can be seen in Fig. 1, a chat is directly tied to the ELO in a drawer that extends to the right from the ELO, which students can open and close. Students can also ask for comments from other students on their ELO by opening the third drawer to the left of the ELO and asking for feedback. This request is then propagated to other students.



Before you actually start performing your experiments, you have to describe what you plan to do. In other words, you have to write an experimental procedure. Read more.

Research question / goal
How is the increase in biomass affected by the level of nutrients in environment?

Hypothesis / anticipated results
The higher is the level of nutrients in water the higher is the growth of biomass.

Principle of the manipulation
I have to carry out several experiments where I change the level of nutrie easure the growth of biomass in a fixed period of time.

Material
nitrates jars water watch algae

Manipulation and data treatment
- take 4 jars
- add water into the jars
  amount of water should be the same
- add different amount of nitrates to the jars
- mark the jars according to the level of nitrates in them
- add algae to the jars
  same amount of algae to each jar

opetaja2: how should we set the research question and hypothesis
[February 13, 2012 7:16 AM]
I think that we should follow our previous ELOs
ok, I like yours but can we add a clarification
margus: what exactly
opetaja2: we have to to talk about the LEVEL of nutrients not just about nutrients
margus: ok

Fig. 1 Example of a SCY mission interface (from the ECO mission)

The services are located in the four corners of the window. First, students can save their ELOs and search for their own ELOs and those of peer students in the SCY repository service in the bottom left corner of the screen. Second, students can invite other students to collaborate on an ELO by dragging the icon representing a student from the *awareness service* in the upper left part of the screen to the ELO. This sends an invitation to the invited student. If this invitation is accepted, that student is ‘teleported’ to the ELO to start collaboration with the students who are already working together on this ELO. Students who are visible as a group in the awareness service are often assigned to the group by their teacher beforehand. Third, if students are satisfied with an ELO they have created, they can drag it to the icon at the top right of the screen to add it to their ePortfolio (see Vold et al. 2012 for more details). When an ELO is placed in the ePortfolio, the teacher has access to the ELO and can give an assessment of it. Fourth, to help students navigate in a mission they can use the mission map that is displayed in the bottom right corner of the screen. SCY missions are composed of larger units that we have called learning activity spaces (LASs). A LAS is a combination of ELOs that form a conceptual unit. An example is the LAS ‘Experimentation’. In this LAS, an example of which is presented in Fig. 1, students need to define an experimental goal, design an experimental procedure, collect experimental data, etc. (see also Table 1). The mission map provides students with a graphical overview of all LASs and their relations. Clicking the icon of the mission map in the bottom right corner opens the mission map and enables students to move to another LAS

Table 1 Description of the LAS 'Experimentation'

Activity	Short description	Output ELOs	Tool support
Define experiment goal	Choose variables (what is going to be tested?) and values (what values of variables are implemented?)	Variables, values	SCYED
Design an experimental procedure	Operationalize the variables and specify conduct of the experiment	Experimental procedure	SCYED
Run experiment	Apply experiment design (for simulation or field or laboratory experiment)	Data	SCYSIM
Organize data	Convert between different representations, e.g., visualize in graphical form; aggregate data	Aggregation, choice of scales, graph, table, diagram	SCYDATA
Interpret data	Make a local interpretation of data (without reference to the hypothesis)	Local interpretation of data	SCYDATA
Compare results	Compare results of different experiments	List of differences between experiment results	SCYDATA

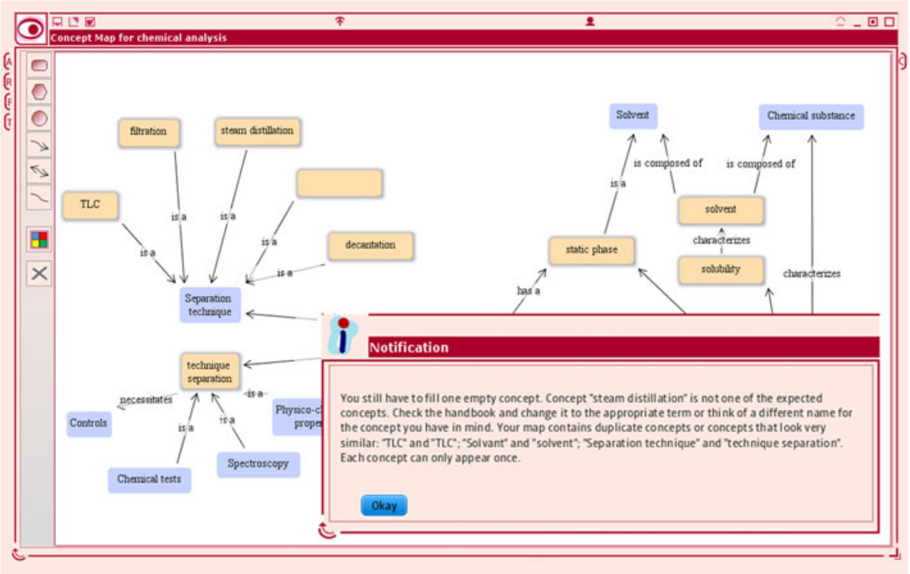
and thereby focus on creating another ELO or set of ELOs. The mission map suggest to students a specific route through the mission, but students are free to diverge from that.

Scaffolding for students

ELOs are automatically and unobtrusively analyzed, and this information is used to provide students with *scaffolds*, either by adapting the tools or by giving explicit guidance and support. For example, we use a number of ways to scaffold students in creating concept maps. First, if students find it difficult to extract main ideas from texts and include them as concepts in a concept map, the learning environment provides a feature allowing them to select and mark relevant pieces of texts (through a dedicated browser plug-in). A keyword extraction agent then extracts the main concepts from these texts and presents them as suggestions for inclusion in the concept map. A similar approach can be used to analyze the information in the resources of the SCY mission itself and suggest (missing) keywords to the students. Second, students can ask to compare their concept map to an expert concept map. In this case, students are provided with feedback on the structure and content of their concept map. Figure 2 presents an example of such feedback on a concept map created by students in the forensic mission. SCY missions also contain several other forms of scaffolding for students, such as feedback on hypotheses they have stated and support in creating collaborative groups. All this support is created automatically without human intervention (Weinbrenner et al. 2011).

Students' experiences with SCY missions

The four SCY missions have been tested with over 600 students from five different countries. We have used a series of different techniques in evaluating students' experiences, including analyses of video recordings, screen captures, and logfiles, as well as analysis of ELOs produced by students (see, Kluge et al. 2011). The data from evaluation



You still have to fill one empty concept. Concept "steam distillation" is not one of the expected concepts. Check the handbook and change it to the appropriate term or think of a different name for the concept you have in mind. Your map contains duplicate concepts or concepts that look very similar: "TLC" and "TLC"; "Solvant" and "solvent"; "Separation technique" and "technique separation". Each concept can only appear once.

Fig. 2 Example of feedback on a student concept map in the forensic mission

of these experiences were used in an iterative design approach to create the interface of the learning environment in its current form. For example, in the course of the design process the navigation features became more structured and explicit for students; in particular, the mission map was added to present students with an overview of the mission. Overall, students had (surprisingly) little trouble navigating through a SCY mission, but to support them further we developed a brief introductory ‘mini-mission’ that introduces students to the main aspects of a SCY mission. We also developed a number of help videos that explain the main functionalities of the learning environment, and we implemented ‘bubble’ help for all of the main elements in each SCY mission. Because ELO creation and re-use is of paramount importance in the SCY learning experience, we looked at students’ ability to assess and re-use each other’s ELOs. Two case studies revealed that students appreciated and used the opportunity to inspect the work of their peers. However, results also showed that additional support is necessary for students to make *productive* use of peer-created ELOs. Three processes in particular appeared to be difficult for students: deciding what information to look for, selecting relevant ELOs, and judging the quality of these ELOs. A follow-up study confirmed that students who received scaffolding for these processes considered the contents of peer-created ELOs in greater depth and therefore created better ELOs of their own than did students without additional support (Kluge, et al. 2011). In another study we examined how students assessed each other’s ELOs, and concluded that students (seventh graders, in this case) could in principle give relevant peer feedback on ELOs, but that their skills still needed further development (Tsivitanidou et al. 2011). Although we have not yet compared learning with SCY missions to conventional instructional approaches, in a number of recent studies we have been able to confirm that, measured through pre- and post-tests, students who learned with a SCY mission made considerable progress in their inquiry skills as well as their domain knowledge (Kluge et al. 2012).

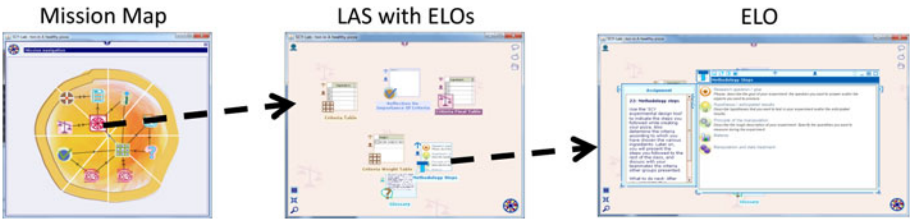


Fig. 3 Structured overview of the three levels of SCY learning environments from a student's perspective. The example is taken from the Pizza mission, in which the mission map has the form of a Pizza with a set of ELOs as toppings

The student's view of a SCY mission in summary

In the current section of this article we have described a student's view of a SCY mission. In summary, students can operate at three levels of abstraction. At the highest level, students view a mission map, which organizes the Learning Activity Spaces (LASs) pertaining to that mission. At the mid-level, each LAS is composed of a grouping of ELOs necessary to create in completing the mission. And at the lowest level, students create ELOs. SCY missions always consist of one mission map, a number of LASs, and a larger number of ELOs. Students start with a view of the mission map. They then select a LAS from the mission map, and that LAS then opens and shows its ELOs. After that, students select from the LAS an ELO to work on, which opens the ELO creation interface. After having worked on an ELO students can close it and move to another ELO in the same LAS or, alternatively, go back to the mission map and open another LAS with new ELOs to produce. Figure 3 presents a graphical overview of the structure of a SCY mission. This structure also forms the basis for the design process of a SCY mission, which is the topic of our next section.

SCY for instructional designers

As stated in the introduction, technology-enhanced learning environments for inquiry, collaboration, and to a lesser extent, learning by designing, are not new. There is also a large set of instructional design theories that prescribe how these kinds of environments should be designed. Because of the learner centered character of the learning environments that are designed, some authors prefer to use the term "learning design" (see e.g., Sims 2006). In the remainder of the article we will, however, use the term "instructional design" to better stay in line with the mainstream literature. Some of the (classical) theories are general in character (Dick & Carey 1990; Gagné et al. 1988), while others focus on a specific learning approach, such as inquiry (e.g., Spector & Davidsen 2000). These theories have proven to be very helpful for designing learning environments, but even the more specific ones limit themselves to providing designers with general guidelines (such as: "challenge the learner to diversify and generalize", Spector & Davidsen 2000, p. 256) that still need to be translated into an actual design. Our goal in the SCY project is to realize multiple different missions, which requires a designated and formalized instructional design method. Having such a design method means that the development of new missions with new content can benefit from re-usable design elements. This helps to decrease mission development time, and also allows different educational designers to develop missions while maintaining a consistent pedagogy. Moreover, having a formalized and unified format for describing the pedagogical design of SCY missions allows systematic comparison between different scenarios and the way they incorporate inquiry, design, and collaboration. In this way, design decisions are made overt and can be compared and debated. The instructional design method we developed in SCY is formalized in what are called 'pedagogical scenarios' that we have used to realize four missions so far (see the descriptions above), with additional new missions currently under development.

Scenarios, blueprints for instructional design

The design process for a SCY mission is based on the same structure as the student's view presented in Fig. 3. To create a mission, a designer starts at the highest level of abstraction and first selects a 'pedagogical scenario' from a fixed collection of scenarios that was created by the SCY development team. A pedagogical scenario is always composed of a set of interconnected LASs, each LAS consists of a set of ELOs, and each ELO has an associated learning activity and a tool for creating it. In the remainder of this section we will describe these different components of the design process, starting at the lowest level, the ELO with associated activities and tools, then moving to the LASs, and finally presenting the available set of scenarios.

Our creation of the pedagogical scenarios proceeded in the opposite direction from that taken by a SCY mission designer. We started at the lowest level of abstraction by defining a set of basic learning activities, based on existing frameworks of such activities (Anderson & Kraftwohl 2001; Azevedo et al. 2004; Ferguson-Hessler & de Jong 1990; Mayer 2002). We identified a total of 53 learning activities that were relevant for our overall pedagogical approach. Examples of learning activities are: *identify resources, distribute tasks, rehearse, build a model, ask a question, reflect on (individual and group) processes, relate data with hypothesis/theory, design a (physical or virtual) artifact, build a (physical or virtual) artifact, design an experimental procedure, evaluate ELO (one's own or a peer's), monitor the learning process,* and *summarize.*[1] We then defined the ELO that is produced by each activity and identified a software tool that is needed to perform the activity and produce the ELO. A straightforward example of such an activity-tool-ELO triplet is the learning *activity* 'build a model', which in case of a conceptual model may result in the *ELO* 'concept map', for which the *tool* 'SCYMapper' is available.

Next, the 53 triplets of activities with their associated ELOs and tools were clustered into 13 larger conceptual units, or LASs, that all fit within our general approach of inquiry, collaboration, and learning by design. A specific triplet could be part of more than one LAS. The LASs were labeled: *Orientation, Management, Information, Conceptualization, Debate, Reflection, Analysis, Designing, Building, Experimentation, Evaluation, Regulation,* and *Reporting*. An example is given in Table 1, which presents the activities, ELOs, and tools that form the LAS 'Experimentation'. The tools SCYED, SCYSIM, and SCY-DATA that are mentioned in the table were created for the SCY project to enable students to produce the associated ELOs; they enable students to set up an experimental design, run a simulation, and perform data analyses, respectively.

Finally, on the highest level of abstraction we can see a SCY mission as a collection of LASs. This collection of interconnected LASs that defines a mission is called a

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[1] The total list of learning activities can be found at http://scy-net.eu/scenarios/index.php/Learning_activities_in_SCY.

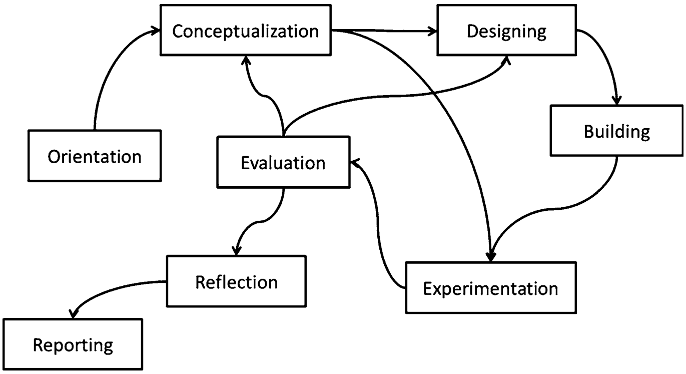

Fig. 4 Interdependencies of learning activity spaces in the ‘design challenge’ scenario

pedagogical scenario.[2] For example, Fig. 4 presents the ‘Design challenge’ scenario, which consists of eight LASs (including the LAS ‘Experimentation’ from Table 1).

The linking arrows indicate the recommended sequences through the scenario. However, while in a mission students can also follow their own sequence of activities, and may revisit a LAS when they think this to be necessary. This allows for flexibility, in that different students can follow different routes through the scenario. The scenario of the mission is shown to the students in the mission map.

The ‘design challenge’ scenario was instantiated in the mission ‘design a CO_2-friendly house’; a walkthrough of the instantiated scenario for this mission is given in Table 2.

In the SCY project we have defined 12 scenarios, each of which is a different assemblage of the 13 different LASs, which, in their turn, are different assemblages of the 53 triplets of ELOs, activities, and tools.

Our design approach is thus based on choosing from a set of available scenarios. This approach ensures that structures and predefined elements in the scenario are used; furthermore, after designers have selected a scenario, they immediately have an overall structure for the mission they are creating. Scenarios thus work as blueprints for the design of missions. All scenarios are available in the SCY technical infrastructure, which handles production of the software; no programming is required from the instructional designer.

The SCY design process in practice

The design of SCY missions requires decisions and choices, both from a pedagogical perspective and from a content perspective. Designers of SCY missions first decide on their target group of students and, based on the curriculum, on the learning goals they would like their students to achieve. On the basis of this decision, they select one of the 12 pedagogical scenarios for the mission; the selection of the pedagogical scenario defines, by default, the mission’s LASs and ELOs. The next step for designers is to specify and to add the domain content in the form of assignment texts for students, resources, and ELO-specific information. Scenarios thus play a central role in the design of a SCY mission. Figure 5 gives a structured overview of the SCY mission design process.

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[2] The complete list of scenarios can be found at: http://scy-net.eu/scenarios/index.php/The_Scenario_Repository.

Table 2 A walkthrough of the 'design challenge' scenario as applied in the mission 'design a CO_2-friendly house'

LAS	Description
Orientation	First, the whole project is framed by explaining the mission in which the students will engage. This mission starts with a short video explaining environment-related issues, i.e., global warming and CO_2 emissions, and the overall task for the students, namely to design a CO_2-friendly house. The video tells about the different choices students will have to make (selecting windows, building materials, energy sources, and more). The students write down the task in their own words
Conceptualization	Here the students try to identify the different concepts involved in the mission. For instance, what is CO_2, how is it produced, what types of activities in the house can produce it? What is energy, and how are energy and CO_2 related to each other? The students use SCYMapper (the SCY concept mapping tool) to link the different elements and concepts together. Students will come back to refine their conceptual models in the course of the scenario
Designing	Students design an artifact—e.g., a house—based on the conceptual model—e.g., the model of factors that influence CO_2 emissions
Building	Students actually build a real or a simulated house artifact. In this mission we use an external tool (Google SketchUp) for that
Experimentation	Students design and conduct experiments with the respective artifacts they have designed. A dedicated tool (SCYED; see also Fig. 1) helps students to set up correct experiments. A simulation of a house gives students the opportunity to try out different parameters from their design
Evaluation	Students evaluate the data collected—e.g., by comparing results with the preset criteria and norms regarding the amount of CO_2 production—and refine their conceptual models
Reflection	Students reflect on whether they reached the mission goals and the learning goals (shown to them in a curtain, see Fig. 6 for an example), and explain reasons for possible deviations. They discuss how (or whether) their gradual increase in understanding led them to modify the goals of the project or if other factors such as time allotted, tool limitations, and lack of appropriate information led them to reconsider their ambitions
Reporting	Students create an overview of their accomplishments and prepare a presentation to the class and the teacher

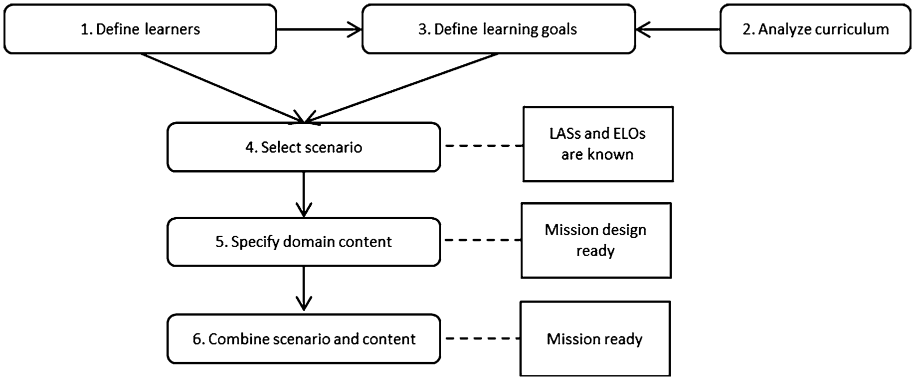


Fig. 5 Overview of the steps in the SCY mission design process

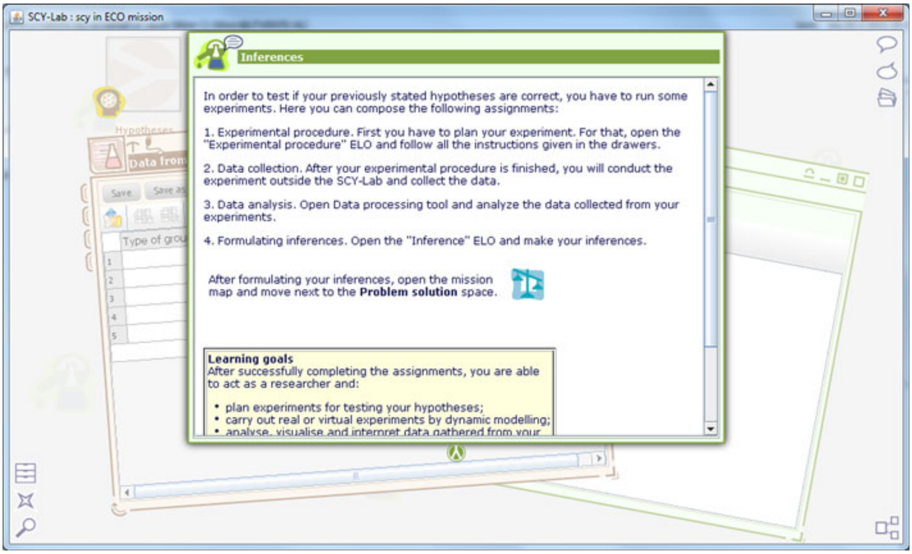
The four SCY missions described above were all designed on the basis of different SCY scenarios. We will illustrate the design process with the example of the ECO mission. Design of the ECO mission started by defining the target group, which was a pre-university track at high school, in the age range 16–19 years old. The learning goals were based on an analysis of the K-12 curricula in Estonia, Cyprus, Norway, France, and the Netherlands. As the mission was planned for use in all of these countries, only those topics covered in all four national curricula were selected for the mission. As a result, three topics were selected in biology and one in chemistry. Mathematics was integrated with the other subjects, as was a physics topic (light) that was included in one of the biology topics.

A set of general and domain-specific goals was specified that guided the further design of the mission. The *general science learning goals* referred to skills such as: being able to critically analyze information from various sources; being able to formulate hypotheses that contain measurable dependent and independent variables; being able to analyze and interpret data; and being able to design a model of a phenomenon. The *domain-specific goals* included: being able to explain the relations between (a) the level of O_2 and population size (plants and animals), (b) the level of CO_2 and population size (plants and animals), (c) light and population size (plants), (d) the environmental factors and pH of water, (e) light and photosynthesis/respiration, and (f) biomass and number of organisms in different trophic levels in an ecosystem. In addition, students should learn to apply concepts in biology (e.g. abiotic and biotic factors, photosynthesis, respiration, population size, trophic levels), physics (propagation of light, temperature), and chemistry (pH) in a conceptually coherent way. Finally, they should learn to model the changes and balance in an ecosystem (level of O_2, CO_2, pH, light, population size, temperature) and to apply domain-specific experimental procedures (measurement of O_2, CO_2, pH, light, population size, temperature).

The general science learning goals made the ‘Inquiry Learning’ scenario the obvious choice. This scenario was especially designed for developing students‘inquiry skills; the learning goals defined above map onto both the overall aim of the scenario and the specific activities pursued in its individual LASs. In this scenario, students also acquire more general problem-solving skills, analytical skills, and self-regulation skills. Because we had four distinguishable topics in this mission, the mission was set up as four inquiry cycles, one for each of the four topics.

After having made the choices of a target group, learning goals, and scenario, domain content was formulated. This content was created based on the national curricula that were analyzed, a review of the relevant literature, and the domain expertise of the designers. In order to identify additional content for this mission, six domain experts (three ecologists and three science teachers) from Estonia, Cyprus, and the Netherlands were interviewed. They were provided with a list of misconceptions and knowledge gaps derived from a literature review. The experts were asked to rate the importance of the issues and to add new elements based on their own experience. The information collected from the literature review and expert interviews was used to develop mission-specific resources, which were then evaluated by a group of science teachers.

Finally, the domain content had to be integrated with the mission. The following elements needed to be concretized: (a) a general mission introduction, (b) LAS-specific assignments, (c) assignments that students receive for each ELO, and (d) resources for students to consult in their work. The general mission introduction and the LAS-specific assignments are presented through a so-called ‘curtain’ that opens upon opening the LAS and which students can roll up or down (see Fig. 6 with an example of a LAS specific assignment from the ECO mission). ELO assignments and the resources are presented to



Inferences

In order to test if your previously stated hypotheses are correct, you have to run some experiments. Here you can compose the following assignments:

1. Experimental procedure. First you have to plan your experiment. For that, open the "Experimental procedure" ELO and follow all the instructions given in the drawers.

2. Data collection. After your experimental procedure is finished, you will conduct the experiment outside the SCY-Lab and collect the data.

3. Data analysis. Open Data processing tool and analyze the data collected from your experiments.

4. Formulating inferences. Open the "Inference" ELO and make your inferences.

After formulating your inferences, open the mission map and move next to the **Problem solution** space.

Learning goals
After successfully completing the assignments, you are able to act as a researcher and:

- plan experiments for testing your hypotheses;
- carry out real or virtual experiments by dynamic modelling;
- analyse, visualise and interpret data gathered from your

Fig. 6 The LAS ‘Experimentation’ with its curtain down (from the ECO mission)

students in so-called ‘drawers’, the extendable side windows of the ELO. This was illustrated in Fig. 1.

Experiences with the design of four missions

Scenarios have been used as the basis for designing all four currently existing SCY missions (CO_2-friendly house, ECO, Healthy Pizza, and forensic missions). Our experiences can be summarized as follows:

- In designing, the creation of learning goals and the choice of a scenario happened close together. Because scenarios bring general science learning goals with them, designers supplemented their original learning goals quickly with learning goals that were part of the selected scenario.
- Designers did not follow a scenario unthinkingly, but left out LASs they found less relevant and also excluded learning activities/ELOs within LASs that they thought did not fit into the specific mission. In this way, the scenario functioned as an overall framework from which elements could be omitted. However, the character and structure of the scenario were preserved overall.
- A given scenario may direct students to return to a LAS two or even more times, typically with the objective of adapting or updating an ELO. Therefore, sometimes the choice was made to have multiple LASs of the same kind in the same SCY mission, so that students could identify the ‘phase’ of the mission in which they were working.
- Several times LASs were also combined, in order to make student navigation easier.
- It was also necessary divide the larger missions (ECO, Healthy Pizza, and forensic missions) into a number of content-related parts, each of which followed the scenario individually. That is, each part followed either a phase in the scenario or a complete scenario, depending on the mission.

The main change with regard to the original design process was that the initial two-step design process (select scenario, instantiate with content) was extended with an intermediate stage in which designers adapted a scenario by leaving out LASs (or within LASs leaving out specific ELOs with associated learning activities) that they did not find applicable for their specific context. In his commentary on a number of Instructional Design (ID) tools that were described in a special issue of ETR&D (vol. 50, 2), Gustafson (2002) stated that whatever ID tool is being used, it only becomes a valuable tool in the hands of a skillful designer: "The degree of both general and specific ID and subject matter expertise expected of tool users is a central factor when considering its application." (Gustafson 2002, p. 60). The observations above underscore Gustafson's point that instructional designers (should) mold the design process toward their own needs and desires, as is supported in the SCY approach.

Discussion: The SCY design approach in relation to other instructional design approaches

The design and development of technology-enhanced learning environments is a costly and time-consuming endeavor. Each and every aspect of a learning environment needs to be designed from both a content and an instructional perspective, and implemented in software. Estimates of the number of hours required to produce 1 h of instruction have ranged from 100 (Tannenbaum 2001) to 300 (Merrill & ID2 Research Group 1998). Therefore, it is not surprising to see that there has been a search for tools to help reduce production time and at the same time improve instructional design quality (Merrill 2002a). Reuse is one of the mechanisms that supports time efficiency and quality assurance (Murray 1999). Reuse may refer to the *content* of a learning environment or to the *instructional design* or to both. When the content and instructional design have been taken into account adequately, reuse may also refer to the *technical realization* of a learning environment. This means that components can be reused more or less directly in a technology-enhanced learning environment, without additional programming. In SCY we have focused on the re-use of the instructional design, in the form of re-usable scenarios that are already programmed in a learning environment. SCY scenarios can be adapted by designers, as was done in practice. Moreover, through an authoring system designers can set specific parameters in the learning environment, such as the level of scaffolding. Designers can even decide to create completely new scenarios with the use of a scenario tool that is available in SCY. In this way, we tried to combine the ease of pre-defined and re-usable structures and, for more advanced use, far-reaching facilities for adaptability. As Murray (1999) explicitly mentions, customization, extensibility, and scriptability are key characteristics of proficient authoring systems.

In SCY, the instructional design approach must be able to realize learning environments with an open and complex structure. Design for ill-structured problems, such as SCY missions, creates a set of specific challenges (Jonassen 1997). Traditionally, instructional system design (ISD) models follow a sequential (but often iterative) process that starts with defining learning goals, ends with implementation/production, and has a number of in-between phases (that may differ between different approaches) (see e.g., Merrill 2002b). The general structure of these models is often labeled as ADDIE (Analysis, Design, Development, Implementation, and Evaluation, see Rowland 1992; Visscher-Voerman & Gustafson 2004). All components of the ADDIE model are incorporated in the SCY approach, with defining learning goals in the beginning and implementation at the end, but the SCY approach has different emphases and also collapses different steps. First, based on an overall topic and idea of what students should learn, an existing pedagogical scenario is chosen rather quickly. Close together with this, the list of learning goals is also completed early in the process, partly based on what the scenario offers in the way of general science learning goals. The availability of scenarios means that parts of the design, development, and implementation phases are done together. The main, and still challenging, task for the designer then becomes to create the domain content. The SCY technical infrastructure takes care of the implementation (see de Jong et al. 2010). The evaluation phase from the ADDIE approach, finally, is realized in the SCY approach in both a formative way, because our approach enables very rapid prototyping, and also a summative way, by currently ongoing experimental and field studies.

The SCY approach to instructional design can be characterized as one of providing templates or blueprints to designers, with the idea that the designers' task is to adapt scenarios whenever necessary and to add the right content. In this way, it follows the approach of, for example, the ADAPT^{IT} method of supporting authors (van Merriënboer et al. 2002), but on a more detailed level. Designers receive a clear overview of all elements in a scenario and the software templates that realize them. It also resembles the SimQuest authoring approach (van Joolingen & de Jong 2003) where the overall structure was also ready-made and content needed to be included, but now with a much larger set and variety of possible scenarios.

In the SCY design approach we have tried to find a balance between providing designers with ready-made structures (scenarios) and giving them the tools and freedom to adapt these structures to their personal needs. The use of triplets of activities with ELOs and tools as the basis of our design structures allows new structures to be composed by assembling existing triplets; further, it would also be possible to create new triplets. These would then, of course, need implementation in the SCY infrastructure to allow their designs to be realized in an actual working SCY mission.

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