A Pedagogical Approach to the Design of Learning Objects for Complex Domains

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ABSTRACT

In this article we describe an approach to the design of learning objects (LOs) suitable to support learning in complex domains. We briefly discuss, from an educational point of view, the methodological choices underlying the design of LOs to be used as didactical materials in a distributed Web-based environment, presently under development, devoted to robotics education at the university level. We show how our pedagogical approach to knowledge acquisition and to the use of technological tools is realised by means of didactical units which can be implemented as LOs with various aims and correspondingly different structures. We also address the issue of supporting students' learning in ways that differ according to the requirements of each situation and illustrate how such support can be implemented by means of our pedagogically oriented LOs.

Keywords: e-learning; instructional material; telelearning; technology enhanced learning

INTRODUCTION

In an active approach to learning, oriented to the acquisition of nontrivial knowledge, to the solution of complex problems and to the development of self-regulation abilities (Ausubel, 1963; Bruner, 1966; Novak, 2002; Piaget, 1976), students build new knowledge based on their previous one, by means of personal reflection and social interaction (Dillenbourgh, 1999; Jonassen & Land, 2000; Vygotsky, 1978). In this framework, an important role for the teacher consists in supporting the students through this process, increasing their motivation, promoting initiative and control, guiding them in knowledge exploration, and organising the use of tools. Following this theoretical characterisation, learning is seen as developing from activities of three different kinds, that is, (1) individual, (2) teacher guided, and (3) in collaboration with peers. Technology can play a meaningful role in all kinds of activities by offering nontrivial working tools and individually adaptable hypermedia learning materials, easing communication and collaboration with peers, supporting self-assessment, as well as by performing some functions which have always been of teachers, such as scaffolding and problem posing.

The increased possibilities of effectively implementing such an active and articulated approach to learning offered by the current development of information and computer technologies (ICT), turns out very useful when the object of study are complex domains, as for instance, mechatronics education at a university level (i.e., the design of robot control). Actual work on the real tools is crucial for suitable learning in this field, and the use of simple simulation programs cannot be sufficient. For economical reasons, however, most universities put at students' disposal a laboratory where only experiments on some specific class of robots can be carried out, and labs with different equipments are spread across several universities. The possibility of sharing such resources at a distance would allow students to avail themselves not only of tools to simulate the operation of equipment, which is available in other universities, but also of the very robots located elsewhere, by means of telepresence.

Exploiting this possibility is the basic idea of the Telepresence Instant Groupware for higher Education in Robotics (TIGER) project, which aims at building a Web-based environment to operatively access robot labs distributed in several Italian universities, hence providing for the students an educational context that transforms the potential of technology into a real opportunity to build up knowledge and experience.

The considered application field is very complex and is characterised by the need to keep a strict connection among theoretical knowledge, methodological competence, and operational skills necessary for the use of robotic laboratories (Fabri, Falsetti, Ramazzotti, & Leo, 2004). Moreover, students are required to develop good abilities of self-regulated work and to be able to fully avail themselves of virtual environments on the Web.

In order to meet the needs of this application, we designed an educational framework (Busetti, Dettori, Forcheri, & Ierardi, 2005a) where LOs (Littlejohn, 2003) are the central tools used to keep a strict connection among theoretical, methodological, and operational competence. This is obtained by defining a typology of LOs, apt to meet the variety of requirements which characterise education on robot control. In this paper, we characterise these LOs. We then consider the issue of suitably supporting students' learning in ways that differ according to the competence of the students and the characteristics of the tasks addressed. Based on an analysis of the literature, we point out different types of support that students may need in different learning situations and show how they can be realised by means of our pedagogically oriented LOs. With our contribution, we aim to propose an approach to the design of educational environments which combine the learning object paradigm with the current pedagogical view of teaching in complex fields.

POTENTIALITIES AND LIMITS OF LEARNING OBJECTS

LOs have been conceived as chunks of self-consistent educational material suitable to be used as instructional components in a variety of contexts. This idea is central to the implementation of e-learning, since it eases, at least in principle, the construction, at limited costs, of flexible, Web-based courses (Malcolm, 2005), which can include contributions of several educational institutions and hence can constitute a means of cultural interchange and mutual enrichment.

In order to effectively implement this concept, an ICT-based technology has been worked out, aiming to suitably catalogue such materials as concerns content, educational objectives, context of use, technical characteristics, and so forth, so as to allow its efficient localisation, retrieval, selection, sharing, and adaptation, independently of the creation context (Quinn & Hobbs, 2000). The characterising features which support cataloguing are usually called metadata; for their descriptions, a standard was created (IEEE, 2002).

In an LO-based educational framework, a course, or, more generally, an instructional proposal, is viewed as a set of instructional units, each of which is self-consistent, endowed with precise educational objectives and modifiable. The use of LOs, however, also provides an effective technological basis to promote autonomous learning, in that it puts at users' disposal libraries of instructional material of various kinds where the learners can freely choose those of their interest. Finally, LOs can promote teachers' professional improvement, in that they offer the possibility to develop structured material by elaborating other teachers' productions and hence giving the opportunity to learn from each other's experience (Busetti, Dettori, Forcheri, & Ierardi, 2004).

Despite the many potential benefits, however, LO technology is still scarcely diffused in schools and universities (Griffith & Academic Co-Lab Staff, 2003), mostly due to the number of problems that rise when implementing it into real contexts and trying to merge it with the currently used pedagogical approach to teaching (Busetti, Forcheri, Ierardi, & Molfino, 2004; Friesen, 2004). In particular, starting an effective process of transferring this technology requires its reinterpretation, so that it can be effectively proposed as a tool to realise educational processes which results are pedagogically well founded and are apt to capture teachers' experience in a variety of didactical situations. The design of LOs within the TIGER project was carried out along these lines.

EDUCATIONAL FRAMEWORK

The TIGER project is developed within the general framework of current education at the university level, in particular regarding robotics education. The design of robot control requires a particularly strict integration between methodological and operational competence, as can be obtained by a learning-by-doing approach. The situation is, however, made particularly difficult by the fact that robots are delicate and expensive devices, and students need to undergo a suitable preparation with exploratory activities on recognition of the environment's features before they can materially access the real tools.

This motivated the need to develop telepresence environments, including the development of a rich and articulated range of abilities; such as technical; instrumental and methodological competence; metacognitive and self-regulatory abilities; and relational abilities so to be able to perform collaborative work on complex tasks (Fabri et al., 2004). Accordingly, from a pedagogical point of view, our proposal is based mainly on a constructivist approach to knowledge, where learning is viewed as resulting from personal activity and comparison with the activity of others. We briefly remind here that the constructivist approach relies on active learning, oriented to the acquisition of nontrivial knowledge and skills, to the solution of complex problems, to the focus on constructing knowledge rather than transmitting it, and to the development of self-regulation abilities. In this view, new knowledge is built up, based on the previously acquired one, by means of personal reflection and social interaction; by analysing and combining experiences; and by abstracting concepts and consciously applying them to the solution of new problems. Moreover, tools need to be provided and activities suggested, so as to help the learners develop metacognitive abilities (i.e., awareness and regulation of cognition) as well as abilities to control one's own motivation and to plan, monitor, and self-evaluate one's own learning (Hacker, Dunlosky, & Graesser, 1998; Pintrich, 1999; Zimmerman & Schunk, 2001). Our view, hence, is essentially learner centred. Nevertheless, we think that teachers have an important role to play by introducing concepts and guiding their deepening, posing problems; organising the overall activity; and supporting and assessing as well as keeping up student's motivation. In this framework, technology can play a meaningful role in every component by offering nontrivial working tools and individually adaptable hypermedia learning materials; easing communication and collaboration with peers; and supporting self-assessment, as well as by performing some functions which are traditionally of teachers, such as scaffolding and problem posing.

Hence, in order to face the complexity of the considered educational situation, we decided to let the TIGER system put at a user's disposal a variety of resources apt to help students to take initiative and control their own learning, as well as to encourage them to interact with their peers and with the teacher. Moreover, we organised and structured the students' work by integrating individual activity with learning guided by the teacher and learning in collaboration, by designing different ways to provide support to students' learning according to the students' needs and the characteristics of the problems at hand. To this end, we devised tools and functions which could be apt to implement this process and worked out a suitable organisation for the educational materials by defining a typology of LOs.

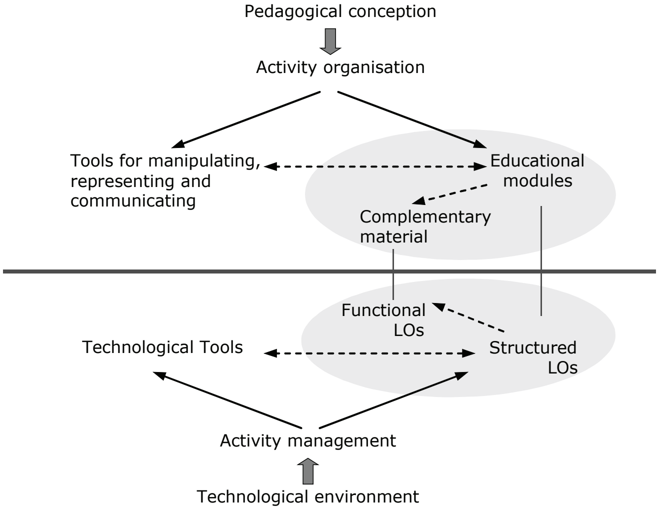
STRUCTURING THE DIDACTICAL ACTIVITY

Educational Modules as Initiators of Constructive Learning Processes

Based on the educational framework outlined, we oriented our designing effort by considering LOs from a teacher's point of view. We started from observing the behaviour of a teacher who designs some educational activity. The starting point of this process is devising an overall learning experience, based on previous educational work, as well as on new contents to be learned and abilities to be acquired. Then, the teacher organises the overall path in a number of educational modules, each focused on addressing a specific topic, either theoretically or by means of some activity. These modules are actually initiators of learning experiences. Thus, they include a specific educational objective and a pedagogical approach to it. They also make use of general-purpose, complementary material, aiming to possibly give different orientations to the learning process they plan. They organise the use of both conceptual and material tools so to be functional to the work development and to suggest the interactions among the actors of the educational experience. Following our pedagogical framework, each didactical module includes, or refers to, a combination of the following resources:

- individual or group activities;
- simulation tools or actual access to the laboratory;
- tools which are meaningful in relation with the module's content, so as to support collaboration, reflection, and evaluation of the experience (notebook, portfolio, qualitative and quantitative evaluation forms, filled in by teacher, peers and the student him/herself, etc.);
- materials to support the development of activities (outlines of activities, proposed exercises, theoretical material, methodological indications, examples, guide to the use of the laboratory, suggestions of tools to use, etc.);
- reports on experiences made by peers, if the teacher considers it suitable to make them available, as well as possibly existing materials related with the tools used, such as journal papers, Web sites of industries producing the tools, glossaries, and notes of use);
- assessment and self-assessment material;
- a pretest aiming to help the students assess whether or not they are pre-

Figure 1. Correspondence between pedagogical conception and technological environment



pared to tackle the module under consideration.

Each module includes a description of the work to be done, motivates its introduction, guides the student to acquire specific skills, and encourages the development of self-regulation abilities.

In order to implement this view of learning so as to cope with the requirements of complex domains, we devised a variety of LOs and tools reflecting the articulated organisation of educational materials and activities that experienced teachers usually employ in their work. This correspondence is shown in Figure1.

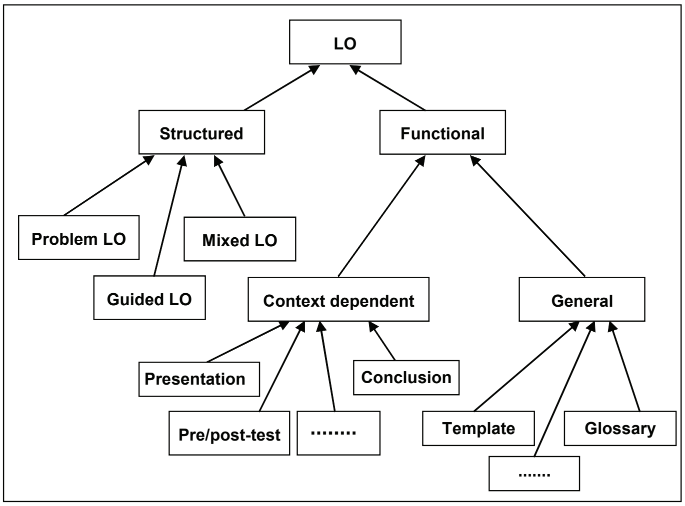
From Educational Modules to Structured LOs

Learning modules are realised by means of LOs, designed to structure and guide an articulated educational activity. We designed these LOs, which embody the modules, so that they can, in turn, make use of, or refer to, other LOs with a different structure, corresponding to materials necessary to carry out the proposed activities. This organisation implies having at the learner's disposal LOs of different types, depending on the characteristics of the educational modules they embody: (1) *structured LOs*, based on a precise educational objective, characterised by a type which determines their structure and didactical function and (2) *functional LOs*, which do not include a specific pedagogical orientation but have a general-purpose or context-related function. These correspond to complementary materials.

These two types of LOs are, in turn, divided into different subtypes, according to their structure and function. The hierarchy resulting from this characterisation of LOs is represented in Figure 2.

Functional LOs can take different types according to the kind and func-

Figure 2. Types of LOs devised in our proposal



tion of their content. We distinguish, in particular, two general types, that is, (1) context-dependent ones, containing material that is relevant only in connection with some particular module; these include presentations, assessment modules, and so forth and (2) general-purpose ones, whose content may be relevant for any module of a whole, articulated course; such as glossaries, templates, and so forth. These two types of functional LOs, in turn, are subdivided into several subtypes, according to their specific function. Hence, we give to each of them names such as *glossary LO*, *presentation LO*, *template LO*, *assessment LO*, and so forth.

Also, structured LOs can take different forms, depending on the objective of the correspondent modules. As a teacher can decide to apply a different educational approach in different phases of the overall learning path, based on the specific requirements of the situation (which depends on the students' competence and maturity level, and partially also on the nature of the topic addressed), we can devise different kinds of didactical modules. This possible diversification of modules led us to introduce a characterisation of structured LOs with different didactical aims, as shown in Figure 2. We describe here briefly the three types we consider necessary for our purposes:

1. **Modules guided by the teacher.** In this case, the control of the activity, which initially relies most on the teacher, gradually passes to the students while they develop some abilities. Such modules aim to introduce content knowledge or some basic approach to problem solving. In this case, teaching and learning are very structured, though still based on the performing of activities. We call *guided LOs* the correspondent of such modules.
2. **Modules oriented to autonomous exploration, where the control is strongly demanded to the student (or group of students).** In this case, a problem situation is proposed. The module includes groups of questions leading the students towards activities necessary to solve the given problem, as well as materials and tools relevant with respect to the task assigned. Here the evolution of learning cannot be completely planned a priori, nor can it easily be evaluated with traditional methods. This approach is suitable for students who have already acquired a basic preparation. It aims to develop high level cognitive abilities, as well as to support metacognition and autonomous learning. We call *problem LOs* the correspondents of such modules.
3. **Modules based on a mixed approach, combining teacher guidance and autonomous exploration.** These can be formed by the combination of more than one LO of the previous two types. They correspond to *mixed LOs*.

We wish to remark that both a problem LO or a guided LO may be suitably applied to support the learning of a same topic, but with different pedagogical aims, as illustrated by the examples in the next section.

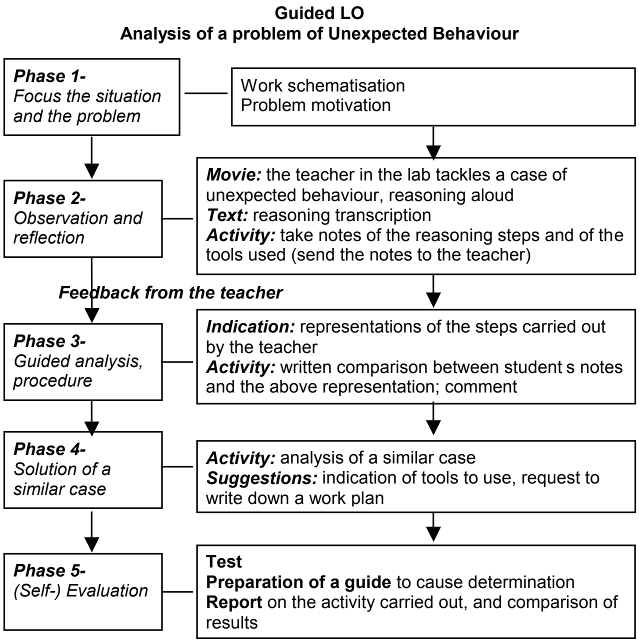
Examples of Structured LOs

Guided LOs and problem LOs can be used to tackle a same problem by applying different pedagogical approaches, which could be required by the characteristics of some educational situations. Let us see, for example, a meaningful problem among those considered within the TIGER environment, that is, how to analyse the unexpected behaviour of a robot.

To acquire this ability, it is necessary that students learn to analyse conceptually and understand several problem situations; they must learn to reflect on the variables of the problems and on the elements of the context that may influence their behaviour, on what tests should be carried out to verify such influence, and on the order to follow when performing such tests. The complexity of this task depends on the characteristics of the problem at hand. This motivates the need to have LOs of different kinds on this topic, so to assist the students during the subsequent phases of their learning.

If the students are at the beginning of their work in this field, and have no practical experience, teacher's guidance is necessary to help them learn *by examples* how experts reason on this kind of problems; hence, we will make use of a guided LO, like the one sketched in Figure 3. We note that in this case the activity is articulated into five phases. First, the teacher (real or virtual) gives a general idea of the situation and motivates the problem. The second phase is still characterised by a central presence of the teacher, who shows how to reason to find the cause of the problem so as to tackle it effectively; the focus is on developing analytical abilities, not on the

Figure 3. The structure of a guided LO for the "unexpected behaviour" problem

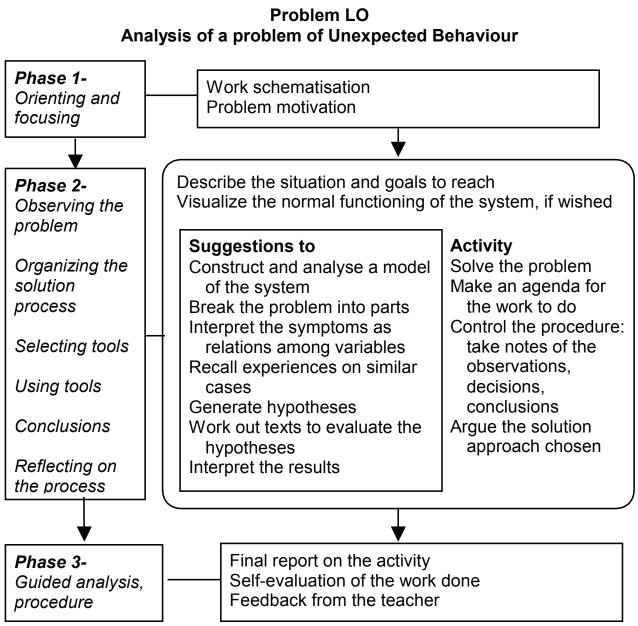


acquisition of some procedure, since it is obviously not possible to figure out a priori all the possible causes of unexpected behaviour. The students start to become active by recording the reasoning steps exemplified. A feedback from the teacher at this point aims to check if the students are approaching the task in the correct way. In the next step, the students are asked to analyse deeply the procedure applied, so to make sure they understand correctly all important steps, still supported by comments of the teacher. In the fourth phase, they are requested to solve (conceptually), by themselves, a similar case and to sketch a work plan. Finally, they need to self-evaluate their work before being evaluated by the teacher. The self-evaluation phase, in particular, is very important for the students to improve their metacognitive abilities (which include awareness of what they know and do not know). This is an important prerequisite for them to be in condition to proceed in their learning path.

In Figure 4, on the other hand, we show the structure of a problem LO on the same topic. Here the activity consists of only three phases, where the central and most important one must be carried essentially autonomously.

The initial phase still consists in focus on the situation considered, analogously to what happens in the previous example. The second phase points out the goals to be reached and offers the possibility to visualise the normal functioning of the

Figure 4. The structure of a problem LO for the "unexpected behaviour" problem



observed robot. It also gives suggestions on what tools could be chosen and how they should be used to solve the problem, as well as recalls on how to organise the work from a conceptual point of view. Finally, a phase of self-evaluation and formal evaluation concludes the module.

Some examples of LOs of either kind implementing constructivist educational ideas are mentioned in Table 1.

SUPPORTING THE LEARNING PROCESS

When designing some educational activity, teachers also need to reflect on what kind of support to provide, as well as when and how to give it. From a theoretical point of view, speaking of educational support to the learning process refers to the interactions that take place within an educational context and give rise to learning. It is sometimes called *scaffolding,* with an overloaded term which can be used to refer both to support in general and to a particular kind of it, also called *Scaffolding* or, more rarely, *Fading*, as specified in the *Scaffolding Section.* The term scaffolding was first introduced within the constructivist framework in order to metaphorically represent effective interactions (Wood, Bruner, & Ross, 1976). The idea of scaffolding is related to Vygotsky's (1978, p. 86) studies on the "zone of proximal development," which is the area of learning where students are not able to proceed by themselves but can do it under an expert's guidance. Distinctions within this concept were later introduced, emphasising different points of view on the supporting activity and consequent differences in the didactical planning, as described next.

Modelling

Modelling received great attention in the framework of social learning theory (Bandura, 1977). This term refers to the kind of support that guides the students to improve their problem solving abilities by observing experts' behaviour. In this case, attention is focused on the analysis of expert's results, on what knowledge they use, and on what cognitive and metacognitive processes they carry out during a problem solving activity. Modelling includes the analysis of meaningful cases and implements an approach to educational support which is problem oriented and guided by the teacher.

An important aspect of modelling is to focus on the observation of expert's reasoning models, not only on the analysis of experts' results. The didactical aim of LOs implementing modelling is thus to lead students to spot and reflect on the differences between how they tackle problems and how teachers do.

Coaching

The term *coaching* refers to the teacher's activity supporting students' efforts to solve some task. In this case, the emphasis is on students' work. Here, the teacher follows and regulates students' activity, by analysing it and providing feedback and suggestions. This kind of support, hence, develops during the activity and entails a high degree of interaction between students and teacher. It is not necessarily limited to class activity, though, since distance communication tools, such as e-mail, CMC platforms, or videoconferences can be used to allow coaching in ICT-based environments.

In our pedagogically oriented framework, coaching is realised by structured

Table 1. Examples of different kinds of LOs to implement educational principles of constructivism

Principles	Examples of realisation: Guided LO	Examples of realisation: Problem LO
Learning content and abilities to acquire should be meaningful to the student	–Preliminary presentation of the work to do –Gradual content development on a meaningful problem –Activity evaluation –Feedback	–Activity based on a real problem –Activity evaluation –Feedback
Learning content and abilities to acquire should be connected to the students' previous knowledge	–Use of pretests –Spiral organisation of teaching –Examples connected with students' experience	–Reasonably challenging problems –Pretests –Presentations showing the competencies required
The development of self-evaluation abilities and metacognitive reflection should be encouraged	–Self-evaluation –Activities focused on the a posteriori analysis of a module, as concerns difficulties encountered and motivation to learn	–Self-evaluation –Activity control: activity planning, monitoring and adjustment, choice of tools to use, and so forth
The comparison among different viewpoints and different problem representations should be encouraged	– Analysing some content according to different modalities (graphical, numerical, textual ...) and from different viewpoints (technical, economical, social, …) –Use of tools of different kind and nature –Interactive classes	–Use of tools of different kind and nature –Analysis of articulated issues –Projects in collaboration –Peer evaluation

Table 1. continued

Evaluation should become a self-analysis tool, aiming to bring further learning	–Evaluation while carrying out the work –Feedback –Reflecting on the quality of possible problem solutions	–Presentation and discussion of own activity highlighting the individual learning aspects –Discussions on on-going work at different phases
Teacher should act as learning facilitator	–Activities favouring autonomous reflection; for example: • make hypotheses on the causes of some phenomenon • compare different solutions to a given problem –Activities entailing the use of typical tools to solve problems in the considered domain	– General indications of possible paths to follow – Questions helping to focus the main aspects of a problem
Learning entails social mediation and negotiation	– Active participation to a teleclass in the lab –Reflecting on the video of a class in the lab	–Group projects
Learning should take place in real contexts	–References to real situations well known to the students –Activities promoting knowledge transfer; for example: • determining the adaptability of a given solution to a different problem or situation • giving examples of different situations for which a certain conceptual solution is suitable	–Presentation of a real situation where a considered problem can take place –Proposal of tools of common use for solving problems

LOs entailing a direct intervention of the teacher or containing links to functional LOs and communication tools.

Scaffolding

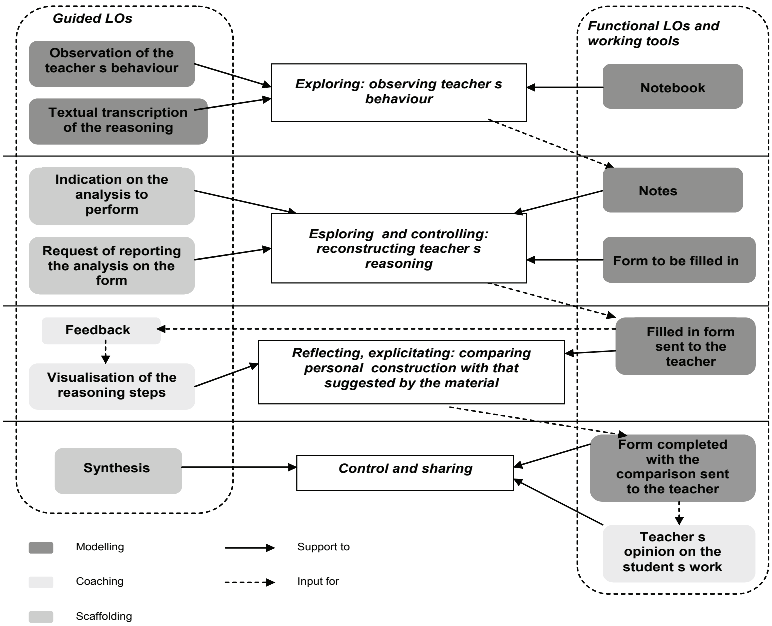
The term *scaffolding* refers to any incentive or help, adapted to the student's ability level, intentionally given in order to help a student to perform some task (Jonassen, Mayes, & McAleese, 1993). In this case, the focus is mainly on knowledge to be acquired and tasks to be tackled, taking into consideration the systemic factors that may affect performance. A distinctive characteristic of scaffolding is to decrease over time and finally disappear. It can also include some activities which are typical of modelling and coaching, provided they are implemented so as to progressively decrease while the learners acquire the ability to work on their own.

From the point of view of application, scaffolding can be subdivided into categories taking into account the requirements of the educational situation at hand (Reiser, 2004; Winnips & McLoughlin, 2001). It is hence possible to talk of motivational, procedural, cognitive, metacognitive, and strategic scaffolding. In our pedagogical approach it can be realised through the interaction among student, teacher, and peers mediated by structured LOs.

Choosing the Right Kind of Support

It is clear that none of the mentioned types of support can be considered the best one for any case, since each of them have potentialities which make it more or less suitable in different educational situations. They should, hence, not be considered as opposite choices, but combined and

Figure 5. Use of different kinds of support within a guided LO



integrated, even within a same activity. Figure 5 shows, as example, a guided LO focused on modelling expert reasoning, which makes use of the three mentioned kinds of support in different phases of the proposed activity.

Creating an effective support is, in general, a complex task (Rasku-Puttonen, Eteläpelto, Arvaja, & Häkkinen, 2003). It is clearly difficult, as a matter of fact, to find a balance between the current development point of students and possible achievements. In order to effectively lead to actual learning, the support given should evolve, over time, to follow the changes of the learning needs (Fretz et al., 2002; Masters & Yelland, 2002), but unfortunately it is not easy to devise and implement rules to guide such evolution. Nevertheless, we can propose some general criteria apt to express at least partially the ever-changing nature of an effective educational support, pointing out, for each of them, what kinds of LOs and tools of our pedagogical framework can be used for that end:

- Develop a pedagogical approach integrating teacher-guided work with an autonomous one, by gradually mixing activities of these two kinds, based on the development reached by the students in the considered topic. These kind of activities can by realised by means of mixed LOs.
- Include in an educational path, moments in which personal activity comes before the analysis of the activity of others. This kind of activity, which aims at letting students try to figure out, on their own, individual ways to tackle problems, instead of replicating solving approaches of others, can be realised by asking them to hand in their results before accessing educational materials, such as:
    - best-cases worked out by peers, when the assignment consists in solving a problem or working out a project;
    - syntheses and overall considerations of the teacher, when the assignment consists of analysing some problem situation; and
    - argued evaluation made by teachers or peers when the assignment is a self-evaluation task.
- Allow students to get help from peers who are possibly online.
- Use evaluation as an occasion of learning, including the possibility for the students to hand in—a second time—their work after a first evaluation, making use of the knowledge gained from the evaluation received and from examples of best cases.
- Include the use of adaptable tools, apt to grant different kinds of support based on the actions made with them. For instance, a collection of *frequently asked questions* can be used as
- *coaching*, if students use them to get the answers to implicit or explicit questions;
- *cognitive scaffolding*, if students use them to rapidly refer to known procedures and methods which are functional to a task they are working on; and
- *metacognitive scaffolding*, if teachers ask their students to organise and update them.

CONCLUSION

We propose an approach to the design of learning objects aiming to realise educational proposals based on the idea that mastering a topic can be achieved through a process of autonomous construction and reflection. By mastering a topic we mean the ability to autonomously and effectively use methodologies and conceptual tools in the solution of complex problems.

Students' attitudes and preferences, specific contents, and learning environment determine the need to organise and enrich teacher's action so as to make sure that students master the conceptual knowledge, which is the basis of complex fields like the considered one. This explains our proposal to combine within an articulated educational intervention moments in which the control of learning depends on the teacher with moments in which such control is given to the students.

Our vision of LOs models a teacher's behaviour while planning an educational activity with this orientation. When we realise this structure with a (structured) LO, we endow the LO with the same pedagogical approach of the correspondent didactical proposal.

This approach, which is currently adopted within the TIGER project, has several advantages from the educational point of view: it gives an operative tool to help the teacher gain familiarity with the concept of LOs; it enriches the expressive power of LOs by representing not only learning materials but also pedagogical orientations; it gives the possibility to shape templates based on different points of view, hence providing materials which are easier to reuse in different educational situations than ready-to-use proposals; and it gives indications on a possible approach to create LOs of a constructive kind, hence capturing the essential nature of the didactical process, which is constantly in evolution.

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