Intelligent Support for Exploratory Environments: Where are We and Where Do We Want to Go?

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Abstract. In the last years, there is a rising interest in exploratory learning environments, due to their positive effects on learning. However, their lack of structure makes the provision of intelligent support and feedback a very challenging problem. This workshop tries to shed some light on several of the aspects of this complicated issue. This preface makes a summary of all topics to be discussed, as well as the innovative methodology that will be used.

1 Introduction

Exploratory learning environments (ELE) support a constructionist approach for learning, encouraging learners to create their own solutions to problems. This has shown to be particularly beneficial in terms of providing opportunities for acquiring deep conceptual and structural knowledge. However, the key learning over many years is that the level of support of the learning process is crucial; this support can be provided by teachers, peers, technologies and the structure of the activity sequences. This is particularly true in the case of mathematics where, unlike physics or other science domains, knowledge is rarely a directly observable outcome of a simulation under exploration and therefore other more expressive tools are required to permit students to externalise their ideas.

Despite important attempts in the last few years to improve the effectiveness of exploratory learning environments (ELEs) employing AI techniques, there is a lack of a place where issues that pertain to intelligent support for ELEs can be discussed and shared among researchers. This has been one of the driving forces behind starting the series of this International Workshop on Intelligent Support for Exploratory Environments (ISEE).

ISEE'08 brings together researchers from different fields of expertise to address the challenging problems posed by the application of intelligent support to exploratory learning environments. The accepted seven full papers will form the basis of a discussion during the workshop held in conjunction with the third European Conference on Technology-Enhanced Learning (EC-TEL'08) in Maastricht (The Netherlands) between the 17^{th} and the 19^{th} of September, 2008.

The innovative format of the workshop, using an adaptation of the Learning Cafe methodology, will ensure productive inter-disciplinary discussions about both technical and pedagogical issues.

2 Where are we now (topics covered)?

The research issues addressed from the submitted papers cut across several subjects. This section provides a summary of the main topics that are relevant to the workshop.

2.1 Design of exploratory learning environments

The designers of exploratory learning environments face a challenging task of striking several balances. The environment must be rich enough to provide good opportunities for learning while, at the same time, being relevant to the domain. It must be general so that different tasks can be developed on top of it, but its interface must not be too cumbersome or the learner will quickly disengage. From the point of view of this workshop, the most important balance is between giving freedom of action to the learner, which recognises the importance of students' autonomy and responsibility over their learning; and providing a structured environment, that eases the intelligent analysis of learners' actions.

These considerations are apparent behind the design of the systems discussed in the papers contributed to the workshop. A particular type of an ELE under development, a mathematical microworld, is presented in [1]. The paper describes its features, as well as the potential for intelligent support. It also highlights the fact that most related work focuses on developing intelligence for exploratory learning environments that are open yet well-defined, meaning that they usually allow exploration of pre-determined models or simulations. It seems however that there are quite a few lessons to be learned from the way ELE are designed for simulations and the requirements for enabling intelligent support. Example of such systems are presented in [2] and [3], which are targeting the domain of physics and chemistry by providing laboratory-like exploratory activities.

2.2 Balance between freedom and guidance and other pedagogic strategies

One of the most important pedagogical considerations in exploratory learning environments is the need for the teacher to maintain a balance between (i) the freedom they allow for learners when interacting with ELEs and (ii) the guidance they provide in order to ensure students' interaction is effective and meaningful. This is discussed in detail in [4]. An important part of the paper is devoted to present pedagogic strategies, outlining the role of the teacher as that of a 'facilitator' who maintains this balance. This seems an important requirement of intelligent support, and a starting point for any exploratory learning situation.

Another paper that deals explicitly with this issue is [5], although from a different point of view. The focus here is in one particular ELE, and situations that can happen when learners interact with it. In order to provide support for their actions, there are times in which the need for support is unclear from the actions of the student. The paper suggest different strategies for this problem, including getting help from the human teacher.

Although the issue is not discussed explicitly in other papers, it is implicit behind the design of the systems presented, all of which are driven by constructivist principles. For example, [2] discusses briefly on the number of *states* in which one task can be expected (in their system) to offer feedback to the learner. Another paper [3] shows how a prompting strategy has evolved from one with a very clear structure to a more loose one, as the authors' experience with a past version of their system showed that too much structure was overwhelming the students.

2.3 Teachers need support too

When ELE are integrated in a classroom, support for teachers' work becomes an important issue. The goal is then twofold: to support the students in order to ease the burden of the teacher and to support the teacher in her specific tasks. As discussed in [4], due to the need to attend to all students individually, teachers find it difficult to accomplish their role as facilitators in a classroom. Although this paper only suggests ways that an intelligent 'computer-based facilitator' can serve the role of a teacher assistant, the strategies presented can form the basis of the development of ISEE. This last aspect is specifically covered in [5].

Some brief suggestions about the potential of intelligent support in their exploratory learning environment are also provided in [1], while [2] goes a step further and provides tools for teachers to (i) author exercises and (ii) enable them to investigate patterns of students' behaviour, offering visual information about how students interact with the ELE. Additionally, some of the techniques presented in [6], although designed to help the students reflect on their interaction with the system, could be used to provide visual information to the teacher.

2.4 Authoring of open-ended tasks with intelligent support

The development of activities in exploratory environments, similar to any other intelligent environment, is an expensive and complex process. Although no analysis has been made in the literature (to the extent of our knowledge) about the cost of developing this kind of systems, they are more complex than the typical ITS. The cost of creating an ITS (i.e. software, rules, content, etc) was estimated by Murray [7] in about 100 hours of work per hour of instruction. The cost of designing a meaningful and general set of activities in an intelligent exploratory environment can be expected to be even higher.

One of the papers [2] discusses ways to simplify the authoring of activities by separation of concerns: some stakeholders design virtual tools that can be used in the environment (with an API), some others design questions relating to the tools, etc. Questions are viewed as related to the status of the whole system, according to some rules. Another paper [8] focuses on developing a framework for the authoring of rules for non-technical users, by using a rule-based expert system combined with a particular framework for the design of exploratory activities.

2.5 Research Methodology

Although the fields of AIEd and ITS are well researched, the particular issues that pertain to ISEE were discussed mostly in the early 90s (e.g. [9]). They have re-appeared the last few years in an attempt to develop support that extends the effectiveness of exploratory learning environments. Therefore, work on research methodologies that can facilitate the development of intelligent support in ELE is required.

The research presented in [3] emphasises the need to develop intelligent support based on models of the cognitive processes applicable to the particular learning scenarios. The authors present an experimental study which uses a Wizard of Oz approach where participants interact through an interface with a human 'wizard'. This is commonly used to investigate human-computer interaction in systems under development in order to inform the design of intelligent support. A complementary approach is followed in [4] . This relies on eliciting knowledge from observing realistic teacher-student interactions, as well as identifying strategies based on relevant theories of learning. Another approach is the use of data-mining techniques *a posteriori* on data collected from the learning environments, as hinted in [2] and [5], although neither paper focuses on this.

2.6 Intelligent inference and analysis

In order to understand the actions of the learner, artificial intelligence, machine learning and data mining techniques can be used to analyse the data provided by the system. This information can be used in order to make inferences and take appropriate actions: e.g. present relevant information to the teacher, suggest collaboration between peers, etc.

A possible approach is the use of expert systems based on rules [8]. This paper focuses on the issues that appear when a rule-based system is integrated with an already existing exploratory environment, providing some interesting discussion about the best architectural approach and the implications of using fuzzy logic. Rules are also used in [2] to determine when feedback is needed.

Another approach is the use of case-based reasoning for detecting similarities in the actions of the learners [5]. The paper illustrates how such a technique opens the door to providing hints that do not distinguish correct from incorrect actions, but rather show what other students have done. This could be a way to address the difficulty in ELEs where the number of possible courses of actions is higher than in other constrained environments; it must be noted that in some activities for ELEs the distinction between correct and incorrect solutions does not always make sense.

Most of the other papers provide suggestions for future work and pointers to relevant literature. Discussions during the workshop will potentially lead to interesting interactions between all the participants.

2.7 Modelling in exploratory environments

In order to understand the actions of the learner, a modelling strategy is needed. Many intelligent systems use a strategy for modelling both the learner and the domain. The user model usually tries to represent the knowledge level or the learners, but they can take also care of other aspects (e.g. their preferences, learning styles [10], etc).

In the last years, many researchers have focused on the use of *open* learner models, that is, models that are shown to the student to help them reflect on their own actions. This is the main topic of [6], and it depicts the different levels of granularity in which the modelling of the learner takes place, the different indicators that they show to the learners, etc. The effectiveness of the approach is being evaluated.

Modelling the actions of the student in an exploratory environment is the main objective of [5]. The modelling of the actions of the learners is used as an indirect approach to model the users. Possibilities of feedback or collaboration are evaluated according to similarities between the learner actions and some paradigmatic actions stored in a knowledge base. The paper describes some of the details of the modelling strategies used (based on case-based reasoning), as well as the metrics that are used to compare different actions and strategies.

2.8 Collaboration scenarios and tools for collaboration

Collaborative learning has been shown to provide a deeper understanding of concepts, and longer-lasting retention [11]. In ELE, if collaboration is introduced properly, it can provide a means of managing the complex balance between freedom and guidance. From the point of view of this workshop, there were two strands in which we were specially interested: collaboration scenarios and tools for collaboration. The first strand is of a more pedagogical nature, and deals with the different possibilities in which collaboration can take place in an exploratory environment. These environments open themselves to many interesting possibilities: co-construction with peers, challenges against other peers in the frame of the system, comparison of equivalent or complementary solutions, etc. The second strand is more technical, studying which tools can be used for collaboration, and how they help overcome some of the problems that take place in a traditional collaborative learning scenario (e.g. domination issues).

This second strand has shown to be interesting to the community, as seen from the papers received. Selecting the best tools for collaboration and designing the right affordances in them is important, because the learning process is influenced by the tools available. Such tools are presented in [3] as extensions to a simulation environment in order to promote collaboration between students. [1] discusses the potential of students co-constructing of models in their microworld and [4, 5] provide suggestions on how to support students' collaboration. [6] alludes to the use of open-learner modelling tools for encouraging and facilitating collaboration and constructive competition between students by inspection of their own learner model and comparison with that of others.

3 Future work

When we where preparing the workshop, there were several topics that appeared on the table as interesting and related to the general theme. Given that the workshop is quite specialised, we tried to connect it to several research strands that are relevant to researchers related to learning technologies. In order to do this, we designed a series of questions that could be answered from different points of view. Those that were answered have been discussed before. In this section we present some of those that were not covered. They will have to be addressed in future editions of the workshop.

3.1 Affect in ELEs

The number of papers that deals with affective aspects of the learning process, from the point of view of learning technologies, increases every year. From our point of view, the main concern related to intelligent support in exploratory environments is that of motivation and encouragement.

Learners in an ELE need a certain level of motivation to remain focused. Without it, they are unlikely to feel they are learning anything and may lose interest in using the system. Detecting motivation automatically is a hard problem in itself. The open nature of exploratory learning activities makes the problem even more difficult to address (e.g. the same behaviour can sometimes be interpreted as meaningful exploration or as disengaged playing with the system). [4] provides pointers to AIEd literature that demonstrate progress in detecting certain student affective factors. It also suggests that, in the cases where the information is very uncertain, the system can provide this information to teachers and let them intervene instead of interacting with the student directly. Given the interest in these issues for the last few years, we expect that future research in this field will be applicable to ISEE.

3.2 What counts as correct?

Traditional Intelligent Tutoring Systems (for a classical survey, see [7]) deal with domains clearly defined, usually of a scientific or technological kind. In these domains, users have to introduce answers into the system, and the answers can be corrected directly because they are either right or wrong.

However, in exploratory environments there are no clear right and wrong answers. Sometimes, there is not even an answer, because the learner is only expected to explore the domain. However, this does not mean that the system should not be able to provide support for this exploration. As a matter of fact, an exploratory environment with no guidance has been reported as being harmful for learning [12].

Knowing when to provide support is far more complicated than just matching answers with a table or a set of calculations: it requires that the system has some knowledge of the task at hand, some understanding of the actions of the learner and some ideas about the support that can be provided. All three of these are open and challenging research questions by themselves.

3.3 Activity model

An intelligent system that aims at supporting the learning process usually follows some strategy for modelling the user (i.e. learner) and the domain in which the learning takes place. The learner model usually tries to capture the knowledge of the student, but could also express other characteristics (e.g. emotional states, preferences, etc). The domain model describes the domain, and is used to assess the knowledge of the student.

Modelling the learner in an exploratory environment poses a difficult challenge, as there are no clearly correct or wrong answers, and there are no clearly correct or wrong behaviours. Exploratory environments are usually used on domains that are not clearly defined, and are difficult to model (a similar problem is discussed in [13]). Furthermore, exploratory environments are sometimes used for different tasks; the actions of the learner are very different depending on the task, making the modelling more difficult.

Therefore, it may be necessary to have an activity model separated from the domain model. Activity or task models have been used in the past in the field of Intelligent User Interfaces [15] and Adaptive Hypermedia Systems [14].

3.4 Learning standards

The number of learning support systems is huge. Usually each of them uses their learning strategy, their own content, etc. This makes it impossible to collaborate between different systems, share resources, etc.

In order to solve this, several initiatives exist to create standards that foster intercommunication between different systems. Arguably the most important are the SCORM initiative[3], the IMS Consortium[4] and the SISO standards[5]. How these initiatives are relevant to exploratory environments and intelligent support remains an unanswered question.

4 Conclusions

The provision of intelligent support in exploratory environments poses a lot of interesting challenges. Some of them are going to be covered in the workshop. We

[3] http://www.adlnet.gov/scorm/
[4] http://www.imsglobal.org
[5] http://www.sisostds.org

hope that the discussions that will take place will produce interesting synergies and help to find some answers, leading to a productive session for all participants.

We anticipate that the outcomes of the discussion will provide new insights into these challenges, and serve as a catalyst for other lines of research. The main findings of the workshop will be published in the future for the benefit of the community.

5 Workshop Methodology

One of the goals of the workshop was to be used as a platform to share ideas and developments, proving worthwhile to all participants. Therefore, we tried to detach ourselves from the mini-conference style in which many workshops are run. In this fashion, most of the time is consumed in presentations of authors' work, which leaves a little time window for discussion among the workshop attendants. We thought that the time spent in discussions should make the best part of the workshop.

That is why we tended towards an adaptation of the 'learning discussion forum' (aka Learning Cafe Methodology) which focuses on discussions ensuring that all participants can have a direct impact in addressing the workshop questions. This methodology (with some variations) had been successfully implemented in at least two previous conferences [16, 17].

The working methodology for this workshop is made up of the following steps:

1. A short discussion was included in the call for papers that raised some open problems in the field and posed challenging questions that the participants of the workshop had to answer in advance. Those interested in the workshop submitted their papers, covering some of the challenging questions. Each paper was reviewed by 3 members of the Program Committee to provide feedback from different angles.
2. After the final papers have been collected into the Proceedings, a collaborative environment is set up to facilitate open discussion among workshop participants previous to the workshop day. Open discussion among participants can take place in advance of the workshop day.
3. On the workshop day, participants bring a sheet with their relevant conclusions for each topic they have worked in their paper.
4. Two round tables are settled, each managed by a Moderator (more details bellow). The tables have A-1 sheets and markers. A brief overview of each of the topics is done, raising the challenging questions. Each table brainstorms led by the Moderator. The ideas are written down in the sheet. When the sheet is full, they are stuck on the wall. The brainstorm and the discussion continues until the break.
5. After the break, people switch to the other table. The Moderators stay in their table and summarise to the new people what was discussed with the previous group. The participants continue the brainstorm and discussion until lunch, taking special care of discussing topics that were left behind by the former group.

6. After lunch, for each table, Moderators present the conclusions to the audience. Open discussions with all participants are expected to be risen. The Moderators summarise the conclusions with the collaborative help of the group. Final conclusions are structured and uploaded to the website to be shared with the EC-TEL community and participants that have not been present in the workshop.

The two tables cover different topics. Discussion on the first table will be related to the design of exploratory environments and activities: microworlds, methodology, authoring, the role of the teacher, reflection on students, etc. The second table will be devoted to the technical aspects of intelligent support: user modelling, data mining, visualization techniques, rule-based and case-based reasoning, etc.

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