DynaLearn - Engaging and Informed Tools
for Learning Conceptual System Knowledge

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Abstract

This paper describes the DynaLearn project, which seeks to address contemporary problems in science education by integrating well established, but currently independent technological developments, and utilize the added value that emerges. Specifically, diagrammatic representations are used for learners to articulate, analyse and communicate ideas, and thereby construct their conceptual knowledge. Ontology mapping is used to find and match co-learners working on similar ideas to provide individualised and mutually benefiting learning opportunities. Virtual characters are used to make the interaction engaging and motivating. The development of the workbench is tuned to fit key topics from environmental science curricula, and evaluated and further improved in the context of existing curricula using case studies. Through this approach, the DynaLearn project will deliver an individualised and engaging cognitive tool for acquiring conceptual knowledge that fits the true nature of this expertise.

Introduction

Understanding how systems work is important to humans. Being able to adequately explain and predict system's behaviour is essential to successfully utilise their functioning for human benefit. Hence, policymakers and other stakeholders strive to accomplish effective science education (cf. Eurydice, 2006). However, science curricula are subject to a worrying decline. The number of students is falling (less students take science curricula and more drop out). Osborne et al. (2003) provide a comprehensive literature review on the matter and identify the lack of engagement and motivation in science teaching as one the key problems. They also point out that ICT is not used for what is currently most needed, namely as tools to interactively deal with the theoretical concepts that explain phenomena (as opposed to data handling).

The DynaLearn project is motivated by these needs from the educational field, particularly for secondary and higher education. The project seeks to address these needs by integrating well established, but currently independent technological developments, and utilize the added value that emerges from this integration. The main project objective is to develop an interactive learning environment that allows learners to construct their conceptual system knowledge, either individually or in a collaborative setting. The workbench is based on three strategic characteristics:

- Accommodate the true nature of conceptual knowledge.
- Be engaging by using personified agent technology.
- React to the individual knowledge needs of learners.

Learners construct knowledge by manipulating icons (and their inter-relationships) using a diagrammatic representation. Expressions can be simulated confronting learners with the logical consequences thereof. Alongside this workspace embodied conversational agents are situated and available for learners to analyse and reflect on their expressions. This interaction is steered using knowledge technology that connects learners to expressions created by peers and teachers (or experts).

Constructing conceptual knowledge

There is ample ICT software in science education for handling numerical data, such as logging, automatic processing, and simulation, although some studies doubt the benefits gained from using these tools (Hucke and Fischer, 2002). Contrary, there is a bulk of research that points out the importance of learners constructing conceptual interpretations of system's behaviour (Mettes and Roossink, 1981; Elio and Sharf, 1990; Ploetzner and Spada, 1998; Frederiksen and White, 2002). There is thus a need for ICT software that 'goes beyond data handling' and supports learners in actively dealing with the theoretical concepts involved, e.g. by using visualisation and diagrammatic techniques, and by having learners

create models and perform concept prediction and explanation (Otero et al, 1999; Niedderer et al., 2002; Hucke and Fischer, 2002). However, such techniques are unavailable or too complex to use, and therefore seldom part of prescribed science education activities (Osborne et al., 2003). This undesired situation is an important motivation for the DynaLearn project.

Learning by modelling

Schwarz and White (2005) argue that modelling is fundamental to human cognition and scientific inquiry. They believe that modelling helps learners to express and externalize their thinking; visualize and test components of their theories; and make materials more interesting. Modelling environments can thus make a significant contribution to improve science learning. In the past two decades, since Papert published Mindstorms (1980), different kinds of modelling environments have been created. Environments such as StarLogo (Resnick, 1994) (later NetLogo, http://ccl.northwestern.edu/netlogo/), Stella (Richmond, 1992) (http://www.iseesystems.com/), and Model-It (Jackson et al., 1998) (http://www.goknow.com) are some examples that offer innovative environments in which students can construct their own simulations to solve problems of interest to them. These environments allow learners to view the invisible and examine complexity in ways that were previously impossible (cf. Blauvelt, 2001).

Despite its value for learning, the use of this technology for handling conceptual knowledge is hampered by a number of issues. First, the underlying representation is quantitative, which means that in order to obtain simulation results, numerical details have to be provided (or to be assumed by the software). However, the required numerical details may not be available. Moreover, having to deal with numbers distracts learners from focusing on the real issue (which is developing their conceptual understanding of how systems work). Second, there is discrepancy between the key characteristics of conceptual knowledge and the vocabulary provided by modelling environments based on numerical simulations. As argued by Kleer and Brown (1984) and Forbus (1984) many crucial notions are not explicitly represented in such approaches, such as landmark values, causality, qualitative distinct states of behaviour, processes, etc. This has two negative consequences. First, when learners cannot use the appropriate language to develop their knowledge, the learning is deemed to be suboptimal. Schumacher and Gentner (1988) have shown that learners develop a better understanding (which also improves transfer to new situations) when they are given the opportunity to use causal relationships to represent system behaviour. Second, when the underlying representation does not capture certain crucial distinctions, it will be difficult to create interactive tools that teach learners the key conceptual insights that explain the behaviour of a system. Hence, the automated feedback that can be provided is suboptimal. See Winkels and Bredeweg (1998) for an overview and further arguments.

Today there are techniques originating from Artificial Intelligence that overcome the above mention problems. These techniques can be employed to provide learners with interactive tools for handling conceptual knowledge that actually fit the characteristics of this kind of knowledge. Particular, the technology known as Qualitative Reasoning is well suited for this purpose (see Forbus (2008), and Bredeweg and Struss (2003) for recent overviews). The vocabulary used in Qualitative Reasoning not only fits the nature of conceptual knowledge, but due to the explicit representation of these notions in the software, it also provides the necessary handles to support an automated communicative interaction that actually discusses and provides feedback at the conceptual level.

Qualitative Reasoning should thus not be seen as 'just another kind of simulation technology'. On the contrary, its objective and its implementation are fundamentally different. Simulation technology mimics the behaviour of a system such that the simulated variables have continuously changing values that closely match observable (measurable) variables. The goal of simulation is thus to obtain a close match between the model (in fact the underlying mathematical equations) and the real system in terms of matching variable values. **Qualitative Reasoning**, on the other hand, **captures human interpretation of reality**, and provides a **conceptual account** that **explains why** a system has certain behaviour. The goal of Qualitative Reasoning is thus to **map closely with human cognition**. The Qualitative Reasoning terms (in fact a symbolic logic-based vocabulary) used in the model **mimic the way humans understand and explain** the observable behaviour.

Interactive qualitative knowledge models

Qualitative Reasoning works without using any numerical information and excels in representing cause-effect knowledge and other conceptual notions crucial to systems thinking. Conceptual models based on Qualitative Reasoning are valuable tools both for pre-mathematical modelling, and as standalone artefacts developed for understanding, predicting, and explaining system's behaviour. Such conceptual models are also 'animated', as they capture the dynamic aspects of a system by reasoning about quantities that change over time, using a well-defined set of modelling primitives grounded in a mathematical foundation. Moreover, recent advancements have delivered diagrammatic representations to interact with Qualitative Reasoning software, e.g. Betty's Brain (Biswas et al., 2001), Vmodel (Forbus et al., 2001), and Garp3 (Bredeweg et al., 2006). Such external representation help reduce the working memory load (known as cognitive offloading (Norman, 1993; Forbus and Feltovich, 2001)), and thereby enabling learners to address more complex problems than they would be able to handle otherwise. It also enables learners to more easily and accurately share their conceptual ideas with others for discussion and collaboration. However, to further enhance usability, approaches such as Betty's Brain and Vmodel

reduce the amount of primitives available in the model-building software. Although this 'makes things simpler', it has the obvious drawback of not using the full potential of Qualitative Reasoning and the means it provides for representing conceptual knowledge. In the DynaLearn project we use the Garp3 software (http://www.garp3.org) developed in the NaturNet-Redime project (EU, FP6) (http://www.naturnet.org), which does utilise the full expressiveness and potential of the Qualitative Reasoning formalism. The DynaLearn approach is therefore more suited for secondary and higher education.

Engaging virtual characters

As pointed out by Osborne et al. (2003), the lack of engagement and motivation is considered one the main problems for the decline in science curricula. Science education fails to deliver the incentives required to attract and motivate students.

There is empirical evidence that pedagogical agents lead to an improved perception of the learning task and help to engage learners (Mulken et al., 1998; Lester at al., 1997). They promote learner motivation, engagement, and self-confidence, and may help prevent and overcome negative affective states of learners, such as frustration, and fear of failure.

Embodied conversational agents may take on a diversity of roles (cf. André, 2008). An early example includes the pedagogical agent Cosmo (Lester et al., 1997), which inhabits a botanical environment together with a student and advises on the task of designing plants capable of surviving in certain environments. The pedagogical agent 'Steve' (Rickel and Johnson, 1999) co-habits with the student a virtual environment and instructs to operate technical devices within this environment.

Virtual learning companions ensure the availability of a collaborator and may increase the students' engagement in a task (Craig et al. 1999). They provide an interesting new training tool since it would be impossible to create a real classroom setting for individual students that fosters their learning progress best. Blair et al. (2006) and Leelawong and Biswas (in press) go a step further and introduce the concept of 'teachable agents', which students can teach by creating a concept map. This relates to the idea of 'learning by teaching' (cf. Gartner, 1971; Renkl 2006). One of the advantages of teachable agents is the fact that their knowledge can be made visible, a feature that helps students to organize their own knowledge. In addition, preparing their agent for a test has turned out to be highly motivating for the students and makes them reflect about what to teach.

Educational role-play promotes learning by enabling a learner to participate actively in a drama-based environment. It provides the student with a safe environment for experimental learning and can make learning a more engaging and enjoyable experience. One of the first applications making use of educational role-play is Carmen's Bright IDEAS (Marsella and Gratch, 2000). It relies on drama-based interventions in order to help mothers of young cancer patients to develop problem-solving skills. A more recent example includes FearNot!, which was developed within the VICTEC project (Paiva et al., 2004) that investigates how social learning may be enhanced through interactive role play with virtual characters that establish empathetic relationships with the learners.

The DynaLearn project utilises the added value on motivation and engagement that comes from using virtual characters, and combines this with content relevant to acquiring system knowledge, and as such make the communicative interaction between learners and software both personified and well informed. Particularly, different characters should be approachable for the learners to convey different kinds of 'knowledge', notably (a) basic help – explaining a particular model, (b) learning companion – discuss similar models (c) critique – feedback on model errors, (d) teachable agent, and (e), quizmaster – taking a quiz.

Semantic technology

A related problem is the lack of personal autonomy (Donnelly, 2001; Eurydice, 2006). Traditional science curricula give learners insufficient control over their learning activities (partly due to not being able to direct the required teaching effort). This negatively influences the learner's attitude towards these subjects.

Providing learners adequate feedback on their work is crucial for successful teaching. The DynaLearn project distinguishes in this respect between an individual and collaborative perspective. The individual perspective concerns feedback on a single conceptual model created by a learner, and supporting the learner in improving that model such that it best explains a phenomenon according to the personal beliefs of that learner. The goal of collaborative perspective is to relate the work of a learner to a wider community, including peer-learners and teachers. It also has a normative aspect.

Three 'resources' are foreseen in the DynaLearn approach: models made by experts, models made by learners (both stored in a repository), and models currently being made by online co-learners. The expert models are meant to explain theoretical concepts relevant to environmental science and will be developed by the DynaLearn project. When a learner queries the 'community' for support, the current model of that learner should be compared to the models available in the resources to find a model that will be most beneficial for the learning experience of that individual.

One problem to solve is the different use of vocabulary in models, particularly when dealing with learners who may still have to discover canonical forms. Ontology Matching technologies (Shvaiko and Euzenat, 2005; Euzenat and Shvaiko, 2007) can be used for this. An ontology mapping approach establishes which concepts in different ontologies correspond (equivalence) to each other

(and possibly other relations such as 'more general', 'less general', 'disjoint', etc). The mapping makes it possible to make meaningful inferences about the union of the knowledge bases. The idea is to compare different models by grounding the terms used in a common vocabulary such as (Euro)WordNet (http://www.illc.uva.nl/EuroWordNet/) or OpenCyc (http://www.opencyc.org/). Using this technology, learners working on similar topics can be matched and start collaborating to enhance their mutual learning experience. It can also be used to identify conceptual models from the repository (created by experts), which a learner can compare and utilise for reflection.

A second issue concerns personalized recommendations (e.g. Billsus et al., 2002; Kalfoglou and Schorlemmer, 2003), which is still a largely open problem within the area of semantic web technology. It is expected that models in the repository will not only differ in content, but also in style and other contextual factors. For the later, an additional mechanism is needed to obtain, store and exploit user-generated data concerning the subjective liking of models (e.g. quality ratings, number of downloads, model-sparseness, etc.). The Dynalearn project will use and advance a technology known as Collaborative Filtering for this purpose.

The online repository, which will be established in the DynaLearn project, is expected to become a valuable learning object itself. The models created by experts (as part of the DynaLearn project) and learners (when using the DynaLearn software) will be stored in this repository. An additional feature of the repository is that a common vocabulary of the models is established each time a model is uploaded. The idea is that a common conceptual knowledge-base for environmental science 'growns' from this. As such, the repository supports the transformation of learning outcomes into permanent and valuable knowledge assets.

Environmental science

Seeking to reverse the decline, science curricula are currently subject of debate and reforms in the majority of European countries (Eurydice, 2006). One tendency is to focus on interdisciplinary approaches, such as health or sustainability, because the relevance for mankind is more apparent (and hence more motivating). At the same time, there is the view that interdisciplinary studies are essential for scientific breakthrough and progress (Eurab, 2004). In fact, given the multiple and integrated aspects involved in scientific knowledge, curricula should be designed to support students learning how to regulate their own learning (Jong, 2006). These observations provide the motivation for the DynaLearn project to initially focus on environmental science as the subject matter.

However, in many countries science education is far from the ideal (cf. Osborne et al., 2003; Eurydice, 2006). Physics, biology and chemistry teachers are lacking, curricula are outdated, didactic materials do not associate

to what children and adolescents experience in the real world. As a result, science is becoming less attractive (to youth).

To be effective, science education should focus on understanding scientific concepts and innovations, on application of scientific knowledge to everyday life, on developing skills for problem solving, decision-making and argumentation building, and strengthening the capacity for elaborating proposals (Brazil, 2005). To engage learners in learning-by-doing activities, these aspects should be developed by adopting open curricula and participative educational methodologies. Such an approach opens up to new ways for knowledge organization (Machado, 1995), and can cope with the diversity of students' interests and aspirations by exploring opportunities to provide interdisciplinary and contextualized contents. The DynaLearn project will utilise the 'Learning by modelling' approach, partially situated as 'Learning by teaching' through the use of virtual characters.

Research questions and Evaluation

The DynaLearn project will run evaluation studies in real educational settings. Particularly, they will address the impact that the DynaLearn results have on learning enhancements. Typical questions to investigate include:

- Does the diagrammatic approach (as organised in the DynaLearn setting) actually allow learners to address more complex problems?
- Does the meta-vocabulary from which a conceptual interpretation is built, provide learners a domain independent analytic instrument that enables them to construct more fine grained and thorough analyses of how systems work?
- Do the embodied conversational agents establish the 'involvement momentum' required for learners to actually benefit from the added value provided by the software for handling conceptual knowledge? Which agents work best? And why or why not?
- Do the instruments to individualise learning (ontology mapping, diagnostic procedures, and semantic repository) adequately steer learners in acquiring the target subject matter?
- Does the personal autonomy cause learners to be more motivated?
- Do learners actually learn better when using the full set of DynaLearn results? And are students more motivated to take on science curricula?

Concluding remarks

The main objective of the DynaLearn project is to develop an engaging interactive learning environment that allows learners to construct their conceptual system knowledge, either individually or in a collaborative setting. Three classes of previously unrelated technologies are used for

that. Qualitative Reasoning as an instrument to handle conceptual knowledge, virtual characters to foster engagement and motivation, and ontology-based collaborative filtering to steer the learning process according to the environmental science curriculum, and to enable collaboration. The learning environment will be informed (it is knowledgeable about the subject matter), individualised (addresses the content and knowledge construction process of an individual learner), and personified (interacts via virtual characters). Integrating these technological components presents challenges well beyond the state-of-the-art. The DynaLearn project will seek to realise this interoperability using common standards on data and knowledge exchange, particularly those originating from the World-Wide Web Consortium (W3C) (http://www.w3.org/) such as the Web Ontology Language (OWL) (http://www.w3.org/2004/OWL/).

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