ART (Analogical Reflection Tool): using analogies to promote reflection in science education

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Abstract. There are two basic categories of reflection, according to where the learner reflects on. In self-reflection, the learner reflects on her/his own actions, while in comparative reflection the learner reflects on others' actions. We propose an alternative reflection type, as a subcategory of the comparative reflection, the analogical reflection. In analogical reflection, students reflect on analogies, collating their actions with the analog's (analogical model) functions. During the collation, students are asked to correlate the source with the target. We designed a software tool that supports analogical reflection and is called ART (Analogical Reflection Tool). The ART is a scaffolding tool that assists students while reflecting analogically.

Keywords: reflection, analogical reasoning, modelling.

Introduction

The contribution of reflection in learning is an issue that concern various research domains, such as psychology, didactics, pedagogical and technology enhanced learning. In educational artificial intelligence, the student model saves information about students' actions. The past artificial intelligence systems used to hide the student model from the student. The modern ones, which are called "Open Learner Modelling" (OLM), bring to light the student model in order to promote reflection. The student model can be visible to the system's user for self-reflection, or to other users for comparative reflection.

W-ReTuDiS (Web-Reflective Tutorial Dialogue System) [1] is an OLM system that uses dialogues based on the student model and it is applicable for teaching history. The system asks questions to the students and then returns their answers, annotating the wrong ones or validating the right ones. The students may ask from the system for extra explanations. In such case, the system responds by setting up a dialog with the students, in order to pull the trigger of reflection. Another tutoring system is DIALOG [2], which exploits the artificial intelligence algorithms to use natural language and reflection arises from Socratic dialogues.

Besides dialogues, concept maps support learning through reflection. Cimolino et al. [3] proposed the Verified Concept Mapper (VCM) system as an innovative way of creating concept maps. In VCM, the user has to verify the created map and justify its components.

Van Joolingen et al. [4] distinguished the reflection in "reflection-on-action" and "reflection-in-action", considering that the reflection-on-action corresponds to the evaluation at the end of the activity, while the reflection-in-action is a kind of monitoring the activity's progress. Manlove [5] also used the distinction between reflection-on-action and reflection-in-action, as Schön [6] had defined it. The reflection-on-action emerges from the requirement to summarise and evaluate the entire activity. On the other hand, by the reflection-in-action students monitor specific stages of the activity and reassign its' progress.

White et al. [7] used the SCI-WISE agent based software, in which each agent has its role, trying to accomplish specific targets. Such agents are the Planner, Collaborator, Assessor, Inventor and Analyser. Their inquiry activities followed the cycle: Question – Hypothesise – Investigate – Analyse – Model – Evaluate. At the beginning, a question about a phenomenon is given to the students, who make a hypothesis, for investigation. Then, they analyse the results and start modelling. Finally, the results' evaluation accomplishes the cycle. At this last stage, students reflect on the entire activity, searching for their model's limitations.

Analogical Reflection

Analogical reasoning is a mental process by which learners adapt their knowledge from a familiar cognitive domain to an unfamiliar domain. Through the analogical reasoning, students exploit their own existed knowledge in the familiar domain in order to understand the studied domain. The two domains are similar in their structure and/or functionality, while students must be capable to analyse and compare them. The analogical system is called "source" and the system that is being studied is called "target". One target may be related to sources from different domains [8]. For example, a computer network (target) could be represented by different analogs (sources), such as road network, rail network or post office. If a characteristic/function of the source shares similarities with the target, then the analogy is "positive", while if the characteristic/function is opposite to the target then the analogy is "negative". Negative analogies may generate misconceptions to students and, therefore, they must be clarified. If the characteristic/function of the source seems similar with one of the target, but it is not actually relative, then the analogy is "neutral" [9].

For example, an analogical model for the simple electric circuit model is the hydraulic analogical model. This analog consists of a water pump and water conductors. The pump causes the water's flow inside the conductors, like the voltage source causes the electrons' flow inside the metal conductors at the simple electric circuit model (Fig. 1).

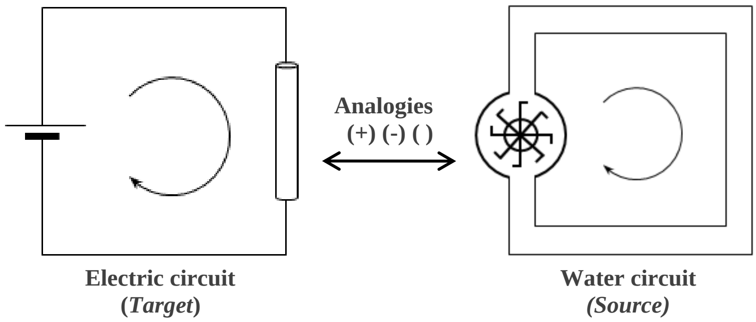

Fig. 1. Simple Electric circuit (target) and hydraulic analogical model (source).

Between these two models, there are positive, negative and neutral analogies. Some examples are given in the Table 1.

Table 1. Analogies between simple electric circuit model and hydraulic analogical model.

Analogies	Simple electric circuit model	Hydraulic analogical model
Positive	1. The voltage source forces the electrons to move inside the metal conductors. 2. The electrons are not generated from the source. They exist inside the metal conductors.	1. The water pump forces the water to move inside the water conductors. 2. The water is not generated from the pump. It exists inside the water conductors.
Negative	1. The electrons move only in one direction, (negative to positive pole). 2. If the electric conductor breaks, the electrons' flow stops immediately.	1. The water may flow in both directions. 2. If the water conductor breaks, the water runs out.
Neutral	1. The model's shape is rectangular.	1. The model's shape is rectangular.

When the learners reflect on their own actions, they may improve their metacognitive skills. If the learners study an analogical model instead of the target domain, then the revision may be more substantial, because they may find out their errors through their own existent knowledge from the familiar source domain of the analogical model. There are two basic categories of reflection, according to where the learner reflects on. In self-reflection [6], the learner reflects on her/his own actions, while in comparative reflection the learner reflects on others' actions [10]. In groupware learning environments, comparative reflection is characterised as collaborative reflection or co-reflection [11]. We propose an alternative reflection type, as a subcategory of the comparative reflection, the analogical reflection. In analogical reflection, students reflect on analogies, collating their actions with the analog's (analogical model) functions (Fig. 2). During the collation, students are asked to correlate the source with the target.

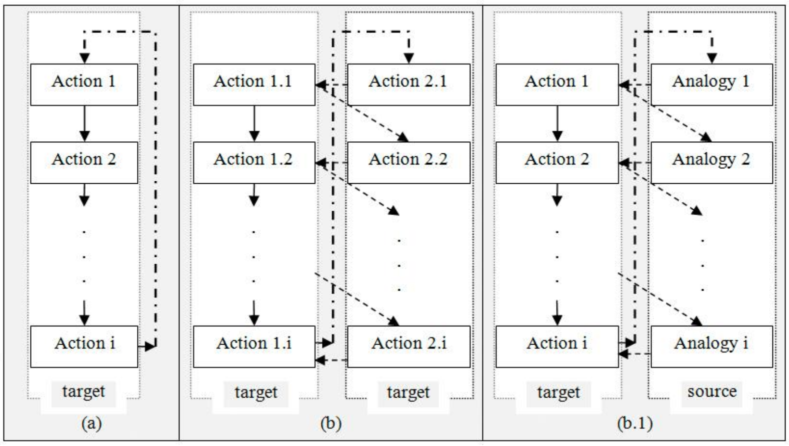

Fig. 2. Reflection types: (a) self, (b) comparative, (b.1) analogical.

The idea for introducing and examine the analogical reflection came from the state of the art and, specifically, from the combination of the analogical reasoning with the comparative reflection:

$$\left.\begin{array}{r}\textbf{\textit{Analogical}}\ \textit{Reasoning}\\ \textit{Comparative}\ \textbf{\textit{Reflection}}\end{array}\right\}\ \textbf{\textit{Analogical Reflection}}$$

In a previous pilot research, in which we tested the three reflection types (a) self, (b) comparative and (c) analogical, we hypothesised that in self-reflection, it is highly probable that someone cannot recognise her/his own mistakes. In comparative reflection, this probability is potentially reduced, because perhaps the others do not make the same mistakes. We estimated that this probability is minimised when the analogical reflection is activated, because it is easier to recognise a strange behaviour in a familiar domain, where the normal behaviour is well known.

Students were asked to reason analogically and reflect on modelling activities, in order to exploit and improve their metacognitive skills. The modelling activities took place in the ModellingSpace [12], an OLM system in CSCL environment with metacognitive support such as Interaction Analysis tools.

According to the results, through the analogical reflection students exploited their correct perceptions in revising the incorrect ones. The students that worked in analogical reflection mode showed better performance than the students that worked in the comparative reflection mode and much better than the self-reflection mode. However, in analogical reflection mode students had some difficulties, especially in the analogical reasoning stage. After proper scaffolding by the teacher, students overcame their difficulties and finally reflected on the analog. Thus, a major conclusion was that there is a need for a scaffolding tool, assisting students to reason and reflect analogically.

ART (Analogical Reflection Tool)

Based on the last conclusion, we designed a software tool that supports analogical reflection and is called ART (Analogical Reflection Tool). The ART is a scaffolding tool, consisted of five steps: (1) Model's Description, (2) Analogies' Record, (3) Analog's Description, (4) Analogies' Validation and (5) Analogies' Report. The main idea is that the user reflects on the source domain (analog) in order to understand the target domain (Fig. 3).

Fig. 3. ART's splash screen.

At first, the user completes her/his personal data (name, etc) and then start to follow the five steps that we describe shortly below.

(1) *Model's Description*: Students describe the model [7] that they had created previously in a modelling software, such as ModellingSpace. The description includes the model's entities, parameters and functionality.

(2) *Analogies' Record*: Students correlate their actions and during the model's creation with analogies (positive, negative, neutral) from an analogical model that is given to them. We changed the terms "positive" and "negative" analogies to "real" and "misleading", correspondingly, in order to be more suitable to the students' perception.

(3) *Analog's Description*: Students study a description of the analogical model, including analog's entities, parameters and functionality.

(4) *Analogies' Validation*: After Analog's Description, students validate [3] or change or even delete any analogy that they had recorded at the Analogies' Record step, or they add a new one (Fig. 4).

(5) *Analogies' Report*: A report presents to the students what they had done before, in order to reflect. This is the stage in which the student model appears to the students, as OLM systems do [1], [2], [12]. The report consists of five tabs: (1) Real Analogies, (2) Misleading Analogies, (3) Neutral Analogies, (4) Deleted Analogies and (5) Total Actions. In particular, the report includes all the real (positive), misleading (negative) and neutral analogies, that students recorded/validated but also those that have been changed or deleted. The "Total Actions" tab presents the number of the initial recorded analogies (Analogies' Record step), the final validated

analogies, those that had been changed, added or deleted, separately for each type of analogies.

Finally, the user saves her/his data in a file (*.art) for future use.

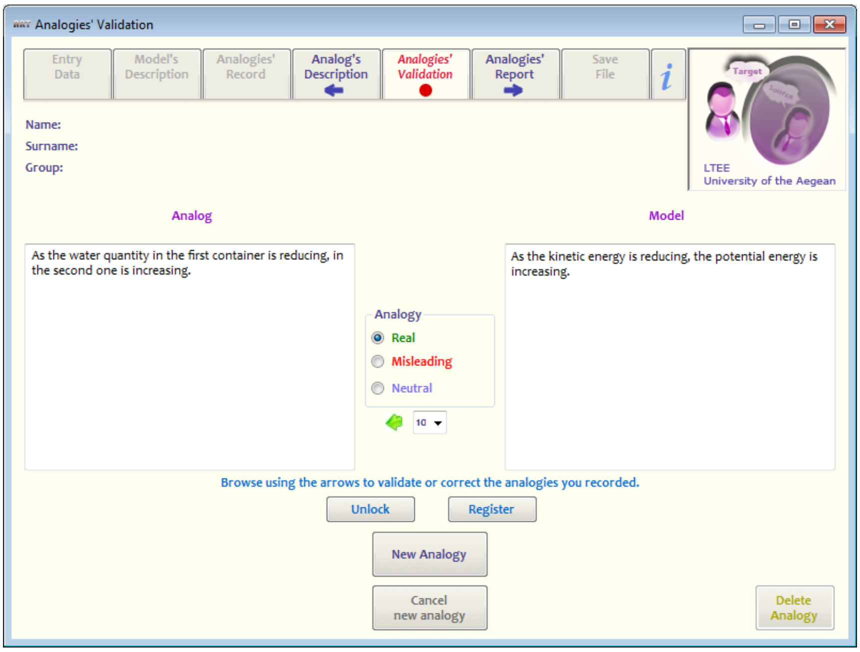

Fig. 4. ART's screen in Analogies' Validation step.

Example: Energy Conservation and Water Transfusion Analogy

We plan to test ART's contribution to reflection and learning in a framework of inquiry modelling activities. When students create models in the ModellingSpace technological environment (collaboratively or individually), they reflect using the Interaction Analysis (IA) tools that the software provides. IA tools are proper for self-reflection or comparative reflection, but not for analogical reflection. These tools are useful for the students to analyse their own activities (self-reflection) or their classmates' activities (comparative reflection), but they don't scaffold students to examine an analogy and reflect on it.

An example of modelling based activities is the motion of a body moving towards the top of an inclined smooth plane. This scenario deals with the Principle of Conservation of Mechanical Energy. After the students finish the modelling activity, the teacher demonstrates (without explanations) an analogical model, created in the ModellingSpace. The analog represents the water transfusion from one container to another. Its visualisation shows the water that goes out of the one container gets in the other one. Therefore, if a third container represents the total water of both containers, its water level should be constant.

Using the ART, students are guided step-by-step to reason analogically and, finally, to reflect analogically. At the first step, students have to describe the model that they had created previously in the ModellingSpace. The description includes magnitudes (such as kinetic, potential and mechanical energy, mass, height and inclination) and the relations between them. At the second step, students correlate their actions with analogies (real, misleading, neutral) from the analogical model. For example, they correlate the relation between kinetic and potential energy with the water transfusion from one container to another. By this way, students justify why they equalised the kinetic energy reduction with the potential energy increment. At the third step, students study a description of the analogical model (including entities, parameters, functionality), while at the fourth stage they have to validate or change or delete each analogy that they had recorded previously or add a new one. If a student made a mistake during the modelling activity and didn't realise it, neither using the IA tools nor at the Analogies' Record step, then she/he may find out the mistake through the analog's description. Therefore, students review their modelling action by reflecting on the analog. The analogical reflection is completed at the fifth step, were students watch their total actions in the ART. They review what they had recorded before the examination of the analog's description and what they changed after. Deleted analogies indicate strong misconceptions (according to data from our pilot research) before the analogical reflection. For example, a student initially may correlate the mass of the body with the quantity of the water, which is wrong. If after the analogical description she/he deleted the analogy, the "Deleted Analogies" tab at the final report of the ART will highlight this misconception.

Discussion-Conclusion

The most interesting modern educational technological environments do not focus on the transmission of knowledge, but on triggering metacognitive functions. Reflection acts as a booster for metacognition. Analogical reasoning can enforce reflection, acting as a booster of metacognition. In the analogical reasoning stage, students exploit their knowledge in a familiar domain (source), in order to understand an unfamiliar domain (target). Scaffolding helps students at this stage to correlate the two domains.

In our work, we presented a scaffolding tool, by which students reason analogically and finally reflect on analogies, in order to exploit and improve their metacognitive skills. The Analogical Reflection Tool assists students while reflecting analogically. We work further to find out more evidence about analogical reflection and to test and improve the ART.

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