The Impact of the Analogical Reflection on the Metacognitive Awareness

George Kritikos and Angelique Dimitracopoulou
University of the Aegean, Greece

ABSTRACT

There are two types of reflection, according to what the learner reflects on, self-reflection and comparative reflection. 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 functions.

The hypothesis of our research is the following. If the learners study an analogical model, the revision may be more substantial than the revision with self-reflection. We have designed a scaffolding software tool that assists students while reflecting analogically, the ART (Analogical Reflection Tool). In our research, we asked from the students (aged 15 years) to reflect (1) on their own actions and (2) on analogies, using the ART. In order to compare the metacognitive awareness due to self and analogical reflection we used three criteria-questions, based on the MAI (Metacognitive Awareness Inventory).

According to the results, the analogical reflection activities are more efficient than the self-reflection activities in two criteria (recur to given data, summarize findings), while there was no significant difference in the third criterion (associate with existed knowledge).

Keywords: Analogies, Metacognition, Reflection, Modeling-based learning, Physics

INTRODUCTION

According to Flavell (1979), metacognition is related to the knowledge about the mind's processes. Metacognition is the awareness of knowledge or ignorance. Reflection, as a metacognitive skill, is the mental process in which the person investigates its own experiences, in order to reach new perceptions (Boud, Keogh, and Walker 1985). Reflection may take place during an activity (reflection-in-action) or at the end of an activity (reflection-on-action) (van Joolingen et al. 2005; Manlove 2007). 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. The reflection-on-action emerges from the requirement to summarize and evaluate the entire activity. On the other hand, by the reflection-in-action students monitor specific stages of the activity and reassign their progress.

There are several ways to promote reflection in technological learning environments. Common examples are the following: (1) *Dialogues* between the learning system and the learner (Kor, Self, and Tait 2001; Tsovaltzi and Fiedler 2003; Tsaganou, Grigoriadou, and Cavoura 2004), (2) *Software agents* with specific role each one of them (White, Shimoda, and Frederiksen 1999), (3) *Concept maps* (Toth, Suthers, and Lesgold 2002; Cimolino, Kay, and Miller 2003), (4) *Conflict awareness* simulations, which accent a strange behavior in order to emphasize the incorrect (Kor, Self, and Tait 2001; Hirashima and Horiguchi 2003), (5) *Interaction analysis tools* (Dimitracopoulou et al. 1999; Phielix, Prins, and Kirschner 2009). For example, White, Shimoda, and Frederiksen (1999) 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 Analyzer. Their inquiry activities followed the cycle: Question – Hypothesize – Investigate – Analyze – Model – Evaluate. At the beginning, a question about a phenomenon is given to the students, who make a hypothesis, for investigation. Then, they analyze the results and start modeling. Finally, the results' evaluation accomplishes the cycle. At this last stage, students reflect on the entire activity, searching for their model's limitations.

Analogical Reasoning

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 existing 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 of analyzing and comparing 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. For example, a computer network (target) could be represented by different analogs (sources), such as road network, rail network or post office.

According to Gentner and Forbus (2011, 267), analogical reasoning consists of five steps: "*1. Retrieval: Given a situation, find an analog that is similar to it. 2. Mapping: Given two situations, align them structurally to produce a set of correspondences that indicate "what goes with what", candidate inferences that follow from the analogy, and a structural evaluation score which provides a numerical measure of how well the base and target align. 3. Abstraction: The results of comparison may be stored as an abstraction, producing a schema or other rule-like structure. 4. Rerepresentation: Given a partial match, people may alter one or both analogs to improve the match.*"

Figure 1 shows two analogical models (analogs) for the energy conversions at the free fall and the fall with air resistance. The analog for the free fall consists of two glasses of water, which is transfused from the one to the other, like the potential energy (U) is converted to kinetic (K) energy. The analog for the fall with air resistance includes one more glass, which represents the mechanical energy loss (Q).

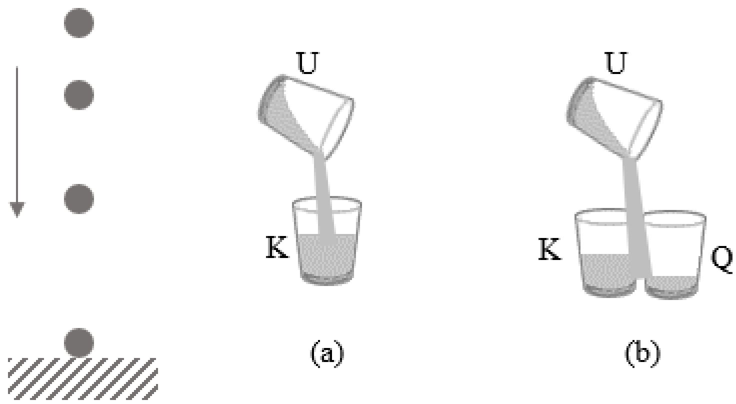

Figure 1. Water transfusion analog for the energy conversion at the (a) free fall (b) fall with air resistance.

Analogical Reflection

There are two basic categories of reflection, according to what the learner reflects on. In self-reflection (Schön 1991), the learner reflects on her/his own actions. In comparative reflection the learner reflects on others' actions (Elbers 2003). In groupware learning environments, comparative reflection is characterized as collaborative reflection or co-reflection (Phielix et al. 2011). 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 (Figure 2). During the collation, students are asked to correlate the source with the target.

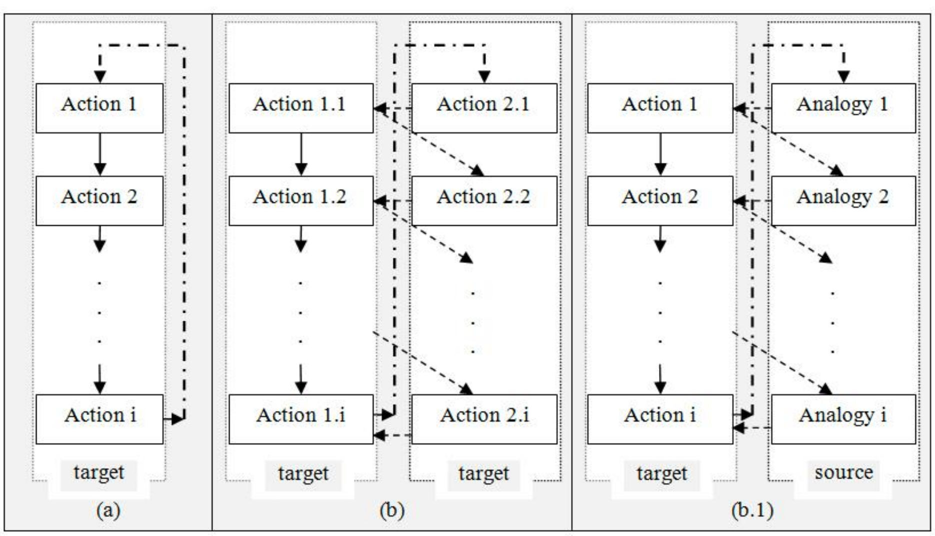

Figure 2. Reflection types: (a) self, (b) comparative, (b.1) analogical.

The idea for introducing and examine the analogical reflection derived from the combination of the analogical reasoning with the comparative reflection:

Analogical Reasoning + Comparative Reflection = Analogical Reflection

When the learners reflect on their own actions, they may improve their metacognitive skills. But, 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. This is main hypothesis of our research, which we describe below.

METHODS

ART (Analogical Reflection Tool)

ART (Analogical Reflection Tool) is a scaffolding tool, assisting students to reason and reflect analogically, consists 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 (Figure 3).

Figure 3. ART's splash screen.

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

(1) Model's Description: Students describe the model (White, Shimoda, and Frederiksen 1999) that they had created previously in a modeling software, such as Modellus (Teodoro 1997). 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", respectively, 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 (Figure 4): After Analog's Description, students validate (Cimolino, Kay, and Miller 2003) or change or even delete any analogy that they had recorded at the Analogies' Record step, or they add a new one.

(5) Analogies' Report: A report presents to the students what they had done before, in order to reflect on. This is the stage in which the student model appears to the students, as Open Learner Model systems do (Dimitracopoulou et al. 1999; Tsaganou, Grigoriadou, and Cavoura 2004; Tsovaltzi and Fiedler 2003). 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 had 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.

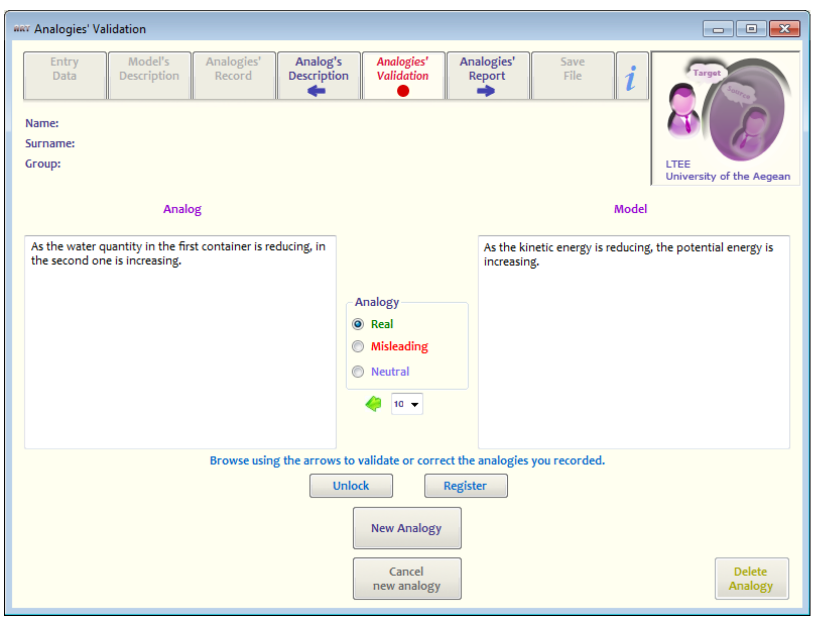

Figure 4. ART's screen in Analogies' Validation step.

In 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 a modeling software, such as Modellus (Teodoro 1997). 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. Consequently, students justify why they equalized the kinetic energy reduction with the potential energy increment. At the third step, students study a description of the analogical model (including entities, parameters, and 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 modeling activity and didn't realize it at the Analogies' Record step, then she/he may find out the mistake through the analog's description. Therefore, students review their modeling action by reflecting on the analog. The analogical reflection is completed at the fifth step, where 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 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.

Research Question and Hypothesis

The main question of the research is the following:

"What is the metacognitive awareness of the students in the framework of computer-modeling activities in Physics?"

The hypothesis of our research is the following. If the learners study an analogical model, the revision may be more substantial, than the revision with self-reflection. We asked from the students (aged 15 years) to reflect (1) on their own actions and (2) on analogies, using the ART. In order to compare the metacognitive awareness due to self and analogical reflection we used three criteria-questions (Q1: associate with existing knowledge, Q2: recur to given data, Q3: summarize findings), based on the MAI (Metacognitive Awareness Inventory) of Schraw and Dennison (1994), by asking the students the following. Q1: Did you wonder if what you were studying was related to your prior knowledge? Q2: In case that you detected an error, did you recur to the data of the given sheet/analog? Q3: Did you summarize your findings at the end of the activities?

Participants

The participants were 12 students aged 15 years in a secondary high school. The students worked collaboratively in 3 groups. Each group consisted of 4 students with various performance in Physics. Two of them, in each group, were high performance (20/20 term grade), 1 was (15/20 term grade) medium performance and 1 was low performance (10/20 term grade).

Learning Environment and Activities

The technological learning environment, in which the students worked, consisted of four separate software units:

(1) Modellus for the modeling activities.
(2) TeamViewer for the synchronous collaboration.
(3) Camtasia for the video capturing as a self-reflection tool.
(4) ART as an analogical reflection tool.

The modeling activities took place in the Modellus (Teodoro 1997). The scenarios, which the students were dealing with, were two motions: (1) free fall and (2) fall with air resistance. The aim of the scenarios were the students to conclude to the Principle of Conservation of Mechanical Energy (PCME) in free fall and to the Principle of Conservation of Total Energy (PCTE) in fall with air resistance.

The plan of the activities was the following; at first, the students created a model based on the scenario of the free fall. At the end of the modeling activity they watched their actions and dialogues from the Camtasia's captured video in order to self-reflect. Then, the students studied a given analogical model for the free fall. The analog was representing the water transfer from one container to another. The visualization shows the water going out of the one container into the other one. Therefore, if a third container represents the total water in both containers, its water level should be constant. Finally, they were guided by ART in order to reflect analogically. After the free fall study, the students repeated the previous steps for the fall with air resistance. In the analog for the fall with air resistance, a fourth container was added, which represented the mechanical energy loss (heat).

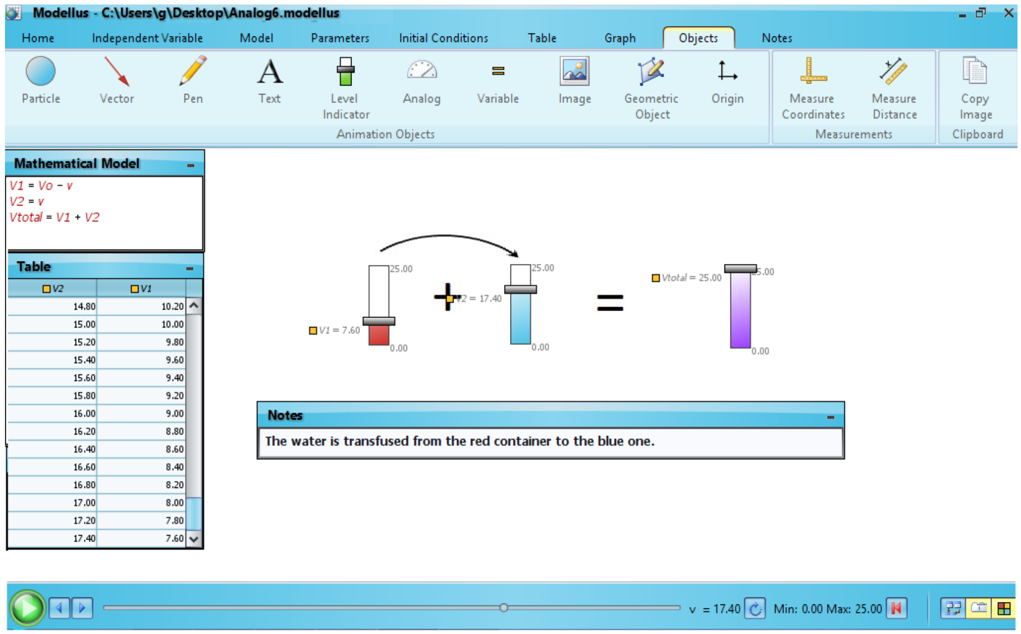

Figure 5. Analogical model in the Modellus.

Data Collection

The dialogue among the students was recorded by the Camtasia software. Thus, Camtasia was used as both a self-reflection tool for the students at the end of the activities (reflection-on-action) and a data collection tool for us. After each activity, students were asked to watch the captured videos from the Camtasia in order to answer to the three questions (Q1, Q2, Q3). Using the same videos, we collected their dialogues and their total actions during the modeling activities.

The data for the analogical reflection analysis were extracted from the *.art logfiles, saved in the ART. These files contain all of the data that the students completed, such as descriptions of the model and the analog, the analogies (positive, negative and neutral), the changes, deletions and additions at the “Analogies’ Validation Step” and a summary of the total actions.

We also collected data from the students’ answers in the three questions (Q1, Q2, Q3), regarding both types of reflection. The answers were taken from an interview and a questionnaire, after “self-reflection” and after “analogical reflection” activities. In the interview we discussed with the students their difficulties during the modeling activities. The questionnaire, based on the MAI (Metacognitive Awareness Inventory) of Schraw and Dennison (1994), consisted of 10 questions in order to detect the metacognitive skills of the students.

Data Analysis

From the Camtasia's captured videos, we pointed the difficulties that the students had during the modeling activities, in order to detect where there was the need for reflection (Q2: recur to given data). We also analyzed their dialogues and argumentations, in order to detect reflection-in-action instances (Q1: associate with existed knowledge). The data for the Q3 (summarize findings) criterion collected from the questionnaires and the interviews. Finally, we analyzed the *.art logfiles, in order to detect the mistakes in students' analogical reasoning, such as false analogies. The answers from the questionnaires and the interviews were cross-checked with the data from the Camtasia's videos and the *.art logfiles.

The statistical significance of the differences in the values of the three criteria (Q1, Q2, Q3) between analogical reflection and self-reflection, was tested by a chi-square test on the following null hypotheses (H_o):

H_o for Q1: There is no significant difference in Q1 (associate with existed knowledge) according to the reflection type.

H_o for Q2: There is no significant difference in Q2 (recur to given data) according to the reflection type.

H_o for Q3: There is no significant difference in Q3 (summarize findings) according to the reflection type.

RESULTS

The three criteria-questions (Q1, Q2, Q3), that we used to compare the analogical reflection with the self-reflection, according to the metacognitive awareness, as already mentioned, were the following:

Q1: Did you wonder if what you were studying was related to your prior knowledge?

Q2: In case that you detected an error, did you recur to the data of the given sheet/analog?

Q3: Did you summarize your findings at the end of the activities?

Q1 (associate with existed knowledge)

When students were studying the scenarios (free fall and fall with air resistance), they were trying to associate their existent prior knowledge with each scenario. Almost every student $(n=11, f=92\%)$ tried to retrieve and adapt the free fall theory, which had learned in the Physics curriculum, to both scenarios. Fewer, but many, students $(n=9, f=75\%)$ tried to associate the scenarios with the water transfusion analog. The association took place only at the points of the worksheet where the energy conversions were mentioned.

Q2 (recur to given data)

During the activities, most of the students checked their models through the graphs. Some examples of the students' argumentations are the following:

> S.4: "*We saw in the graph that the total energy was increasing, as the body was moving down. This is like the total water quantity in both containers was increasing.*" (Figure 6)
>
> S.1: "*In the graph window, we set the height and the potential energy and we saw the body moving down, the height decreasing and the potential energy increasing. We noticed that this was wrong. It was like the container was getting empty, the water level was getting lower and the water quantity was increasing. We looked deeper and saw that in the vertical axis we had set the velocity (v) instead of potential energy (U). As the body was moving down, the velocity was increasing.*"

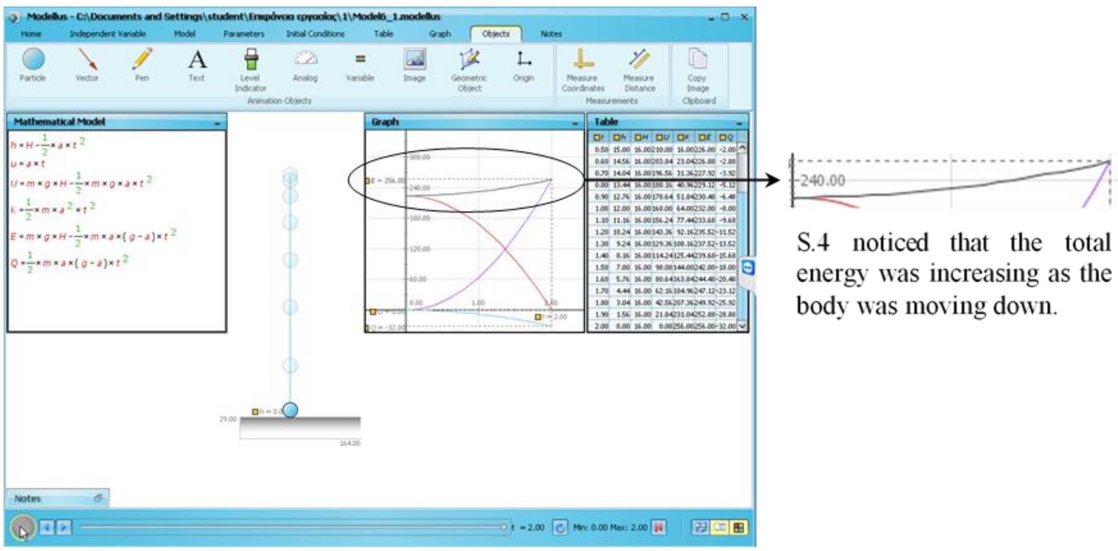

Figure 6. Snapshot from the modeling activity: fall with air resistance.

Students S.1 and S.4 correlated their model with the analog, but both of them noticed the mistake in the graphs, thus, from their Physics background. All the students $(n=7, f=58\%)$ who recurred to the analog, had noticed their mistake through their Physics background. There were also students $(n=5, f=42\%)$ who were based only at the Physics background, without recurring to the analog. Thus, all the students $(n=12, f=100\%)$ reflected in self-reflection mode. Therefore, during the activities, self-reflection (in-action) was always present, whereas analogical reflection was optional.

Q3 (summarize findings)

After each activity, students were interviewed and they answered a reflection questionnaire, in both self-reflection and analogical reflection activities. There were only a few students $(n=2, f=17\%)$ who summarized the modeling activity's findings at the self-reflection questionnaire or at the interview. On the other hand, most of the students $(n = 10, f = 83\%)$ summarized at the analogical reflection questionnaire. Some examples of the students' comments are the following:

S.3: "*I understood that the energy is conserved and it just changes from one form to another, like the water is conserved and it just transfused from the one container to the other.*"

S.11: "*The mechanical energy is a form of total energy that is conserved only in specific cases, e.g. if there is not air resistance. If there is air resistance, the mechanical energy is not conserved. This is like the container. Its water could be transfused to another container, but the transfusion could be divided in two other containers, as well.*"

Differences between analogical reflection and self-reflection in Q1, Q2, Q3

The answers from the questionnaires and the interviews were cross-checked with the data from the Camtasia's videos and the *.art logfiles. The cross-checked answers of the students to the three questions (Q1, Q2, Q3) are given in the Table 1.

Table 1: *Cross-checked students' answers to three questions (Q1, Q2, Q3).*

	Q1		Q2		Q3	
	SR	AR	SR	AR	SR	AR
No	1	3	0	5	10	2
Yes	11	9	12	7	2	10

SR: Self-Reflection, AR: Analogical Reflection

The statistical significance of the differences in the values of the three criteria (Q1, Q2, Q3) between analogical reflection and self-reflection, was tested by a chi-square test (Table 2).

Table 2: *Chi-square test between analogical reflection and self-reflection according to the three criteria (Q1, Q2, Q3) for the metacognitive awareness of the* $(N = 12)$ *students.*

	χ^2	p (2-sided)
Q1	1.200	.273
Q2	6.316	.012
Q3	10.667	.001

The test showed that there was no significant difference $(p = .273 >> .05)$ according to the criterion Q1 (associate with existed knowledge). On the other hand, there was significant differences $(p = .012 < .05)$ according to the criterion Q2 (recur to given data). While all the students $(N = 12)$ recurred to the given data when they had difficulties, only 58% $(n = 7)$ of them took in mind the analog. However, the difference in the criterion Q2 was not very significant ($p = .012 > .01$). Very significant differences ($p = .001 < .01$) found in the criterion Q3 (summarize findings). Only 17% ($n = 2$) of the students summarized their findings in the self-reflection activities, while the 83% ($n = 10$) of them summarized in the analogical reflection activities.

Therefore, the reflection type did not affect the association between the given data with the existed knowledge of the students. The existed knowledge from both the target domain (Physics background) and the source domain (analog) were recalled in order to study the model. But, when students had difficulties, they preferred to use their Physics background rather than the familiar behavior of the analog. This means that the self-reflection showed better results in criterion Q2. However, at the end of the activities, only the analogical reflection helped students to summarize their findings. Therefore, self-reflection is better during the activities (reflection – in-action) while analogical reflection is much better at the end of the activities (reflection-on-action).

DISCUSSION

In our research, we compared the self-reflection with the analogical reflection, in order to study the impact of the analogical reflection to the metacognitive awareness. According to the results, there was not any significant difference in whether students wondered if what they studied was related to their prior knowledge. In contrast, there were significant differences in whether students were recurring at the given data or the analog, when they were noticing a mistake. In this case, self-reflection activities were more useful for the students. Very significant differences found in whether students summarized their findings at the end of each activity. The students summarized their findings through the analogical reflection activities, rather than the self-reflection activities.

Therefore, a first conclusion is that the reflection type did not play an important role in the association of prior knowledge with the activity's scenario. Both the knowledge of the "target" (Physics) and the knowledge of the "source" (analog) had been retrieved when the students were studying the scenarios.

On the other hand, when students had difficulties, the reflection types led to different results. In case they detected an error, they preferred rather to lean on their scientific background than to the familiar analog. An explanation for this, is that the analogical reflection activities are more limited than the self-reflection activities. For example, the analog with the water transfusion focuses only on the energy conversions, while the Mechanics theory covers the whole phenomenon. Thus, a second conclusion is that the self-reflection type is more helpful for the students than the analogical reflection type.

Instead, the contribution of the analogical reflection to the summary at the end of the activities was much greater than what the contribution of the self-reflection. When the students finish their tasks, they just check the correctness in order to end the learning activity. But, they miss a very substantial metacognitive learning task, which is the reflection on their findings. Through the reflection, they will be able to judge, review, reallocate and validate their cognitive background. Analogies were found very important reflection tool, which forced the students to summarize their findings at the end of the modeling activities (reflection-on-action). Therefore, a third conclusion is that the analogical reflection type is the only one that assists the students to organize their findings in order to make meaningful conclusions rather than to complete correctly their tasks without any conclusions.

At this point we have to make clear that analogical reflection is more than a mapping between the source and the target. The mapping is the part of the analogical reasoning, which aims to the comprehension of the context. When students study an analog in order judge, review, reallocate and validate their cognitive background, they reflect on their actions through the analog. This is what we call analogical reflection, which includes both analogical reasoning and comparative reflection.

In conclusion, the analogical reflection, after the completion of the modeling activities, enhances the students' metacognition awareness. Based on the results of our research, we propose that after modelling activities in learning Physics should follow analogical reflection activities, which guide the learners to bring to light their outcomes.

In closing, we cite a quotation from Oscar Wilde, which highlights both the advantage of reflection, and the disadvantage of self-reflection.

> *I like hearing myself talk. It is one of my greatest pleasures. I often have long conversations all by myself, and I am so clever that sometimes I don't understand a single word of what I am saying.*
>
> Oscar Wilde

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