PRELIMINARY FINDINGS REGARDING STUDENTS' PREDICTIONS IN NOVEL SITUATIONS: THE ROLE OF SELF-GENERATED ANALOGIES IN NON-SCIENTIFIC REASONING

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Abstract: This small scale pilot study was the first stage of a larger cross age study designed to investigate students' predictions in novel situations and the role that self-generated analogies play in non-scientific reasoning. The study used a mixed method approach composed of a combination of interviews and questionnaires. Thirteen, sixteen and twelve students were recruited from Year 4, Year 9 and Year 11 (aged 9-10, 15-16 and 16-17 years) respectively from three different schools in Greece.

Nine student focus group interviews were conducted in combination with the administration of a six pictorial item questionnaire. All interviews were audio-tape recorded and additional data were also collected through the use of written responses to the questionnaire. Students' responses were analysed to ascertain whether their predictions drew on the use of analogies and, if so, the nature of the analogy that was used. It emerged that there were many similarities among students' predictions as well as the analogies they used to explain the latter. Also, preliminary findings suggest that in many cases when students demonstrated non-scientific reasoning they drew on analogies which made them make a prediction which is not compatible with the scientific view. It also emerged that the analogies used by students in Years 4 and 9, when presented with the same novel situations in which they were required to make a prediction, were, in many cases, similar irrespective of their year group. Whilst students in Year 11 did make use of those similar analogies the frequency with which they drew on analogies, to make predictions, appeared much less that for the two younger student groups

This study found that students regularly make use of analogies, rather than scientific thinking, and that teachers need to be more aware of the nature of the analogies used and how, and why, these analogies can, in many cases, lead students to make scientifically incorrect predictions.

Keywords: predictions, analogies, reasoning, novel situations

INTRODUCTION

Analogies as tools for instruction and analogical reasoning have been of interest to scientists, educators and philosophers ever since Aristotle. Research in this area has consistently found that analogies play a significant role in students' understanding and learning about natural phenomena (Goswami, 1991).

Within a constructivist approach the learning process involves a search for similarities between the unfamiliar and the familiar, between what is new and what is already known

(Kim & Choi, 2003). Therefore, apart from being useful as instructional tools, analogies are also valuable as tools for reasoning and understanding.

Using analogies can help people to better understand a novel situation by allowing them to see similarities (albeit that the similarities that they see are not the ones that will lead them into making the scientifically correct prediction) between that novel, and hence unknown situation they are presented with, and a more familiar situation.

Whilst previous studies have provided an insight about the effectiveness of analogies as a tool for understanding new phenomena, they did not consider the extent to which students' use of particular analogies could be used to better understand how and why student made either correct or incorrect prediction in novel situations. As such there is still a lack of clarity as to whether there is any connection between the analogies generated by students and their misunderstanding of situations. Moreover, as several authors have argued (Pittman, 1993; Wong, 1993), the use of spontaneous and self generated analogies might serve as a useful diagnostic form of formative assessment in so far as it reveals misconceptions that might be held.

This article presents findings from a study that investigated students' use of spontaneous and self generated analogies and their possible relation with erroneous beliefs when asked to make predictions regarding outcomes to novel situations presented to them by addressing the following questions:

a) What predictions do students make regarding novel situations?

b) How do students of different ages make predictions regarding novel situations?

c) What analogies do students draw on when making their predictions?

d) To what extent do students of different ages draw upon similar analogies?

THEORETICAL FRAMEWORK

Analogy

In terms of structure analogies, normally take the form of similes or metaphors. Generally speaking, analogies have two main components- the base and the target. The latter being the unfamiliar and in some cases novel situation that is being considered whilst the former refers to known situations which will provides means of engaging with the target.

In an analogy each of the two domains has certain relationships or attributes which can be mapped as being quite similar. An example of attributes mapping is the analogy that water is like electricity (they both flow) whereas a mapping of relationships could be the solar system as an analogy for the planetary model of the atomic structure (similarities in orbits between electrons around the nucleus and planets around the Sun).

Spontaneous analogy

In the present study the term spontaneously generated analogy is used to denote an analogy that is self initiated in contrast to situations where the subjects are presented with an analogy. Similarly, a self-generated analogy has the meaning of an analogy that is created by the individual as opposed to analogies that are provided but in this case the subjects might be asked to generate an analogy.

Clement (1988) identified three resources or processes for an analogy generation these be generation via: a) a formal principle (recognition of the target as an example of a principle or an equation and generation of the analogous situation B as another example of that principle), b) a transformation (an analogous case is produced by modifying some features of the target situation), c) an association (the individual is reminded of an analogous situation in memory which although differing in many aspects from the target situation but it can still have important similar features).

RESEARCH METHODOLOGY

Study sample

The pilot study sample was composed of students from each of the three main levels within the Greek education system. As such the sample comprised thirteen, sixteen and twelve students participated, aged 9-10 years (Year 4, primary education), 14-15 years (Year 9, secondary education, Greek 'Gymnasium') and 16-17 years (Year 11, secondary education, Greek 'Lyceum') respectively. The schools were selected opportunistically, to ensure a sample that was, in terms size, status and socio-economic background, broadly representative of schools across the same geographical region of central Greece. Such a selection process was principally concerned with ensuring what Bell (1984) refers to as "naturalistic coverage" (p. 75) rather than with meeting the statistical sampling requirements associated with traditional quantitative research. In order to ensure the anonymity of the students when presenting data (results section) students were given codes. Codes started with S (to indicate Student) and it was followed by a number indicating the Year of the students and at the end with another number indicating which case is represented (Student 1, 2, 3 etc...). So, for example, S9.3 would indicate that this student is in Year 9 and that they are recorded as student number in this study.

The research instrument

The situations in which students were asked to make a prediction were novel in the sense that they had not been asked previously to think about/make predictions regarding those specific situation before and this would have been because the actual situation presented was unlikely (although this was not in itself necessary) to have been seen before. As such the students' predictions regarding those specific situations were new in the sense that the students could not have had any prior opportunity to have thought about those situations before they were presented in this study.

All of the situations were presented to the students in a pictorial form. This approach was used to avoid providing any kind of lead to the students in terms of selecting one particular option from those enlisted in the multiple choice question. Students were allowed to make their predictions about the novel situation and to express their own ideas about the concepts involved in the novel situations. This approach also had the advantage that pictures have the potential to be very effective in terms of generating engagement (Kaplan & Howes, 2004; Miles, Kaplan & Howes, 2007) a fact that was considered important in work across such a wide age range and the fact that combining these with the use of multiple choice questions has the potential to reduce ambiguity (Bock & Milz, 1977).

Examples of the questions can be seen below (Figure 1, 2 & 3). The novel situation and the multiple choice question were followed by an open-ended question. In a separate sheet, students were asked to explain their prediction ('what makes you think that').

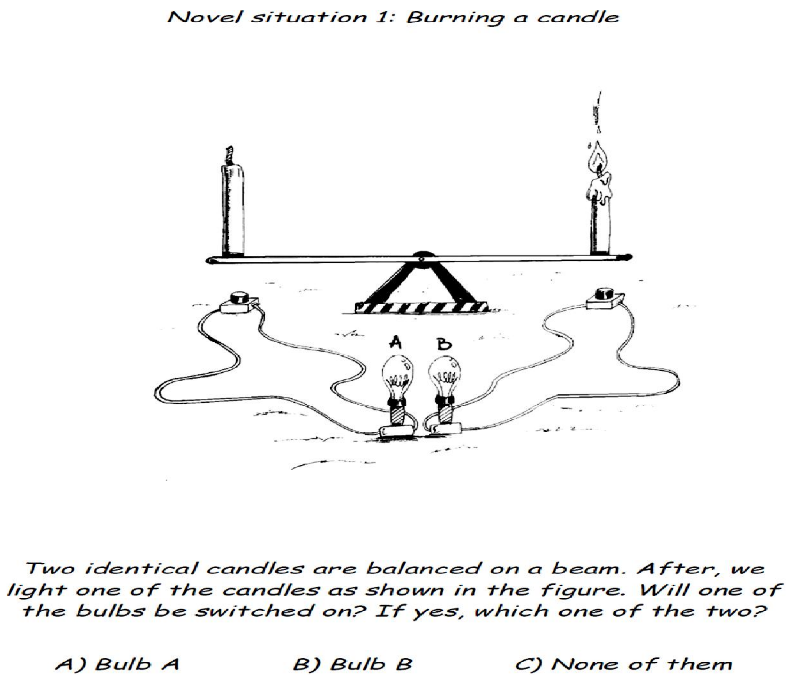

Figure 1. Burning a candle novel situation as presented to the students.

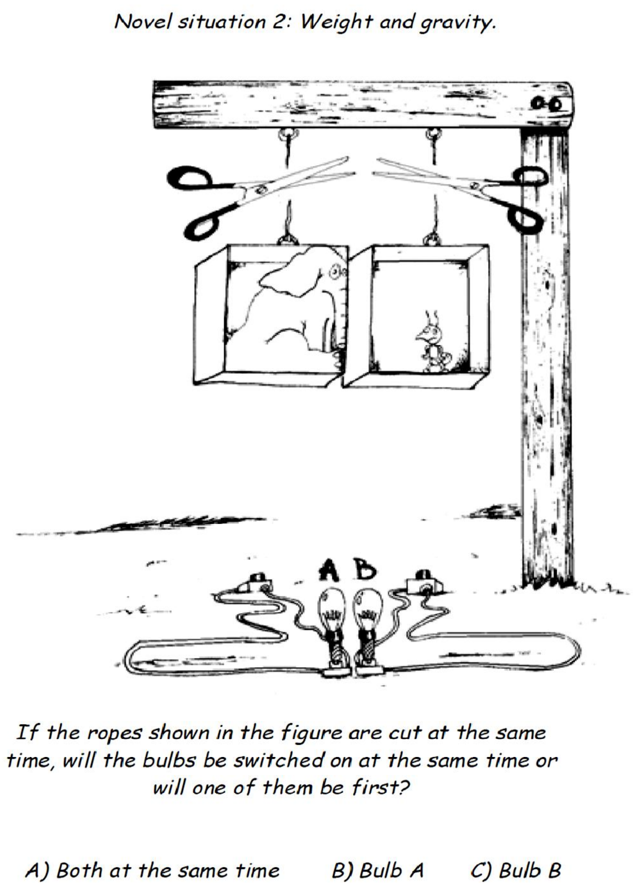

Figure 2. Weight and gravity novel situation as presented to the students.

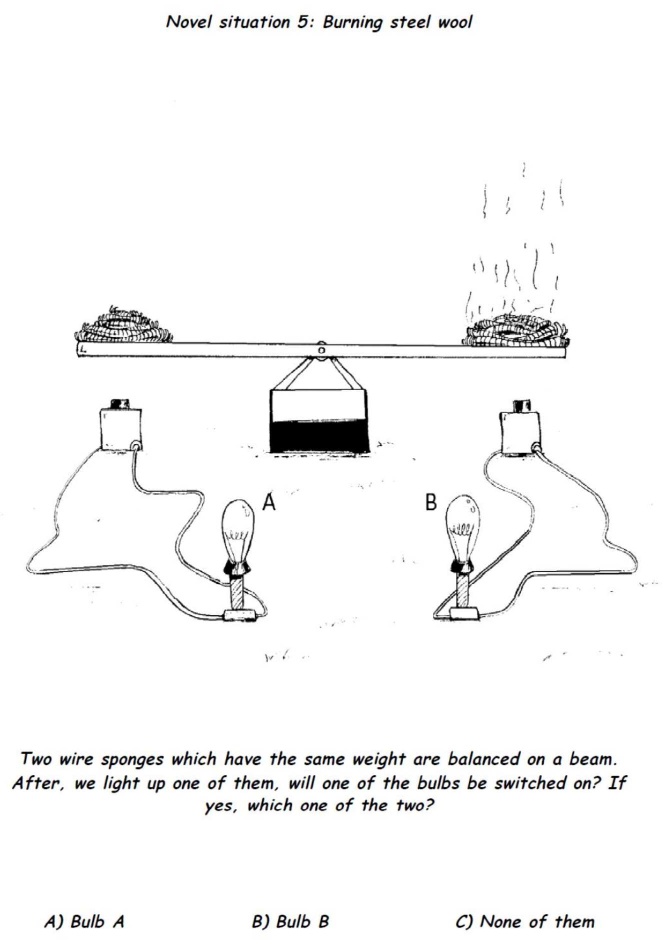

Figure 3. Burning steel wool novel situation as presented to the students.

Procedure

The data collection session lasted approximately two hours for every age group. In the first hour, the questionnaire was administered to the students who were asked to complete it without any guidance being provided. Straight after students answered the questionnaire, they were divided into two groups of about 5 participants for each age group and they were interviewed for one hour. The interviews were conducted straight after the first hour in which students completed the questionnaire in order not to let them have a second thought about the prediction they made and discuss it with their classmates losing this way the spontaneity of their answers. The interviews adopted a clinical interview approach (Clement, 2000) in which they sat around tables and the interviewer asked them about the prediction they made in the novel situation and to explain what led them to make their choice. Although the questions were not standardized some basic questions such as, 'why do you think this will happen?', 'what makes you think that?' or 'why do you think your prediction is the correct one?' were used. This semi-structured interview approach was used in order for the interviewer to be able to adjust or change subsequent questions in light of students' explanations of their options. The aim here was to induce students to further explain their thought processes that had led them to select their answer to the multiple choice questions.

Data analysis

The questionnaire data were quantitatively and qualitatively analysed with predictions made in the first part of the multiple choice test being statistically compared across the three different age groups. Responses given in the second open ended questions were examined to see whether there was evidence for the use of a self-generated analogy in the explanations students used to explain what let them to make their prediction.

All interviews were audio recorded and then transcribed. As it is the case with the responses in the open ended question, the transcription scripts were examined in terms of analogy generation in the explanations of the predictions made and the basic idea upon which students claimed that they made their prediction.

Moreover, the identified analogies in students' explanations from the interview transcriptions as well as the written responses in the questionnaire were analysed in terms of a modified version of Clement's (1988) framework in which the way that analogies were generated was classified in terms of the three categories described above. Moreover, explanations that involved analogies being generated without any elicitation were classified as 'direct spontaneous explanations' (DSE). It was highly unexpected to find this type of explanations in the interview transcriptions. This is because if students were about to reason spontaneously on the basis of analogies making their prediction this way, they would have done so when they were completing the questionnaire and thus, this type of explanations (DSE) would be identified in students' responses written on the space the questionnaire included to provide an explanation to the open ended question. Analogies that were generated by students when they were asked to elaborate more on their explanation constitute another category, that of 'indirect spontaneous explanations' (ISE). The third and final category, 'prompted indirect explanations' (PIE), is when students were asked to provide an analogous case with the one already presented to them. Contrariwise with the spontaneous generated analogies, the latter two ways of generating an analogy were mostly used to code students' explanations identified in the interview transcripts.

Students' responses in the open ended question of the questionnaire and responses recorded in the interview settings were combined in order to identify common themes. The ideas expressed in the explanations of the predictions made as well as the way of generating the analogy, the analogy generation method and the analogies themselves were compared among the three different groups. Two science education researchers and one more person (outside the area of science education specialism) analysed the data (questionnaire and interview responses) and coded the responses. Where disagreement about the coding existed it was resolved through discussion among the coders.

RESULTS

There were many similarities among students' predictions with the majority of students choosing the same option in the multiple choice question. From the 41 students participated in the pilot study, 34 made the predictions that might have been expected based on the existing literature on students' ideas about similar phenomena with those that the novel situations set out to probe. Across the 6 novel situations only 38 out of the 246 predictions were correct (15%). Also, students in Years 4 and 9 made fewer scientifically correct predictions when compared to the older students of the study sample.

Students seemed to be seeking for ways to facilitate their thinking about the novel situations. Many of them (39 out of the 41 students) appeared to be looking for analogous cases that would help them in formulating (or selecting) the correct predicted answer in the novel situation.

For these predictions a total of 234 analogy explanations were generated. From the 234 analogies identified, 108 were spontaneously generated (DSE), 103 were indirectly spontaneously generated (ISE) and 23 were prompted by the researcher. Almost half of the analogies identified were used from all the students in the three different age groups. Also, even if the analogies generated were not identical they were similar in terms of the generation method and the elements that students focused on and changed in order to create the analogies as described above. The following two responses given for the novel situations 1 and 2 as shown in figures 1 and 2 respectively attest to that:

> In my opinion bulb A will switch on first because the left box has greater mass than the right and therefore, the one that includes greater mass will fall down first. I think that this is like the example in which we throw from the top of a roof a dumbbell and a feather, the dumbbell always falls faster. This happens because the weight is greater.
>
> (S9.1)

> If you have a wet sponge and a dry one trying to balance them on a beam, the only way to make it is to squeeze and twist the wet one! That is why I chose that bulb A lights up. I think that the candle that is on side A switches on because when the candle burns it melts it loses parts of its weight due to the wax drops that flow.
>
> (S4.2)

It can be seen in the first example that the student changed very few characteristics of the novel situation (the target) generating this way an analogous situation (the base) that, according to the answer given, helped in making a prediction. This student, as was the case for many others, focused on the difference of mass between the animals being placed in the boxes (the elephant and ant) and their analogy was generated by simply exchanging these two, more familiar, objects that also had different masses. In this case the analogous situation (the base situation) was similar in many ways with the novel situation (the target situation) and thus it is coded as being generated via transformation.

From the 41 students participated in this study, 26 followed a very similar reasoning process in this novel situation. The only difference was that instead of replacing the elephant and the ant with two other objects, some students provided analogous cases of two other animals being dropped from the same height (for example, a bee and a rhino, a fly and a sheep or a fly and a cow) or they even gave examples of two people of different mass (a fat and a thin one as some students wrote) falling from a tree, a roof or into the sea. This way they came to the same conclusion making an erroneous prediction according to which the box with the elephant falls faster (bulb A is switched on first). However, the scientific prediction here is that both bulbs will light at the same time because their acceleration under gravity is constant for both masses (ignoring air resistance).

The generation method of transformation was evenly distributed among the 3 age groups and across the 6 novel situations was the most common method for generating analogies among this study sample. The majority of the analogous situations identified in the present study were cases that were transformed in order to fit with the novel situations. They were phenomena that students observed in their early stages of life. This became apparent as some of the older students did make use of the same analogies such as younger did.

Of the 234 analogies identified, 41 were coded as being generated via an association. The analogy generated by S4.2 is a typical example of this generation method. As it can be seen in the example above, this student, focused on the element of the liquid that flows while the candle is lit and they made the student made a prediction by being reminded of an analogous situation in memory that was different in many ways from the burning a candle situation. Without any doubt this reasoning is incorrect in the sense that although the candle loses mass this is not due to the wax drops that flow. Rather, this is because the carbon particles in the candle react with the oxygen in the air to make carbon oxides. Subsequently, these gases (CO_x) are given off and therefore the remaining candle weight less than before being lit.

Nevertheless, there were students who made the correct prediction in this question by reasoning on analogies and furthermore, in explaining their answers did use scientifically compatible ideas. This is shown in the questionnaire script response below:

> I chose A bulb to light up. I can see that this is like the case of a piece of paper. After being burnt, the paper will not have the same weight anymore, it becomes lighter. I think that the same happens with the candle, it loses its weight as it gets burnt.
>
> (S11.3)

In the above response this student, as was the case for many others (28 out of the 41 students followed a similar reasoning process), focused on the element of an object being burnt in order to come to the conclusion that burning objects lose their weight or to justify what makes them believe that the latter is a correct idea which indeed appears to be compatible with the scientific view in this novel situation. In other words, there might be some cases in which students' ideas of objects being burnt are not only incorrect in relation to the experiences they are based upon and as the above example shows, they can be used to make correct predictions of situations students did not considered before.

Nevertheless, students who came to a correct prediction in the novel situation 1 (Figure 1), made an incorrect prediction about novel situation 4 (Figure 3) by following a similar reasoning process and using similar analogies. In both cases, the most common underlying idea identified in students' responses is that there should be a decrease in the mass of objects being burnt. Students' explanations offered about their ideas and what led them to make their prediction explained what led them to think that burning objects lose weight. It appeared that their idea is a reflection upon experiences like the firewood being burnt and the remaining ash, which is less bulky than the wood and the coal, being lighter (this analogy was the one mostly expressed about these two novel situations). Whilst this is correct for the burning candles situation and can lead to a correct prediction, this is not the case for the steel wools. Contrariwise with the first case, in the steel wool situation the iron wool has chemically combined with oxygen during the burning process and thus, having oxidized to form an ‘ash’ of iron oxide, its weight would increase.

One possible explanation concerning what led them to a correct prediction in the first case is that students made their prediction on the basis of their experiential knowledge of burning fuels which is known to contain carbon. The analogies students generated and used in their explanations attest to that. On the other hand, there appears to be an absence in students’ everyday experiences of objects known to contain iron to be burnt. Therefore they were led to an incorrect prediction in the steel wool situation because they draw on analogous cases of carbon made materials being burnt. This would suggest that there could be some cases in which students have done their observations well and they can use this experiential knowledge in such a way leading to a subsequent understanding of new phenomena and information.

DISCUSSION AND IMPLICATIONS

The use of the same analogies by students across the three age groups suggests that students were, in many cases, led into making incorrect predictions because of their use of analogies drawn from personal and everyday experiences.

However, these results also suggest that spontaneously generated analogies, although frequently leading to erroneous predictions, do have the potential, in some situations, to lead to a scientific correct answer

The spontaneously and self generated analogies showed that students were forced to look for similarities between the novel situation (target) and their prior experiential knowledge (base situations that they perceived as being similar) and it was in drawing on these that they made their predictions. This supports constructivists’ argument that in order for students to understand a new situation they should construct personal interpretation of new information by using prior experiences (Driver & Bell, 1986).

These preliminary findings suggest some implications for science teaching in that teachers not only need to be aware of students’ prior knowledge (Hewson & Hewson, 1983) but also need to better understand how their students use that prior, often experientially grounded everyday knowledge, when thinking about novel situations. In this respect a better understanding of the generation and use of self generated analogies could be a valuable tool in assisting teachers to address existing students’ ideas which are not compatible with scientific concepts. Conversely, with self generated analogies reflecting and explaining where students’ erroneous ideas stem from, they could be used in order to help teachers in the identification of the latter.

What should be noted here is that the findings of this pilot study are based on a relatively small localized study from one geographical area in Greece and, as yet, we make no claims about the generalisability of these findings. We are continuing with further research to explore students’ predictions and explanations in these novel situations with a larger study sample that will also include individual, as opposed to focus groups, interviews with all students so as to gain deeper insights about their predictions and reasoning in novel situations.

Also, future research could focus on students’ reasoning in other novel situations than these examined in the present study and furthermore across different countries in order to see if reasoning spontaneously on the basis of analogies is a common way of understanding new situations.

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