

From the known to the unknown: The role of spontaneous and self-generated analogies in students' predictions about novel situations.

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ABSTRACT

Background: The use of analogies as reasoning tools that play a key role in human cognition at all ages has been of interest to educators, scientists, and philosophers ever since Aristotle. Indeed, research has consistently found that analogies provided by teachers can, and do, play an important role in facilitating student understanding of scientific ideas. Despite the effectiveness of teacher provided analogies little research has been undertaken on the use, and effectiveness, of student self-generated analogies in helping them to understand novel situations.

Purpose: This article reports on a cross-age study of student prediction-making in novel situations. The purpose was to investigate the basis and justification that students provided when asked to make predictions about novel situations and whether they self-generated analogies (SGAs) in order to make their predictions and, in particular, whether such predictions and justifications were based on their use of SGAs.

Sample: A total number of 166 students were recruited from ten, opportunistically selected, schools in Greece. The sample consisted of 37 primary students in Year 4 (9-10 years), 31 primary students in Year 6 (11-12 years), 29 secondary students in Year 7 (12-13 years), 35 secondary students in Year 9 (14-15 years) and 34 secondary students in Year 11 (16-17 years).

Design and methods: A mixed method approach was used with data being collected through the administration of a paper and pencil survey followed by group discussions. In the former, students were presented with six novel situations in a pictorial form and were asked to make a prediction about the outcome of a future event (effectively what would happen in the event depicted in the novel situation), solving this way the novel situation. Students were then asked to provide written explanations about what led them to their predictions. The focus of the group discussions was the predictions and the explanations provided.

Results: The study found that students, when faced with making predictions about novel situations, regularly SGAs and that such SGAs were predominantly

based on their everyday experiences. It emerged that the use of inappropriate SGAs was the predominant reason that predications, and subsequent justifications for those predications, were at odds with the scientific account. The study also found, by analysing the SGAs across a range of student ages, that predictions in novel situations were generally the same and that this similarity was based on the use of the same, or very similar, SGAs that were, in turn, based on the same, or very similar, everyday life experiences.

Conclusions: These results suggest that it might help teachers to be better aware of the common SGAs students are likely to use and the predictable implications of their use in developing misconceptions when learning science.

Keywords: analogies, analogical reasoning, novel situations, predictions

Introduction

Evidence from an analysis of the use of analogies and metaphors in science suggests that analogical reasoning constitutes an important source of innovation and an effective technique for solving problems. For example, Sheldon Glashow (1980), who was awarded the 1979 Nobel Prize for Physics, made specific reference to their use of analogies when developing the unified weak and electromagnetic interactions theory:

I was led to the group $SU(2) \times U(1)$ by analogy with the approximate isospin hypercharge group which characterises strong interactions (...) Part of the motivation for introducing a fourth quark was based on our mistaken notions of hadron spectroscopy. But we also wished to enforce an analogy between the weak leptonic current and the weak hadronic current... (1321-1322)

Analogies are not only important elements in people's reasoning but also, from a constructivist perspective, fundamental components within the learning process as they enable knowledge, about novel situations, to be constructed from components of prior understanding and experience. The term 'novel situation' is used here to refer to an unexpected and unique event or scenario that has not previously been encountered and/or considered and for which a pre-existing understanding and/or familiarity does not exist.

Indeed, Dagher (2005) reported that the use of analogies can be an especially powerful learning tools in situations in which abstract concepts, such as some of those

encountered by students when learning science, are difficult to understand. Furthermore, research in science education has found that the use of analogies by teachers for didactic purposes (e.g., Blanchette and Dunbar 2002; Coll 2006; Clement and Brown 2008) is an effective means of introducing students to novel concepts and novel situations.

The present study draws on Driver and Bell's (1986) model in which an analogy consists of a *target* situation, about which new knowledge is sought, a *base*, which is a situation that is thought (sometimes mistakenly) to be already understood, and a relation that maps elements from the target onto the base. These elements are those perceived by the individual as characteristics and/or relationships that are, in some sense, similar across both the base and the target. An example of element mapping is the analogy that electricity is seen as being similar to water in the sense that both are perceived to flow (Fotou and Abrahams 2015). In this sense, once established, the analogy to flowing water (the base) provides a person with the basis for making a prediction about a novel situation (the flow of electricity in a circuit) given that they expect that the outcome in the novel situation will, in some sense, be similar to the outcome in the base situation of which they are already familiar.

Spontaneous analogical reasoning in novel situations

Podolefsky and Finkelstein (2006) defined a *spontaneous* analogy as one self-generated *without any prompting* and used this term to distinguish such analogies from those referred to as being *Self-Generated Analogies* (SGA). Whilst both are self-generated, a *Spontaneous Self-Generated Analogy* (SSGA) must be self-initiated whilst a SGA is one in which an individual's self-generation of an analogy is prompted, for example by a teacher, and they are expected to use that analogy to explain and understand a phenomenon and/or situation that has been presented to them.

According to Clement (2009), SSGA arise when an individual, presented with a novel situation, identifies, without any prompting, a base situation that they perceive to have similarities to/with that novel situation. If the mapping perceived by the individual is inappropriate its use can lead to an erroneous prediction with respect to the outcome of the novel situation. The use of SSGA is, according to Clement (1988), different to other approaches to problem-solving as it does not entail deconstructing the novel situation into smaller parts that can then be analysed in terms of basic scientific understanding.

A four-stage model about the process of thinking about a novel situation and trying to reason about it on the basis of either a SGA or a SSGA is that proposed by Clement (1982) for analogy generation in general, according to which the stages are:

1. An individual sees, or is asked to see, a base situation that is analogous to the target is identified.
2. The cogency of the analogy is confirmed through examination of the relation between the base and the target.
3. Elements from the base are mapped onto the target.
4. Predictions relating to the target situation are inferred from the base.

Clement's (1982) model is utilised here to analyse students' analogical reasoning in order to determine how `distant` (577) the base is from the target and the nature of their similarities.

The present study

Previous studies on the SGA, and fewer on SSGA, in science have focused on college students (e.g., Cosgrove 1995), undergraduate students (e.g., Sandifer 2004), postgraduate students (Clement 1988), and pre-service teachers (e.g., James and Scharmann 2007). However, as Wong (1993) pointed out, the self-generation of analogies, and the influence of these analogies on understanding, should also be explored with students of all ages including younger students still at school. Whilst there have been some studies on the self-generation of analogies by school students, these have tended to focus on the analogical reasoning as a *process* (e.g., Haglund and Jeppsson 2012; May, Hammer, and Roy 2006), rather than seeking, as this study does, to address the extent to which students' SSGAs or SGA could be useful as a means of better understanding how and why students make either correct, or incorrect, predictions in novel situations as well as what their reasoning is based upon.

Methodology

Sample

The process for selecting the schools was principally concerned with ensuring what Ball (1984) refers to as `naturalistic coverage` (75) rather than meeting the statistical sampling requirements associated with traditional quantitative research. The schools were opportunistically selected so that a sample was, in terms of size, status and socio-economic background, broadly representative of the wider population of Greek students

where the study took place. As such, the sample comprised students from ten schools and consisted of 37 primary students in Year 4 (9-10 years), 31 primary students in Year 6 (11-12 years), 29 secondary students in Year 7 (12-13 years), 35 secondary students in Year 9 (14-15 years) and 34 secondary students in Year 11 (16-17 years). All students' names have been replaced by a unique identification code such that S17.3 is used consistently to refer to the same student (number 3) who is aged 17 so that quotes from any one student can be clearly identified.

Data sources and procedures

Data was collected in two stages; the first involved a paper-and-pencil questionnaire and the second a series of group discussions. In the first stage students were asked to make, without any guidance, predictions about certain novel situations (closed-choice question) presented in pictorial form and then to complete, in a short open-ended written response, what led them to their predictions.

Novel situations were presented in pictorial form as such an approach is reported (e.g., Miles, Kaplan, and Howes 2007) to be effective in terms of generating engagement - a fact that was considered important in working across a relatively wide age range. In addition, the use of pictures, within brief written multiple-choice questions, has the potential to reduce possible ambiguity, maximise simplicity and, thereby, reduce the possibility of any unintentional guidance being provided to the students about the novel situation (Bock and Milz 1977). These pictorial situations can be seen below (Table 1). Having selected one of the outcomes students were then asked to provide, on the same question sheet, brief written explanations about their predictions (open-ended question - 'what makes you think that?').

The second stage of the data collection, which followed on directly after the completion of the questionnaire so as to avoid any discussion about their predictions and/or explanations with other students, involved the students being divided into two groups of about five students for each age group, and they were interviewed for one hour. The interviews adopted a clinical interview approach (Clement 2000) in which students sat around tables and were asked about the prediction they had made regarding the novel situations and what led them to make those predictions. Instead of simply asking the question 'What makes you think that?', as had been the case with the open-ended written question in the questionnaire, there were additional questions, during the group

interviews, that were used to help scaffold students' explanations seek out any allusion to reference to any analogies they had perhaps drawn on when making their predictions. Although these questions were not standardised 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.

Analysis

The data collected through the questionnaire were qualitatively and quantitatively analysed through SPSS with the students' predictions, and their analogies from both the questionnaire and those from the interview transcripts, being statistically compared using bivariate analysis. Whilst we report the p-values of these tests these are not seen as statements that provide causal explanations of the data, but rather as statements about the data related to hypothesis testing (Wasserstein and Lazar 2016) - for example whether the age (or the schooling year) of students were independent of, or unrelated to, other variables, such as the predictions they made or whether they used SSGA and/or SGA.

The identified analogies in students' explanations from the interview transcripts, as well as their written responses in the questionnaire, were analysed in terms of Clement's (1988) framework described above. Students' responses in the open-ended section of the questionnaire and responses recorded in the interview settings were analysed to identify common themes in terms of the predictions made, the analogy generation method, and the analogies themselves. Inter-rater reliability methods were employed with two science education researchers and one more person (outside the area of science education specialism) analysing the data (questionnaire and interview responses) and disagreement resolved through discussion.

Results and Discussion

The results are presented in three sections. The first section presents the predictions students made in terms of their compatibility with the scientific account while also comparing them across the five age groups. In the second section, their reasoning in making these predictions across the five age groups is discussed, and in the third section the analogies students generated are discussed and compared across the five age groups together with the predictions they made.

Students' predictions in the six novel situations

As can be seen (Table 1) over 80% of students' predications across the six novel situations were incompatible with the scientific account suggesting a lack of understanding of the concepts involved in five out of the six novel situations. An exception to this high-level of incorrect predictions observed in novel situation 2 which was included because every day experiences were expected, unlike the other situations, to lead to correct predictions. In novel situations 3 and 5 the percentage of incorrect predictions rose to almost 95% and 90% respectively.

In all six novel situations the predictions made were those that might have been expected on the basis of the existing literature on students' ideas regarding similar phenomena to those the novel situations were set to probe. For example, the ideas of heavier objects falling faster and an absolute view of falling downwards (not an Earth-centred one) due to gravity in novel situations 1 and 5 respectively are in accordance with those reported in other studies which dealt with the same notion (e.g., Driver et al. 1985) with the students of that study being of similar ages to those in the present study.

Table 1 goes here

There were cases in which students, although they selected the correct answer, did not exhibit any scientifically correct understanding of the concepts involved in their explanations of their predictions. In the burning iron wool situation, for example, none of the students who selected the right answers showed any understanding compatible with the scientific account. For example, a student wrote:

I chose option B because I think that as we light the steel wool there is a boost from the fire acting upon it. This boost makes it move downwards. I can't explain why that happens, but this reminds me of how rockets are pushed forward simply by throwing backwards something like a fire.

(S13. 1)

Such responses revealed that correct predictions were not always the result of scientifically compatible understanding and reasoning. However, there were examples in which older students, who made the correct prediction, included in their reasoning ideas compatible with the scientific account and it was through reasoning, on the basis

of scientific knowledge, that they were led to a correct prediction. Consider, for example, the response given by one of the students in the weight and gravity novel situation:

I chose A as there is no difference between the falling of the two boxes regardless of what is in them. In absence of air resistance, both should fall at the same rate regardless of their mass as g is common in both cases.

(S17.2)

Comparisons of predictions across age groups showed that older students aged 15-17 years, outperformed those in the younger age groups in making a correct prediction and exhibiting some scientifically compatible understanding in their explanations of the predictions made. There was a statistically significant correlation found between students' schooling level (primary or secondary) and the prediction being made (Table 2) with secondary school students making more correct predictions than primary across five novel situations (in the burning a candle novel situation students across ages were successful in making the correct prediction as expected, and explained below, with no statistically significant differences found), which reflects a progression in their ability to draw on scientific concepts as they progress through their schooling.

Whilst these results are not, in themselves, unexpected – students' understanding of the concepts involved in the novel situations has already been questioned in past studies showing similar results (e.g., Driver et al. 1985; BouJaoude 1991) – the fact that most of the students, across all five age groups, made an incorrect prediction in five out of the six novel situations indicates the persistency of the ideas students used in their explanations *despite* their science education.

Table 2 goes here

Students' analogical reasoning in making their predictions

At least 40% of the students, across all ages, SSGA or SGA for all six novel situations and/or subsequently used analogical reasoning when explaining their predictions (Table 1). There were cases, like that in 'weight and gravity' or 'melting an ice cube', in which the percentages were higher with 58% and 50% of the whole study sample respectively based their predictions on the use of SGA. Of a total of 467 analogies identified, 440

were identified as being SSGA in the sense that the students spontaneously generated their analogies without any prompting from the researcher.

It was highly unexpected to find SSGA in the interview transcriptions as if students were about to reason spontaneously on the basis of analogies to make their prediction, they would have done so when they were completing the questionnaire and thus, such analogies would be identified in students' responses written on the space the questionnaire provided.

Analysis of the interview transcriptions revealed there were a few students who, whilst they had not used SSGA in the first stage of the data collection, did SGA in the interview when asked to explain further what led them to make their predictions. There were 16 cases of such SGA, with students' analogical reasoning being very similar to that of those who SSGA as they did make their prediction by using a more familiar situation in order to understand the novel one.

SGA were also used by some students when explicitly prompted by the researcher to think of analogous cases to the novel situations they were presented with, but this was the exception rather than the rule. Only 11 analogies of this type were identified with students explicitly asked to SGA that was or would have been, helpful in making their predictions. Following Blanchette and Dunbar (2000), it can be plausibly assumed that even when students did not SSGA, they were still active in identifying and accessing analogous situations and connecting them to the novel situation. Irrespective of whether the analogies were SSGA, SGA, or SGA that were explicitly prompted by the researcher, students were seen to engage frequently in analogical reasoning when trying to make sense of, or make predictions about, novel situations and also to subsequently explain their thinking to the researcher.

In agreement with finding relating the use of analogies amongst an older age range of students (e.g., Kurtz Miao and Gentner 2001), this study also found that the use of SGAs was widely used across the full age range. Indeed, in the case of the younger students (aged between 9 and 13 years) who, according to their curriculum and had not been taught any of the concepts involved in the six novel situations, the analogies showed that, they too looked for similarities between the novel situations and base situations they were already familiar with to make their predictions. The role of analogies as a starting point for making predictions can also be seen by the fact that

many students claimed, as exemplified below, that they had previously never thought of these novel situations.

S12.3: I have seen many times something like this! I know the answer!

Students: Yes! It is the elephant that falls faster! [General consensus in this focus group].

S12.3: I have seen an elephant at the zoo, and I know they are really big and heavy, and we do have many ants in our backyard. They are so tiny!

Interviewer: Great, could you please tell us more about your choice? What do you mean you've seen something like this before? Have you ever thought of this before?

S12.3: Well, I have not seen an elephant and an ant in boxes being dropped but I have seen many times heavy objects falling really fast. Ahhhhh... I thought it but I know it is true because I have chosen A, I am sure it is right. I've seen my book falling faster from my desk than my pencil. Even if I let them fall at the same time, the book will fall faster to the ground.

The above example illustrates that students had never considered the weight and gravity novel situation before in the manner in which it was presented to them and, as such, had no pre-existing ideas about this particular situation and/or ready-made predictions. As similar responses were obtained for all six novel situations it is evident that most of their predictions could not have been retrieved from memory of identical events but were made *in situ* when students presented with them. Students' associated memories of what they perceived as being analogous situations were triggered on seeing these novel situations and these, in turn, provided them with the basis for analysing and making their predictions.

The analogies (SSGA, SGA or explicitly prompted SGA) were seen to provide, as Clement (2008) has suggested, a bridge between the novel situation and a situation already familiar to the student and by reasoning on the basis of the SGA, students made their predictions by directly applying the *same* predictions they would have made in the base situation (SGA) to the novel situation. In Clement's (1988) words, an analogy is accommodating in solving problems as 'one is moving to a more familiar area one knows more about, and one may then be able to transfer part of this knowledge back to the original problem' (p.581).

The SGAs were evenly distributed across all five age groups and the analysis demonstrated no statistically significant correlation between students' age and the generation of analogies in explaining their predictions (Table 3) thus showing that elementary students reasoned on the basis of analogies almost to the same extent as students in secondary education did.

Therefore, irrespective of the age of the students, reasoning on the basis of analogies was found to be a common approach when presented with those novel situations. The self-generation of analogies even by the younger students in this study challenges the view that analogical reasoning is a feature to be found only amongst adolescents (e.g., Piaget, Montangero, and Billeter 2001). Indeed, the use of analogical reasoning by students of all ages in this study supports a constructivists' argument that in order to understand a novel situation, students need to construct a personal interpretation of new information by using prior knowledge and experience (Driver and Bell 1986).

Table 3 goes here

The analogies students, from across all age groups, generated were generally found to have been based on phenomena they had observed in earlier childhood, a fact that became apparent when some of the older students made use of similar analogies from their early childhood that remained unchanged. The following two responses given for the weigh and gravity novel situations illustrate this point:

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.

(S15.1)

I have answered B. It is the one under the box with the elephant [bulb A] that has to switch on first because it has greater mass than the other. If you cut the ropes, then both boxes will fall and the one with the greater mass will fall down first. This is like holding a stone and a small marble in your hands and if you let them go, the stone will go faster. It always goes faster because the weight is greater, just like here.

(S12.5)

The conclusion, in terms of students' reasoning in all six novel situations and across the five age groups, is that the use of student-generated analogies – be they spontaneous, prompted, or explicitly prompted – led them, in most cases, to the same predictions as they were reasoning using the same or very similar analogies.

Self-generated analogies and correct/incorrect predictions

The above findings are indicative of students' reasoning using self-generated analogies (a term we henceforward use to encompass SSGA, SGA and explicitly prompted SGA) that were grounded in their everyday life experiences. They indicate, as the following example shows, that many erroneous predictions appear to reflect the fact that students had either not yet been taught, or were unable to recognise, the relevant scientific knowledge that would be needed to approach these novel situations from a scientific perspective:

If we throw a concrete brick from a rooftop and then a piece of paper, the concrete brick will reach the ground first, because it is heavier and its weight, the gravity, will pull it and it will fall faster, there is more power.

(S13.9)

However, there were some older students (aged 15-17 years) who, whilst reasoning using similar analogies, did manage to make a correct prediction:

I think that both will fall together as there is no air resistance but elephant first if there is. It is like throwing a metal ball and a piece of paper which I have done before. Now in vacuum, in absence of air, the objects will fall simultaneously, and I believe that this is because air in the atmosphere [meaning wind] makes the heaviest objects to fall faster because of the friction. Like paper which is thin and can be carried away by the wind. I have seen that. But in case there is no wind they will both fall together.

(S17.10)

Despite making their predictions on the basis of self-generated analogies in which objects of different mass fall from the same height, the older student was able to make

the correct prediction as having evidently developed a better understanding of both the self-generated analogy and the related scientific knowledge. This factor could potentially explain why older students showed greater aptitude in making the correct prediction because of both their developing understanding of the weaknesses in some analogies and their improved scientific knowledge.

This suggests that the effectiveness of analogical reasoning is mostly based on an individual's knowledge -scientific and/or experimentally grounded, implying that students' ability to reason on the basis of self-generated analogies and reach a correct prediction, advances alongside an individual's conceptual development rather than from a developmental change. Another way to understand older students' greater predictive success in novel situations is that they have experienced a additional experiences from everyday phenomena that can provide a richer source of analogies upon which students can draw. The following example illustrates how such additional experiences can provide the basis for explaining a prediction in a novel situation ('melting ice cube in a glass of water').

What I chose is option B. I can't explain why this is the correct answer, but I know that this is true because I have seen that happening at my family's workplace. My father has a coffee shop. When I am quite late to serve a glass of coffee with ice to the customers, I have noticed that when it melts the level of coffee in the glass does not rise.

(S17.8)

Other studies (e.g., Mozzer and Justi 2011) have also argued that as students mature their cognitive skills develop and experiences expand both of which have the potential to impact positively on the effectiveness of their analogical reasoning.

Younger students (aged 9-12) were also able to reason and make a prediction compatible with the scientific account using self-generated analogies. In the situation of 'burning a candle on a balance', students' experiential knowledge of burning fuels (which, from a scientific point of view contain carbon) proved relevant and useful in understanding this particular situation. In contrast in the novel wire wool situation (which, from a scientific point of view relates to the oxidation of iron), the same analogical reasoning leads unavoidably to an incorrect prediction. Indeed, with this situation, older students did not perform better in terms of their predictions than

younger students due to the fact the oxidation of iron in everyday life is unlikely to be observed and, in addition, the teaching of oxidation of iron and mass increase does not occur in Greece until the end of Year 11 that the oldest students in this study were in.

Conclusions

The use of very similar analogies by students across the five age groups suggests that students' incorrect predictions arose because of their use of inappropriate self-generated analogies. The use of such analogies in prediction making in novel situations supports constructivists' argument that students understand novel situations through a personal interpretation of new information on the basis of prior experiences (Driver and Bell 1986); a construction which, as the study showed, can frequently lead to incorrect understanding of novel situations and phenomena.

However, the results also suggest that such analogies, although frequently leading to erroneous predictions, do have the potential, in some situations, to lead to scientifically compatible predictions and understanding of novel situations that are new and unknown. The study results showcase two factors that, when satisfied, seem to explain why these older students are doing better in making correct predictions on the basis of self-generated analogies. This occurs when students are able to draw better inferences from their analogies to the novel situation because of a better understanding of the scientific knowledge relevant to the analogy and/or the novel situation, and know how, and under what circumstances, the two differ.

Implications

The main implications arising from this study relate to the highly predictable nature of self-generated analogies (regardless of their type) that many students use when presented with a novel situation and the resilience of those analogies to change across a relatively wide age range. Teachers not only need to be aware of students' prior knowledge, but also need to better understand how their students use that prior, often experientially grounded, knowledge, to reason when presented with 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 and provide an insight into the basis of many common misconceptions.

There were also cases in which whilst the older students had been taught the scientific concepts needed to understand the novel situations, they presented predictions that were a synthesis of that scientific knowledge and their everyday experiences. Therefore, self-generated analogies could be utilised as a teaching tool both before and after instruction of a concept as a diagnostic form of assessment. Such analogies, as opposed to traditional summative assessment test of knowledge, could provide insight into the extent to which the scientific explanation had replaced both their prior knowledge and their use of self-generated analogies. That is encouraging students to self-generate analogies and then helping them see why, and how, these contradict with the scientific view could increase conceptual understanding (Coll, France and, Taylor 2005). For example, while teaching burning and combustion, teachers can make these concepts more meaningful to the students by relating and connecting them to their prior knowledge and daily experiences, offering them opportunities to apply the scientific concept in a variety of situations and drawing on these to explain the differences between the burning of carbon made materials and materials of other substance. In the example of the weight and gravity novel situation, in which students' analogies showed that they reasoned on the basis of their experiential knowledge according to which heavy objects fall faster, the teachers could explain why in our daily life lighter objects are seen to fall slower explaining at the same time the role of air resistance and the surface area of the objects falling. In the example of the melting ice cube in a glass of water novel situation, the teacher can productively utilise the student's self-generated analogy of the water level remaining the same and the robust experiential knowledge is founded upon can serve as an instructional tool to introduce the scientific concept and understanding. Thus, in line with Cheng and Brown (2010), an important implication derived from the finding of this study is that students should be allowed, and taught, how to connect their prior knowledge with the scientific concepts.

Given, as Huxley (1894) claimed that, 'all truth, in the long run, is only common sense clarified' (282) it is important for students to be given the opportunity to connect reasoning in science with their common sense since, as the study has found, this is actually the way many of them reason both in, and out of, the classroom.

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