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Students' analogical reasoning in novel situations: theory-like misconceptions or p-prims?

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Abstract

Over the past 50 years there has been much research in the area of students' misconceptions. Whilst this research has been useful in helping to inform the design of instructional approaches and curriculum development it has not provided much insight into *how* students reason when presented with a novel situation and, in particular, the knowledge they draw upon in an attempt to make predictions about that novel situation.

This article reports on a study of Greek students, aged from 10 to 17 years old, who were asked to make predictions in novel situations and to then provide, without being told whether their predictions were correct or incorrect, explanations about their predictions. Indeed, their explanations in such novel situations have the potential to reveal how their ideas, as articulated as predictions, are formed as well as the sources they draw upon to make those predictions.

We also consider in this article the extent to which student ideas can be seen either as theory-like misconceptions or, alternatively, as situated acts of construction involving the activation of fragmented pieces of knowledge referred to as phenomenological primitives (p-prims). Our findings suggest that in most cases students' reasoning in novel situations can be better understood in terms of their use of p-prims and that teaching might be made more effective if teachers were more aware of the p-prims that students were likely to be using when presented with new situations in physics.

1. Introduction

When presented with a situation that students are able to connect to a scientifically familiar situation they are able to identify what they believe to be the appropriate scientific conceptual 'tool' to apply in order to understand it or to make predictions about its future behaviour. Yet when the problem is sufficiently novel that they are unable to connect it to any scientifically familiar situation students draw instead on their personal, everyday, experiences [1]. This process of making comparisons between two situations is a central feature of analogical reasoning which involves a search for similarities between the unfamiliar and the familiar: between what is new and what is already known [2]. In this sense the use of analogies provides a means (albeit possibly an erroneous one) to infer something about a novel situation by drawing on existing knowledge of a familiar situation that *appears to* be similar to the novel situation in some respect.

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AQ2 ### 1.1. Students' ideas as misconceptions

Much of the research on students' misconceptions shows these to be firmly held, resilient to change [3] and appeal to the students on the grounds that they are consistent with their own understanding of the world and have served them effectively as a means to understand, and make predictions about, phenomena they observe in their everyday life [4]. In much of the research conducted on students' reasoning in physics, the term misconception has been used to refer to students' ideas which are in conflict with the scientific account and, being coherent, indeed almost theory like, need to be avoided or replaced in order for scientific understanding to be achieved [3]. However, such an approach has, we believe, led to an overemphasis being placed on the discontinuity of these students' misconceptions with physics concepts, rather than considering how such misconceptions might productively been used as a means for achieving scientific understanding [5].

1.2. Students' ideas as knowledge in pieces

In this respect diSessa's [6] has challenged the view of students having theory-like ideas in the form of misconceptions and has introduced the notion of phenomenological primitives to explain students' reasoning in physics. P-prims are the basic, fine-grained, knowledge elements characterised as phenomenological in that they are minimal abstractions derived from experiences and closely tied to familiar phenomena, whereas they are primitive in that they 'stand without significant explanatory substructure or explanation' (p 15) [7]. In contrast to the misconceptions perspective, which perceives students' ideas as being inherently inconsistent with accepted ideas in physics, and, as such, needs to be replaced, the p-prims perspective acknowledges that there are productive aspects in students' non-scientific knowledge and reasoning that might be used to reach a scientific idea as currently accepted by physics experts. From this perspective learning physics is perceived as a process in which students' non-scientific ideas are developed into physics concepts whilst at the same time acknowledging that these prior non-scientific ideas might continue to coexist for the student alongside scientific concepts and manifest themselves in how students think [7].

For example, the 'maintaining agency' p-prim [3] (which, when activated, leads to an understanding that a *constant force* is needed for any motion to occur/be sustained) may be adapted to promote the scientific view that *momentum* (rather than force) is necessary to maintain motion.

2. The study

The study involved a sample of 166 Greek students ranging in age from 10 to 17 years old. A mixed method approach was used with data being collected through the administration of a paper and pencil survey followed by focus group discussions. In the paper and pencil survey students were asked to make predictions about six novel situations and then provide explanations about their predictions. All of the situations were novel, in the sense that it was unlikely that they would have encountered that situation in the form presented prior to this study and had been drawn from previous research on misconceptions. These situations were presented to the students in a pictorial form so as to be accessible across a wide age range irrespective of reading age and also to avoid providing any kind of lead in terms of the selection of one particular option from those listed in the accompanying multiple choice question. In these questions students had to make a prediction about the outcome of a future event (effectively what would happen in the event depicted in the novel situation). Indeed, this approach has been used as it has been suggested that students' thinking about novel situations can be made accessible to the researcher when they are asked to explain their ideas/beliefs [8]. For more details about the study sample, and the research methodology, see our previous work [1, 9].

Two of these six novel situations, that were used to examine students' ideas about gravity, are presented here. In the first situation (figure 1) students' ideas about falling objects, in which it has been reported [10] that many students harbour misconceptions from a very young age, were examined. In the second situation (figure 2) students' ideas about gravity, in terms of its acting 'downwards', were it has previously been reported that students have a person-centric misconception of down (rather than an Earth-centric one) from early childhood [11], were examined.

2.1. Free falling objects

The majority of the students (144/166) in this novel situation erroneously predicted that the bulb beneath the box containing the elephant

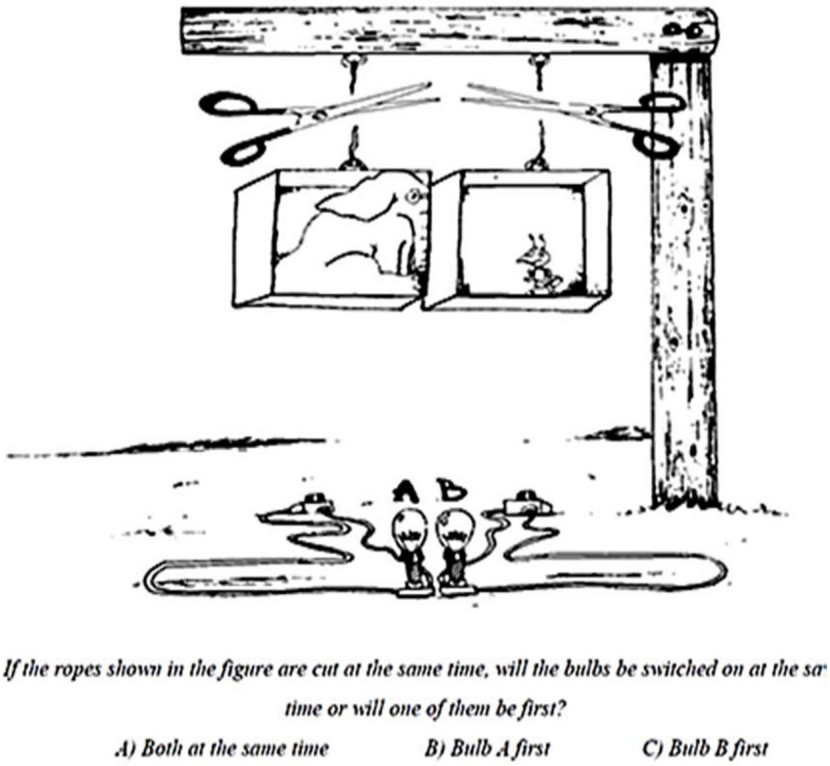

Figure 1. Weight and gravity novel situation.

switches on first. Many of these students (84/144) explained that they were led to their predictions by generating their own analogies without being prompted in any way by the researcher. For example, a 14 year-old wrote:

> *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 the elephant and has greater mass will fall down first. I believe that this is like throwing from the top of a roof a dumbbell and a feather, the dumbbell always falls faster. This happens because the weight is greater and that means it should go faster.*

The above quote illustrates how many of the analogies that emerged in students' explanations were generated from their own personal, everyday, experience. Similar, and in many cases identical, explanations were obtained from students across the entire age range.

A total number of 116 students articulated in their explanations a rather common idea identified in the literature according to which heavier objects fall faster. From the misconceptions perspective this idea is seen to be a stable knowledge structure which directly relates the time, speed and acceleration of a falling object with its mass constituting, in this way, an incorrect idea and a misunderstanding of free fall. In contrast diSessa has argued that such predictions occur as a consequence of a knowledge element in that has been termed the Ohm's p-prim [6]. This p-prim proposes that 'the stronger the agency, the greater the effect' (p 104) [3] and with the agency, in this case, being the mass of the object the activation of the Ohm's p-prim would be expected to lead to a prediction that the heavier an object is, the faster it falls. Such an explanation can also arise as a result of an even more basic p-prim, that of 'the more x, the more y' (p 147) [6], that would again lead to a prediction that the heavier object would move faster. These p-prims, arising as they do from abstractions of many similar everyday experiences, provide the familiar basis from which the student, as the above quotation exemplifies, was then able to generate the analogy that they used in order to make their prediction.

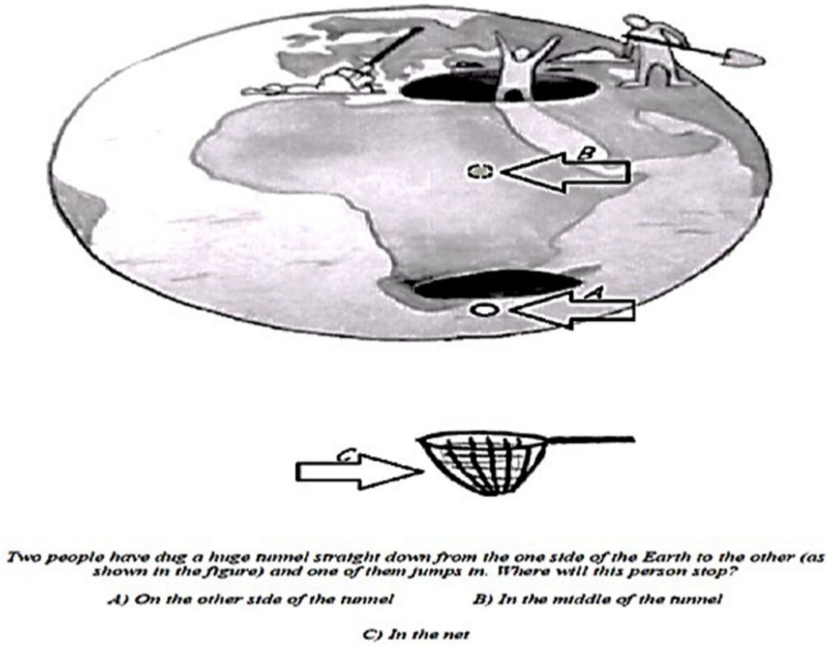

Figure 2. A person falling through a hole dug through the Earth.

Whilst these p-prims are not wrong per se they do have the potential to lead to incorrect predictions if they are used outside their range of legitimate applicability. In this case, for example, both the p-prims, and the idea of heavier objects falling faster, are correct in an environment in which there is friction. Indeed, this fact could be used by the physics teacher to help students understand why, in their everyday experience, heavier objects are frequently observed to fall faster than lighter objects and what is different if air resistance is neglected as was the case in this novel situation in which students were asked to ignore it. In this sense, both the analogical reasoning and the idea of heavier falling faster could be productively used to help lead students towards a scientific understanding of free fall. Teaching approaches like that suggested by Pendrill *et al* [12], in which experiments of different pairs of objects being dropped are filmed and then students discuss any detected differences, could help students understand the differences between objects falling with and without air resistance.

2.2. Gravity and downwards direction

The most common predictions in this study (147/166 students) were that the person would either fall into the net or that they would stop on the other side of the tunnel. From a misconceptions point of view both predictions reflect a view of 'down' that it has been reported arises from a misconception about the shape of the Earth [11].

However, as the figure above shows, students in this study were presented with an image of the Earth as a sphere and even the younger students (aged 10 years) appeared to already know that the Earth is spherical.

Rather than seeing students predictions here as arising from a misconception about the shape of the Earth the alternative, from a p-prim perspective, can be understood as arising because 'a determined path directly causes an object to move along it' (p 220) [6]. This p-prim, along with all others, is formed from repeated observations of what are perceived to similar situations such as that of how a train follows a rail track, or how a ball follows the predetermined path if dropped down a tube. Indeed, there were students in this study who explained their predictions in this novel situation on the basis of such analogous situations such as, for example, a 15 year-old student who wrote:

> *I believe that the person will stop in the net, because the tunnel is vertical and has no obstacles. Thus, when he will fall, he will stop in the net, which is located right*

beneath the tunnel in which he jumped in. Like when we let a basketball ball to fall in the nets. It is always the kid standing underneath the net who catches the ball, not any other kid around him.

Similar reasoning was provided by almost half of the students (73/147) across the whole age range who made these two particular predictions (in the net or on the other side of the tunnel) and, as was the case with the previous novel situation, not only was the students' reasoning similar but so too were the analogies they used (others referred to a ball coming through a tube or even water coming through hoses). Such examples illustrate that students can sometimes be led to make incorrect predictions in novel situations because they drew on incorrect analogies that they had formed from phenomena they had previously observed in their everyday life.

There were however some students (19/166) who made the correct prediction of the person stopping in the middle of the tunnel. Amongst them, a 17 year-old student wrote:

I think the person will stop in the middle of the tunnel. It is not possible for him to stop neither on the other side nor in the net and this is like people who live in both sides of the Earth. People who are located at the other side of the world, let's say in Australia, do not fall and the same happens with people who live in the upper side of the Earth like Canada or North Pole. There is something in the centre that keeps them and that is why I answered B.

Such students evidently searched their knowledge and experience in a different way tothe majority of students who made an incorrect prediction. Their different way of thinking led them to a correct prediction and a correct understanding of the novel situation. Our findings suggest that such reasoning is the exception rather than the rule and it would be overly ambitious to expect students, as currently taught, to reason in a similar way more frequently. We suggest that if physics teachers better appreciate the type of *reasoning* students will use they might better formulate questions about such novel situations and conduct follow-up discussions using these p-prims as a way of introducing the notion of Earth's gravity as always being directed towards the centre of the Earth.

3. Conclusion

Our findings suggest that students' ideas can be better understood not as misconceptions that can be considered as being theoretically grounded but rather as spontaneous constructions based on analogies which, in turn are derived from their prior knowledge and experiences. The analogies were generated *in situ* when students were trying to explain and understand a novel situations they were presented with. Indeed, in both of the novel situations discussed above, their origins and widespread prevalence across the whole age range within our sample is best understood as arising from the fact that the majority of students reasoned on the basis of the same, or very similar, analogies.

What has emerged from this study is that p-prims provides a more plausible and systematic approach to interpreting and understand the ideas students involved in the explanations of the predictions they made. p-prims also offered an understanding of the origins of these ideas as well as their connection to the way that students reasoned in order to make and explain their predictions. Few would doubt that 'flipping from the misconceived view to the correct view' (p 10) [13] is difficult to achieve. Whilst from a misconceptions perspective there was nothing scientifically correct within the students' ideas or reasoning, the use of p-prims provides a means by which students' ideas could be productively used by a teacher in helping lead students towards the correct physics concepts. This way, we see p-prims perspective as offering a different orientation toward student learning and a productive account on how the change from students' ideas to physics concepts occurs as well as what happens to the prior non-scientific ideas.

One example of this might be how teacher could utilise certain aspects of the idea that many students have that heavier objects fall faster than lighter ones, rather than trying to replace it in its entirety, by focusing to a greater extent on significant role that resistance has in determining which objects fall faster. For example two identical sheets of paper, of which one is crumpled up into a tight ball, can be simultaneously dropped from the same height and students are *not* surprised that the crumpled one researches the ground first. If a small piece of paper is subsequently crumpled and dropped next to an uncrumpled larger sheet (with a greater mass) the students are again not surprised that the lighter, crumpled, sheet falls faster. Such an approach gets them to recognise that whilst heavier objects often fall faster than lighter object in air this is not always the case. Helping students recognise *why* they think that heavier things fall faster than light ones i.e. helping them to understand their everyday experiences such as leaves and feathers falling slowly whilst apples and stones fall rapidly helps them to understand *why* in the case when air resistance is excluded science tell us that heavy and light objects fall at the same rate.

At the same time, we suggest that analogies should be utilised more in education and should go beyond their didactic aim—i.e. teachers providing ready-made analogies to the students to support and facilitate the learning of concepts. Indeed, we argue that analogies can be used both as a diagnostic form of assessment for the identification of students' incorrect ideas which challenge the learning of physics concepts. Similarly, students' analogical reasoning could be used for what has been described in the literature as metaconceptual awareness [14] with teachers giving their students the opportunity to reason about new situations after they have taught the physics concepts in order to assess how these are embedded in students' existing ideas.

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References

[1] Fotou N and Abrahams I 2015 Students' reasoning in making predictions about novel situations: the role of self-generated analogies *2013 Conf. Insights from Research in Science Teaching and Learning, Book of Selected Papers from the European Science Education Research Association (ESERA)* ed N Papadouris *et al* (Berlin: Springer)
[2] Kim M and Choi K 2003 Access to structural similarity in the analogical problem solving of children *Sch. Psychol. Int.* **24** 218
[3] Hammer D 1996 Misconceptions or p-prims: how may alternative perspective of cognitive structure influence instructional perceptions and intentions? *J. Learn. Sci.* **5** 97
[4] Sanger M J and Greenbowe T J 1997 Student misconceptions in electrochemistry: Current flow in electrolyte solutions and the salt bridge *J. Chem. Educ.* **74** 819
[5] Hammer D 2000 Student resources for learning introductory physics *Am. J. Phys.* **68** S52
[6] diSessa A A 1993 Toward an epistemology of physics *Cognit. Instr.* **10** 105
[7] diSessa A A 1983 Phenomenology and the evolution of intuition *Mental Models* ed D Gentner and A L Sevens (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 15–34
[8] Moore T and Harrison H 2004 Floating and sinking: everyday science in middle school *Annual Proc. of the Australian Association for Research in Education*
[9] Fotou N 2014 Students' predictions in novel situations and the role of self-generated analogies in their reasoning *Unpublished Doctoral Thesis* University of Leeds, UK
[10] Kavanagh C and Sneider C 2006 Learning about gravity I. Free fall: a guide for teachers and curriculum developers *Astron. Educ. Rev.* **5** 21
[11] Vosniadou S and Brewer W F 1992 Mental models of the Earth: a study of conceptual change in childhood *Cogn. Psychol.* **24** 535
[12] Pendrill A M, Ekström P, Hansson L, Mars P, Ouattara L and Ryan U 2014 The equivalence principle comes to school-falling objects and other middle school investigations *Phys. Educ.* **49** 425
[13] Brown D E 2010 Students' conceptions-coherent or fragmented? And what difference does it make? *Paper Presented at the Annual Meeting of the National Association for Research in Science Teaching (Philadelphia, PA)*
[14] Vosniadou S and Ioannides C 1998 From conceptual development to science education: a psychological point of view *Int. J. Sci. Educ.* **20** 1213

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