Article begins on following page.

Please note:

Copyright Agency Limited (CAL) licensed copy. Further copying and communication prohibited except on payment of fee per Copy or Communication and otherwise in accordance with the licence from CAL to ACER. For more information contact CAL on (02) 9394 7600 or info@copyright.com.au

The use of magnets for introducing primary school students to some properties of forces through small-group pedagogy

By Rebecca Carruthers and Kevin de Berg

Seventeen Grade Six students were divided into small groups to study the concept of forces in the context of magnets and their properties. The researcher, a pre-service primary school teacher, encouraged the students into conversation about magnets and it was found that, without hesitation, they talked about their prior experience of magnets. The words, 'pushing' and 'pulling', endemic to an early introduction to the notion of force, were used spontaneously by the students when referring to the repulsion and attraction properties of magnets. In conversation, the students were prepared to make claims or hypotheses about magnet behaviour and often sought evidence for these. This study indicates that, given the right context, the rudimentary elements of argumentation can be appropriated naturally by children. In this paper, the focus is on the push-pull character of forces and the fact that forces appear to interact in pairs.

Introduction

This paper relates the experiences of a pre-service primary school teacher who developed a strategy of small-group pedagogy for introducing the concept of force to a Grade Six primary school class as part of her honours project. The concept of force was chosen because of its importance in the primary school science curriculum and its interest to the pre-service teacher. Magnets were chosen as the medium for introducing the topic as it was expected that most students would have had some prior tactile experience of pushes and pulls when playing with magnets (Heywood & Parker 2001; Reiner & Gilbert 2004). While not all primary science curricula suggest the use of magnets for the topic of force, we suggest in this paper that there are some distinct advantages in using magnets for introducing this topic. Prior experience has been recognised for some time now as being an important factor in the learning experience (Driver 1983, p.76), and teachers have been encouraged to take account of it when designing learning experiences for children.

Small-group pedagogy was chosen as the learning and teaching strategy because of its capacity to stimulate conversations with children which helped link everyday concepts to scientific concepts and vice versa, strengthening both in the process (Yuruk, Beeth & Andersen 2009; Segal & Cosgrove 1993; Fleer 2009). The scientific literacy movement also encourages such conversations to include not only scientific knowledge, but also how that knowledge is validated. Central to this process is one's use of evidence and argument in mandating a particular claim to scientific knowledge. In fact, one teacher education programme in the USA (Zembal-Saul, 2009) builds its whole elementary school science programme on the framework of argumentation, in the strong belief that,

> *early attention to evidence and argument can leverage consideration of other important features of science instruction* (p.714).

So, small-group pedagogy was considered to be a manageable proposition for a pre-service teacher who was interested in looking at ways in which primary children reason about forces in a context in which they were encouraged to ask questions, make claims as to what they thought was happening in a situation, and consider what type of evidence was available to stake their claims. Sampson and Clark (2009) summarise the variety of frameworks that have been used for studying argumentation. In our study we focus on only the most rudimentary elements of argumentation, such as the making of *claims* to scientific knowledge and the *evidence* provided for them. Conversations, of course, can take place in whole-of-class discussions but there are likely to be more of them in smaller groups and shy students are more likely to participate when the atmosphere is not quite so confronting. Pre-service teachers also find it easier to hone their organisational and discipline skills with small groups.

We continue with a brief review of the literature on children's understanding of 'force'; a profile of the students who participated in the study; the methodology used to support small-group conversations; and a report on student conversations and how they articulated the operation of magnets and the associated concepts of force.

Children's Understanding of Force

Common student conceptions of force and motion are well summarised by Alonzo and Steedle (2009) from their study of the literature. This summary is used by them to develop what they call a 'learning progression', which they broadly define as an *ordered description of students' understanding of a given concept* (p.390). They stress that learning progressions are subject to change as our knowledge of children's' understanding changes, but can still be a useful guide for assessment and curriculum development. As far as the concepts of force and motion are concerned they suggest four levels students might be expected to traverse as they negotiate the learning experiences of their formal education. We are particularly interested in the first level description, which presumably will be

most applicable to primary school students. This level is described as *the student understands force as a push or pull that may or may not involve motion* (p.405). This description resonates with the way in which both the English curriculum (Qualifications and Curriculum Authority (QCA) 1999) and the Primary Connections curriculum (Department of Education, Employment and Workplace Relations (DEEWR 2008) describe force at this level. The learning progression proposed by Alonzo and Steedle also lists four common errors that have been found in children's conversations about force at this level. These are:

> *Forces are caused by living things; Force is an internal property of objects related to their weight; Forces prevent the natural movement of objects; Objects cannot move in the absence of friction.* (2009, p.405)

To the best of our knowledge, children's understanding of force in the context of magnetism has not been reported in the research literature but yet, in our thinking, magnets potentially offer some significant advantages over typical mechanical equipment for dealing with some of the fundamental ideas of force. The idea of 'push' and 'pull' should be evident in the repulsion and attraction modes of permanent magnets, and the idea that forces occur in pairs can be elegantly illustrated by successively holding one of two magnets, each in turn, and observing its effect on the other. While the idea that forces exist in pairs has been emphasised by some researchers (for example, Driver, Squires, Rushworth & Wood-Robinson 1994, p.151; Brown & Clement 1987 p.39), it has not been focused on as a fundamental concept in other research literature. However, we believe that magnets can be a very useful way of introducing this fundamental idea, so our research agenda was to assess two things:

1. The ease with which children would talk about the push-pull and pair-wise interaction feature of forces in the context of magnet play; and

2. The extent to which children would be driven to make claims about forces, and the evidence provided to support such claims, when playing with magnets.

Student Profiles and Methodology

Seventeen Grade Six students (nine males and eight females aged from 10 years 10 months to 12 years 3 months) from an Australian State primary school of about 500 students participated in this study. With the help of the supervising teacher, the seventeen students were divided into four focus groups. Three of these groups contained four students and one group contained five students. All the groups were either all male or all female. Each focus group was given the opportunity to play with and observe the behaviour of two permanent bar magnets. They were then asked by the pre-service teacher to focus on five questions (see Figure 1). Each focus group was also given the opportunity to play with and observe the behaviour of one permanent bar magnet and a peg with a metal spring. They were then asked to focus on four more questions (also shown in Figure 1). Each group participated in two sessions of about 30 minutes each. All the proposed questions were reviewed by two physicists for validity and trialled with a group of six students from the same school, who had almost completed Grade Six in the year prior to the research. Minor adjustments produced the questions shown in Figure 1.

The focus group sessions were small group discussions surrounding a physical practical activity. These oral/

a. Children experience playing with two magnets
   (i) Bring the magnets closer together. What do you feel?
   (ii) Why do you think this happens?
   (iii) Was there a force between the two magnets?
   (iv) Is magnet A exerting a force on magnet B?
   (v) Is magnet B exerting a force on magnet A?

b. Children play with one magnet and a peg with a metal spring
   (i) If you bring the magnet closer to the peg, what happens?
   (ii) Was there a force between the magnet and the peg?
   (iii) Was the magnet exerting a force on the peg?
   (iv) Was the peg exerting a force on the magnet?

Figure 1: Question-activity plan for a focus group session with magnets

practical sessions were thought to generate rich data from this group of children, even though paper and pencil tests and individual interviews had commonly been used with the older students in previous studies. The oral discussion of ideas is an important step in developing scientific thinking because as students listen to the ideas of others, and are forced to consider their own ideas more deeply when questioned, it is often necessary for them to change their own predictions about a situation (Cosgrove & Osborne 1985; Tasker & Freyberg 1985; Woods 1994). Thijs (1992) chose to include group discussion in his research. based on the expectation that *interpersonal interactions and conflicts are stimulants for a student's conceptual change* (Thijs 1992, p.167). Hake (1998) noted that interactive-engagement was a more effective strategy than traditional teaching methods in enhancing problem-solving ability. Recorded and subsequently transcribed oral discussion also enables a teacher-researcher to identify opportunities the children took to make a knowledge claim; what, if any, evidence they provided for it; and whether they gave any justification for this evidence. That is, the oral transcriptions helped to determine whether the conversation contained the rudiments of argumentation. Recording these opportunities can greatly influence a teacher's own professional development. The teacher-researcher kept a reflective journal which commented on any opportunities for enhancing cognitive growth taken (or not taken) during the focus group sessions.

The style of the group sessions was built around the five Primary Connections phases of learning: *Engage, Explore, Explain, Elaborate, and Evaluate* (DEEWR 2008). The first focus group session for each group concentrated on engaging and exploring, whilst the second session concentrated on explaining, elaborating and evaluating. However, in practice, some explaining and elaborating might have occurred in the first session, depending on student responses. It was in the second group session that students were introduced to science as a special way of studying the world and the ideas expressed in the first session were built upon to achieve some understanding.

We now turn to the research findings:

Research Findings and Discussion

During the first group sessions students were given the opportunity to hold and feel the attraction and repulsion of two bar magnets and to describe what they were experiencing. Students were questioned as to whether a force existed between the two magnets and were then asked to isolate the action of each magnet. Students were also questioned about the

interactions of a bar magnet and a small plastic peg with metal fastenings. This questioning uncovered some students' ideas regarding how it is possible to detect the presence of a force within a system, and also the ways in which forces act within a system. When these comments are quoted in the following discussion, T-R refers to Teacher-Researcher.

Prior Experience and the Push-Pull Feature

What became clear during the group sessions was that the students were very familiar with the action of magnets and felt free to describe some of their experiences:

> Megan: *I used to have these really big ones (magnets) in a tool box, or my Pop had one...*
>
> T-R: *Mmm*
>
> Megan: *In his tool box and all his tools stuck to it.*
>
> Abby: *Usually they (magnets) go together 'cos I've got really strong ones at home. You put them this far apart and let them go and they go together.*

When asked to indicate what could be felt when moving the magnets close together, a number of students labelled the attracting or repelling sensations as 'force':

> Ally: *I can feel force.*
>
> Dale: *It's got like, force, and it brings it together.*
>
> Mark: *All I could feel was probably the force.*
>
> Julie: *It's like a force.*

Others used terms such as magnetism, pressure, power, and strength to describe the sensation. The student responses were spontaneous because of the tangible sensation of the interacting magnets and some students had no hesitation in identifying this sensation as a force although, understandably, not in the richest of scientific language. What is interesting is that a number of the students described the feeling of these forces as 'pushing' and 'pulling' before any formal definition of force as a 'push' or a 'pull' had been discussed in the second group session:

> T-R: *What can you feel Bree?*
>
> Bree: *Um, them pulling together.*
>
> Dale: *It is force. It's pushing it (the magnet) away.*

On other occasions, when part of the push-pull concept had been suggested by the teacher-researcher, students readily identified the other part of the concept, as illustrated below:

> T-R: *Did it…Was it (the magnet) pulling?*
>
> Jackson: *Yeah, and pushing.*
>
> Glenn: *No…pulling.*
>
> Darren: *Pulling and pushing - depends on which side you put it (the magnet) on.*

When queried as to why magnets can push or pull, three possibilities featured in the discussion. These related to North and South poles, positive and negative charge, and the presence of a special metal:

> Bree: *Um, well once, like ages ago, we were talking about magnets and someone said that one has North and the other has South.*
>
> Julie: *It's like… Ah, negative and positive up against it and it's like, the other way is positive and positive.*
>
> Megan: *Um, because they have a special metal inside, and it makes them go together.*
>
> Ally: *Like one would be normal metal and the other might be titanium, stainless steel, or that sort of thing.*

The students' ideas are obviously not well-developed but, as described by Halloun and Hestenes (1985) and Hestenes, Wells, and Swackhamer (1992), students tend to use their prior experiences in making sense of the world. Thinking of a magnet as being constructed of a special metal; or possessing a north and a south pole; or possessing positive and negative charges does correlate with the students' spontaneous reference to magnets as possessing a force:

> Megan: *I reckon this (the peg) has some force.*

Gunstone and Watts (1985) suggest that students tend to view the world in an anthropomorphic manner. Consistent with this idea, the students in our study showed a tendency to describe objects and phenomena in terms of human characteristics and attributes. In describing the actions of the two magnets in relation to one another, students gave responses such as the following to describe attraction:

> Megan: *Like they (the magnets) want to be together.*
>
> Paige: *They're best friends.*

In the case of the magnet and the peg, Fred identifies the presence of an attractive force as follows:

> Fred: *Because the magnet wants to get to the peg.*

Interacting Pairs of Forces

All students correctly believed that a force existed between the two magnets, although they were still comfortable with the idea of a magnet possessing force. When asked if magnet A exerted a force on magnet B and magnet B exerted a force on magnet A, students originally identified only one magnet as exerting a force. However, in the case of several of the groups, the conclusion was finally reached that there was in fact a force exerted by both magnets. One group gave the following responses:

> T-R: *Do you think that magnet B is exerting a force?*
>
> Darren: *Uh, no.*
>
> T-R: *No? You guys just reckon that magnet A is exerting a force?*
>
> Darren: *I reckon both.* [Claim]
>
> Glenn: *No, it can't be both Darren...Oh, wait...* [Counter Claim]
>
> Darren: *Both.* [Claim]
>
> Glenn: *Oh, because they have separate sides.* [Evidence]
>
> Darren: *Yeah. I reckon it is both because if you put one [magnet A], here and you had this one [magnet B] here, like close enough, it will suck [attract] that one that way and if you turn...if you do it the other way.....*[Counter evidence]

In the above example the student, Darren, was demonstrating that if magnet A is fixed in position, magnet B will move towards it, and if magnet B is then fixed, magnet A will move towards it. Students were

willing to make counter claims and also offer evidence to back their claims, even if the evidence was not substantial. Students in another group responded as follows:

> T-R: *Is magnet A exerting a force on magnet B?*
>
> Mark: *Yes, it is a pulling force.*
>
> T-R: *OK.*
>
> Nick: *A is pulling it.*
>
> Dale: *B could be pulling A.* [Claim]
>
> Phillip: *A is pulling B because I can feel it.*
>
> T-R: *Is B pulling A too?*
>
> Students: *Yes.*
>
> Gavin: *Sometimes, but....*
>
> Nick: *Like if you have it one way, A will pull B, and if you have it the other way, B will pull A.* [Evidence supporting Dale]

This time a claim, and the evidence supporting that claim, were made by different students.

Thijs (1992, p.167) suggests that *it is also to be expected that interpersonal interactions and conflicts are stimulants for a student's conceptual change*. Discussion and conflict between students requires them to explain and often re-think their conceptions and hence is a useful exercise in the teaching and learning of scientific ideas (Eryilmaz 2002). When students are required to think about their own conceptions and learning, it is possible for them to devise their own examples and theories. This is evident in the two recorded group discussions above.

Students generally agreed that a force existed between the magnet and the peg but when questioned more deeply about this scenario the clear majority of students indicated that they did not believe that the metal in the peg was exerting a force on the magnet, but rather that all the force in this system could be attributed to the magnet:

> Darren: *Only the magnet is making force to pull the peg.*

When the peg was fixed in place the students observed that it did attract the magnet, but only when the magnet was brought very close to the peg:

> T-R: *And the magnet jumped over to be with the peg.* [Evidence]
>
> Glenn: *The magnet didn't do it.* [Disputing the evidence]
>
> Jackson: *The magnet did.* [Confirming the evidence]
>
> Darren: *Which meant that the magnet had put some stuff inside the, magnetic force inside the peg.*

A small number of students responded in partial favour of the understanding that both objects within the system exert a force of some degree on the other. When asked whether the small metal peg was exerting a force on the magnet, Chelsea and Glenn gave the following response:

> Chelsea: *Sort of because it's got a magnet in itself because of the metal, but it doesn't really have it because it's only got a little charge.*
>
> Glenn: *Oh, it does, but only a small one.*

In the case of the two equivalent magnets the fact that both exerted a force was relatively easy to demonstrate in that each magnet was able to move the other magnet. This was more difficult to demonstrate in the case of the magnet and the peg because of their different sizes. One student came up with the following example, demonstrating an intuitive understanding that larger objects require more force to move them:

> Glenn: *No, but if you had a cupboard like that [motions to the large metal cupboard in the room], you could put the magnet near it, and the magnet would go to the cupboard, but the cupboard would not come to the magnet.*
>
> T-R: *Why?*
>
> Glenn: *Because it (the cupboard) is too big.*

In direct relation to the magnet and peg example, Julie gave the following example demonstrating this understanding:

> Julie: *But it doesn't do as much because the magnet is more heavier (sic) than the peg. And the peg can't really handle the weight.*

It is when students begin to show these signals of understanding that teachers have a great opportunity to enhance cognitive growth.

In three of the groups one of the students wanted to know precisely how you could tell if the peg was exerting a force on the magnet:

> Darren: *Is that the way you test which one has force or whether they both exert a force?* [Checking nature of evidence]
>
> Nick: *How is the peg exerting a force?* [Calling for evidence]
>
> Paige: *How can you tell that like, the peg does and doesn't* (exert a force)*?* [Calling for evidence]

We classify these questions as critical because they focus on the heart of the issue of identifying the duality of forces. If one fixes the magnet close to the peg, which is free to move, the magnet pulls the peg. If one fixes the peg and holds it close to the magnet, which is free to move, the peg pulls the magnet. In Darren's case he had followed this procedure with the two magnets and was asking if one could use the same procedure in the case of the magnet and peg. In Nick's case another student answered the question for him:

> Nick: *How is the peg exerting a force?* [Calling for evidence]
>
> T-R: *Well, have a think about it.*
>
> Mark: *It (the peg) is pulling it (the magnet).* [Gives evidence]
>
> T-R: Do you remember when we moved the peg closer to the magnet?

In Paige's case, after asking the question, she arranged the peg and magnet so that the peg was fixed and the magnet free to move. She then declared:

> Paige: And I found out that the peg actually can pull the magnet. [Evidence]

The case of deciding whether the peg would pull the magnet proved to be a discrepant event for some students:

T-R: What if I let the magnet move but hold the peg in the same spot? Do you think it will pull the magnet?

Students: No [Claim]

Glenn: Cos it hasn't got the….

Darren: Because it hasn't got enough magnet on the….

Fred: Magnetic force [Reason]

Glenn: yeah.

T-R: (holds the peg and moves it closer to the magnet, which is free to move)

Glenn: Oh, it does…but only a little one. [Counter evidence]

Students then suggested that if the magnet was smaller, or the peg was larger, the peg would be better able to move the magnet. The fundamental idea of forces acting in pairs was reinforced by this phenomenon.

Students naturally spoke of objects 'having force' on many occasions, although they also began to adopt the idea of force as an action between objects. For example, Dale said, *I reckon force is in both (peg and magnet)*. While it may not be initially appropriate to bring this to the attention of the students, it will be important eventually for them to use the appropriate terminology for 'force' in a scientific context; that is, to encourage students to think in terms of the magnet attracting the peg and the peg attracting the magnet.

When the teacher-researcher moved a magnet closer and closer to the peg, Paige hypothesised that the magnet would push the peg away:

T-R: If I have that (the peg) there and I bring the magnet closer and closer and closer…

Paige: It'll (the magnet) push it (the peg) away. [Hypothesis] Oh….[when she sees that the magnet attracts the peg] It (the magnet) pulls it (the peg) in. [Counter evidence]

The small group activity provided a great learning opportunity for Paige and the other girls in her group. Small focus group sessions created a positive framework for enhancing understanding of many fundamental concepts relating to the idea of force.

Conclusion

We conclude from this study, in answer to the two research questions posed, that students will spontaneously identify the pushing and pulling nature of forces when using magnets. The dual nature of interacting forces is a somewhat more difficult concept, but students willingly engage in making claims and offering evidence for them when playing with magnets. In the context of small groups one student can sometimes make a claim and then another student offer evidence to support that claim. On other occasions the claim and evidence are both provided by the same student. We suggest that this kind of activity provides a firm foundation for more sophisticated reasoning in later years.

References

Alonzo, A.C. & Steedle, J.T. (2009). Developing and Assessing a Force and *Motion Learning Progression. Science Education*, 93(3), 389-421.

Brown, D.E. & Clement, J. (1987). Misconceptions Concerning Newton's Law of Action and Reaction: The Underestimated Importance of the Third Law. *Proceedings of the Second International Seminar on Misconceptions in Science and Mathematics*, 111, 39-53.

Cosgrove, M. & Osborne, R. (1985). Lesson frameworks for changing children's ideas. In R. Osborne & P. Freyberg (Eds.), *Learning in science. The implications of children's science* (pp.101-111). Auckland: Heinemann Education.

Department of Education, Employment and Workplace Relations (DEEWR). (2008). *Primary Connections - Linking science with literacy*. Retrieved September 29, 2008, from the Australian Government website: http://www.science.org.au/primaryconnections/additional.htm

Driver, R. (1983). *The Pupil as Scientist?* Milton Keynes: Open University Press.

Driver, R., Squires, A., Rushworth, P. & Wood-Robinson, V. (1994). *Making sense of secondary science*. London and New York: RoutledgeFalmer.

Eryilmaz, A. (2002). Effects of Conceptual Assignments and Conceptual Change Discussions on Students' Misconceptions and Achievement Regarding Force and Motion. *Journal of Research in Science Teaching*, 39(10), 1001-1015.

Fleer, M. (2009). Understanding the Dialectical Relations Between Everyday Concepts and Scientific Concepts Within Play-Based Programs. *Research in Science Education*, 39(2), 281-306.

Gunstone, R. & Watts, M. (1985). Force and Motion. In R. Driver, E. Guesne & A. Tiberghien (Eds.), *Children's ideas in science* (pp.85-105). Milton Keynes: Open University Press.

Hake, R.R. (1998). Interactive-Engagement Versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses. *American Journal of Physics*, 66(1), 64-74.

Halloun, I.A. & Hestenes, D. (1985). Common sense concepts about motion. *American Journal of Physics*, 53(11), 1056-1065.

Hestenes, D., Wells, M. & Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher*, 30, 141-157.

Heywood, D. & Parker, J. (2001). Describing the Cognitive Landscape in Learning and Teaching about Forces. *International Journal of Science Education*, 23(11), 1177-1199.

Qualifications and Curriculum Authority. (1999). National Science Curriculum *England and Wales Key Stages 1 and 2*. Retrieved October 1, 2008, from the website: http://curriculum.qca.org.uk/key-stages-1-and-2/subjects/science/

Reiner, M. & Gilbert, J.K. (2004). The Symbiotic Roles of Empirical Experimentation in the Learning of Physics. *International Journal of Science Education*, 26(15), 1819-1834.

Sampson, V. & Clark, D.B. (2009). Assessment of the Ways Students Generate Arguments in Science Education: Current Perspectives and Recommendations for Future Directions. *Science Education*, 92(3), 447-472.

Segal, G. & Cosgrove, M. (1993). 'The sun is sleeping now': Early Learning About Light and Shadows. *Research in Science Education*, 23, 276-285.

Tasker, R. & Freyberg, P. (1985). Facing the Mismatches in the Classroom. In R. Osborne & P. Freyberg (Eds.), Learning in Science: the Implications of Children's Science (pp.66-80). Auckland: Heinemann Education.

Thijs, G. (1992). Evaluation of an Introductory Course on 'Force' Considering Students' Preconceptions. *Science Education*, 76(2), 155-174.

Woods, R.K. (1994). A Close-up Look at How Children Learn in Science. *Educational Leadership*, 51(5), 33-35.

Yuruk, N., Beeth, M.E. & Andersen, C. (2009). Analyzing the Effect of Metaconceptual Teaching Practices on Students' Understanding of Force and Motion Concepts. *Research in Science Education*, 39(4), 449-475.

Zembal-Saul, C. (2009). Learning to Teach Elementary School Science as Argument. *Science Education*, 93(4), 687-719. TS

About the Authors:

Rebecca Carruthers recently completed the BEd(Primary Honours) degree at Avondale College and is currently a primary school teacher in South Australia.

Kevin de Berg is an Associate Professor in the Faculty of Science & Mathematics at Avondale College and is the Director of the Avondale Centre for Interdisciplinary Studies in Science (ACISS).