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Contents

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Editorial

There have always been tensions in the early years science curriculum. One source of tension arises because of the different ages that children are when they start formal education, and move away from learning about the world around them through informal play and exploration (see, for example, EURYDICE at NFER, 2013). Children in some countries learn through informal play and exploration up to 7 years of age (e.g. within Europe, Finland, Sweden and Latvia and, worldwide, Brazil and South Africa). Others start compulsory education as early as 4 years of age (Northern Ireland) or 5 years of age (e.g. Malta, Cyprus, Australia and Argentina) and can have more formal classes before compulsory education begins (e.g. in England, Scotland and Bulgaria). Most children begin school education at 6 years of age (e.g. Austria, Belgium, France, Germany, USA, Canada, China, Russia), but can have more formal experiences before compulsory education begins. The trend is also for early years education to be earlier and earlier, so Hungary are set to make kindergarten compulsory for children of 3 years of age from 2014 (EURYDICE at NFER, 2013). As children move into more formal education, there is often a loss of scientific learning and development that is child-initiated, stemming from their curiosity about the world around them. There is a danger that science becomes less awe-inspiring and relevant for children.

Another tension exists because of the difference in scientific knowledge and scientific pedagogical knowledge between professionals working with pre-school children and those in compulsory education. This may mean that, for some early years professionals with insecure scientific knowledge, it is difficult to support the development of children whose curiosity takes them into unfamiliar concepts and leads them to ask challenging questions. There are many differences that exist between the training of professionals and teachers for work in pre-school and compulsory school, but understanding of scientific development and learning is usually weaker in those working with younger children and there is less time spent on it compared to literacy and numeracy.

A further tension exists with the formularisation of the curriculum for both pre-school and compulsory education in England in recent years, so that the gap between learning through exploratory play and learning 'scientific facts' for performance in tests grows wider. In England, the gap between the Early Years Foundation Stage (DfE, 2012a) for children from birth to 4 years of age and children studying within the National Curriculum (DfE, 2012b) from 5 years of age is probably as wide as it has ever been, with children from 5 years old learning factual information, such as the names of parts of plants, or parts of the body, rather than exploring the world around them.

In this edition of *JES*, we have articles from Portugal (Cid & Fialho), Brazil (Blasbalg & Arroio) and Cyprus (Constantinou, Raftopoulos, Spanoudes & Natsopoulos). We also have a review of the changes in the National Curriculum in England from a primary science perspective (Schofield). A common theme in all the articles is how pedagogical approaches are used to support early scientific development. Cid and Fialho look at how improved teacher education in Portugal has impacted on teachers' ability to support children as they attempt to explain the natural world. Blasbalg and Arroio examine science education from a sociocultural perspective and particularly focus on how children create scientific meanings through explorations and interaction. The research by Constantinou and colleagues indicates a possible transition in children's conceptual development from around 5 years of age and the effectiveness of pedagogical intervention/ interaction as a result. The articles illustrate a further tension around pedagogical approaches that support scientific development at different stages and, maybe, they indicate the need to look at early scientific development and learning from a child's perspective, to value all experiences but, most importantly, to consider how the child synthesises both formal and informal experiences and how early years professionals support them in this synthesis.

References

DfE (2012a) *Statutory Framework for the Early Years Foundation Stage. Setting the standards for learning, development and care for children from birth to five*. London: DfE

DfE (2012b) *National Curriculum for Science. Key Stages 1 and 2 – Draft.* London: DfE

EURYDICE at NFER, (2013) *Compulsory age of starting school in European countries.* http://www.nfer.ac.uk/nfer/index.cfm?9B1C0068-C29E-AD4D-0AEC-8B4F43F54A28 Accessed 22/4/13

Jane Johnston
Co-Editor, *JES*.

Contributing to the Journal of Emergent Science

Instructions for authors

The Journal of Emergent Science (JES) focuses on science (including health, technology and engineering) for young children from birth to 8 years of age. The key features of the journal are that it:

- is child-centred;
- focuses on scientific development of children from birth to 8 years of age, considering the transitions from one stage to the next;
- contains easily accessible yet rigorous support for the development of professional skills;
- focuses on effective early years science practice and leadership;
- considers the implications of research into emergent science practice and provision;
- contains exemplars of good learning and development firmly based in good practice;
- supports analysis and evaluation of professional practice.

The Editorial Board of the journal is composed of ASE members, including teachers and academics with national and international experience. Contributors should bear in mind that the readership is both national UK and international and also that they should consider the implications of their research on practice and provision in the early years.

The Editorial Board

Please send all submissions to:
janehanrott@ase.org.uk in electronic form.

Articles submitted to *JES* should not be under consideration by any other journal, or have been published elsewhere, although previously published research may be submitted having been rewritten to facilitate access by professionals in the early years and with clear implications of the research on policy, practice and provision.

Contributions can be of two main types: full length papers of up to 5,000 words and shorter reports of work in progress or completed research of up to 2,500 words. In addition, the journal will review book and resources on early years science.

Guidelines on written style

Contributions should be written in a clear, straightforward style, accessible to professionals and avoiding acronyms and technical jargon wherever possible and with no footnotes. The contributions should be presented as a Word document (not a pdf) in Times New Roman point 12 with double spacing and with 2cm margins.

- The first page should include the name(s) of author(s), postal and e-mail address for contact.
- Page 2 should comprise of a 150-word abstract and up to five keywords.
- Names and affiliations should not be included on any page other than page 1 to facilitate anonymous refereeing.
- Tables, figures and artwork should be included in the text but should be clearly captioned/ labelled/ numbered.
- Illustrations should be clear, high definition jpeg in format.
- UK and not USA spelling is used i.e. colour not color; behaviour not behavior; programme not program; centre not center; analyse not analyze, etc.
- Single 'quotes' are used for quotations.
- Abbreviations and acronyms should be avoided. Where acronyms are used they should be spelled out the first time they are introduced in text or references. Thereafter the acronym can be used if appropriate.
- Children's ages should be used and not only grades or years of schooling to promote international understanding.

- References should be cited in the text first alphabetically, then by date, thus: (Vygotsky, 1962) and listed in alphabetical order in the reference section at the end of the paper. Authors should follow APA style (Author-date). If there are three, four or five authors, the first name and et al can be used. In the reference list all references should be set out in alphabetical order

Guidance on referencing:

Book

Piaget, J. 1929 *The Child's Conception of the World.* New York: Harcourt

Vygotsky, L. 1962 *Thought and Language.* Cambridge. MA: MIT Press

Chapter in book

Piaget, J. 1976 'Mastery Play'. In Bruner, J., Jolly, A. & Sylva, K. (Eds) *Play – Its role in Development and Evolution*. Middlesex: Penguin. pp 166-171

Journal article

Reiss, M. & Tunnicliffe, S.D. 2002 'An International Study of Young People's Drawings of What is Inside Themselves', *Journal of Biological Education*, **36**, (2), 58–64

Reviewing process

Manuscripts are sent for blind peer-review to two members of the Editorial Board and/or guest reviewers. The review process generally requires three months. The receipt of submitted manuscripts will be acknowledged. Papers will then be passed onto one of the Editors, from whom a decision and reviewers' comments will be received when the peer-review has been completed.

Books for review

These should be addressed and sent to Jane Hanrott (JES), ASE, College Lane, Hatfield, Herts., AL10 9AA.

Pre-schoolers' construction of operational definitions in magnetism

■ C. P. Constantinou ■ A. Raftopoulos
■ G. Spanoudes ■ D. Natsopoulos

Abstract

In this article, we examine the ability of young children to construct operational definitions in magnetism and the importance of scaffolding the learning environment. To achieve this, we first discuss the conceptual background of pre-schoolers and the role of operational definitions in science teaching and learning. We then present an experimental study of 165 children aged 4-6 who took part in an extended structured intervention, in which they were guided to develop one or two operational definitions of a magnet. One operational definition is property-based and the other draws on interactions between magnets. In order to discern the influence of cognitive maturation, we also administered the Raven Test of Colored Progressive Matrices to 95 of our subjects. Our results demonstrate that, with guidance, children older than 5 years are mostly able to construct both definitions, while younger children are able to construct only the first one. We also find that learning of the second definition is more strongly dependent on age than on cognitive maturation. Finally, children who were taught the second definition without prior learning of the first are found to demonstrate a significantly lower success rate. Based on this last result, we elaborate on the necessary role of scaffolding the curriculum materials to achieve successful learning.
We interpret the results by exploring various constraints to the development of certain cognitive abilities. The two definitions differed with regard to the cognitive demands imposed upon the children attempting to construct them. More specifically, the construction of the second definition required cognitive abilities that the construction of the first did not. Furthermore, the cognitive complexity of the two tasks, as indicated by their relational complexity, was different. The paper concludes by discussing the issue of cognitive readiness and its role in learning.

Keywords: Early years, science concepts, cognitive readiness, structured scaffolding.

Introduction

Science in the kindergarten is in an interesting situation. On the one hand, the natural environment and his/her interaction with it are inherently perplexing and motivating for the average 4-6 year-old. On the other hand, in actual school practice, the teaching emphasis tends to remain focused on socialisation, language development and artistic expression, rarely putting even to inspirational use children's interest in the physical world. From the point of view of research, publications that focus on science education in the early years tend to be scarce (Pinto & Couso, 2007). There are a number of reasons for this. Children's limited language abilities (at least as perceived by researchers) impose a constraint that is of significantly less importance at higher ages. Teaching expectations in science are not as high for this age level and hence the motivation to work towards improved practice is substantially lowered. Furthermore, science learning is not as well defined as for other age groups and hence the decision on what to probe is not immediately obvious.

We have developed a framework for science learning in the kindergarten (Constantinou, 2002). In this framework, four categories of learning objectives are promoted in unison: experiences with natural phenomena, positive attitudes towards inquiry and preservation of the environment, understanding of a small number of basic scientific concepts, and scientific method and reasoning skills. One of the skills included in our curriculum is the formulation of operational definitions. This is one of the skills (along with formulating questions, prediction and hypothesis) that link science learning to the overall effort for supporting language development in the early years. Operational definitions play an additional role in our curriculum: they serve to differentiate between experiences and concepts in the formally declared objectives. In other words, we expect children to gain experiences with a wide range of phenomena, to be able to talk about them, to enjoy their explorations, to experiment and to make simple graphical representations of patterns that emerge. However, we constrain our expectations of children of this age to really understand to only those science concepts that they can be engaged in developing original operational definitions.

This is a stringent criterion, which severely limits the number of concepts that can be taught at this age level. However, we believe that the use of operational definitions as a teaching tool in science has a two-fold advantage; firstly, it enables the programme to clearly communicate to the kindergarten teachers that understanding is a complex process; in science, it can be usefully constructed on a solid experiential foundation and, as educators, we need to have very clear criteria as to when it is taking place in our classrooms, or not. Secondly, by restricting the number of concepts around which it requires real understanding, the programme serves to reassure the kindergarten teachers that they can actually learn with their class and that the more important expectation is for them to guide processes of investigation in a manner that is meaningful, rather than to serve as media for revealing pre-acquired knowledge. The programme is designed to provide a detailed scaffolding for teachers to be able to do this.

The work reported here is motivated by a need to examine the following research question. Can pre-schoolers be usefully guided to construct operational definitions? To our knowledge, operational definitions of science concepts have not been systematically used as a teaching tool at this age level. Specifically, we aim to examine the extent to which young children (4-6 years of age) could successfully construct two operational definitions of magnets, the second of which is based on the interactions between magnets. Successful construction of this second definition provides a more advanced understanding of magnets.

First, we present the theoretical background regarding pre-schoolers' representation of the world and the constraints that shape it. Within this framework, we will discuss pre-schoolers' intuitive theories of magnetism and relate them to the way in which they represent the world. Then, we present the school-based teaching intervention aiming to test whether pre-schoolers could successfully be taught two different operational definitions of a magnet. The first definition treated magnetism as a substantial property of objects. The second definition requires that children understand magnetism as a relation between two objects. Prior to and after the intervention, we carried out individual interviews designed to evaluate the children's prior experience of magnets and their ability to apply each of the two definitions. Finally, in the discussion, we will attempt to (a) provide an explanation of the developmental patterns in children's performance on our tasks, (b) assess children's understanding of magnetism through analysing their actual responses as they were trying to reconstruct the two operational definitions, (c) analyse the tasks in order to examine the interface between their epistemic and logical complexity, and (d) draw some conclusions regarding the learning of science concepts and the role of effectively scaffolding the learning environment.

At this stage, it would be useful to point out two assumptions that underlie our work. Firstly, we assume the usefulness of teaching science in the kindergarten and the necessity of intervening to facilitate pre-schoolers' construction of meaning from their interactions with natural phenomena, both for psychological and pedagogical reasons, and we will refrain from discussing this further. (For such arguments, see Althouse, 1988; Harlan, 1988; Lind, 1991; Wortzman, 1992). Secondly, for reasons of conciseness, we do not present a comprehensive picture of a wider vision of science education for the early years. However, it is important to qualify that we do not wish to imply that science education should be reduced to continuous understanding of operational definitions of the different science concepts. In contrast, operational definitions are one of many useful tools in support of a teacher's effort to facilitate science explorations and, in a wider sense, the elaboration of children's conceptual understanding as well as their continued cognitive development. The issue that we seek to examine is whether this tool can be usefully employed at this age level and we propose to do this in the context of magnetism.

Theoretical background

The cognitive basis of the intuitive notions of magnetism

There is abundant evidence that pre-schoolers possess a rich conceptual and pre-conceptual background on the basis of which they apprehend material objects and interpret their interactions with the environment. This 'knowledge' constitutes pre-schoolers' 'intuitive science'. It includes *contact-mechanical* knowledge; that is, knowledge of the way objects interact with each other (Baillargeon, 1995; Carey, 1986; Chi, 1992; Karmiloff-Smith, 1992; Nersessian & Resnick 1989; Spelke, 1990), knowledge about causality (Medin, 1983; Leslie, 1984), and spatio-temporal knowledge; that is, knowledge regarding the apprehension of the existence and individuation of objects, of their permanence through time, and their enumeration (Baillargeon *et al*, 1985; Rosh, 1978; Spelke *et al*, 1995; Xu & Carey, 1996; Wynn, 1992).

Even though intuitive science includes principles that allow children to make personal sense of their world experience, some of these principles deviate from established scientific theories in that they are often approximately correct in a restricted field of application, usually that of everyday action (Barrow, 1987; Carey, 1985; Clement, 1982, 1983; diSessa, 1982, 1993; Halloun & Hestenes, 1985; McCloskey, 1983; Nersessian & Resnick 1989; Viennot, 1979). Such principles are not merely erroneous pieces of knowledge about the world that the child could easily be persuaded to reject. Since they constitute the schemata on the basis of which he/she has come to interpret his/her surroundings, they function as organising principles. Experiences are made meaningful on their basis; thus, they are the least likely items to be exposed to experimental inquiry (Quine, 1961).

Thus, in an institutional setting, part of the pedagogical challenge is to find ways of facilitating the transformation of the content of intuitive science. This process is known to be hampered by epistemological obstacles that sometimes emerge in the process of learning and which instruction must guide children to overcome if it is to be effective (Bachelard, 1994). One such obstacle concerns the tendency of children to confuse science concepts with objects or observable aspects of phenomena (Heath & Heath, 1982). This is one important reason that makes operational definitions potentially useful as a teaching and learning tool in the science classroom.

One of the concepts that have proven recalcitrant to successful teaching is that of magnets. Prior research (Barrow, 1987; Gagliari, 1981; Selman *et al*, 1982) shows that pre-schoolers notice the phenomenon of magnetic attraction, but cannot spontaneously offer a successful definition of a magnet. It also shows that they have fewer experiences with repulsion than with attraction and, thus, they find magnetic repulsion more difficult. Since repulsion is especially significant in defining magnets, particularly as a means to differentiate them from magnetic materials that are not magnetised, it is important that an understanding of magnets be based on the interactions between magnets (Gagliari, 1981).

According to Chi (1992, 1993), one of the basic traits of intuitive science, and probably its unifying feature, is the tendency of children to view all properties of objects as substantial characteristics; that is, as properties that belong to these objects and exist independently of interactions with other bodies. Thus, they find it very difficult to comprehend physical concepts that are relational in nature and represent processes among interacting bodies, such as electrical or magnetic interactions, gravity or thermal transfer.

Another significant element of pre-schoolers' intuitive science is the concept of force. The notion of force is gradually rendered meaningful on the basis of experiences with situations that involve the exercise of forces, either by, or upon, the infant. Johnson's (1987) image schemas constitute one of the attempts to explain the gradual construction of the notion of force. Image schemas are imaginative structures (imaginative in that they involve the body as well as the mind) that ground our concepts. Certain image schemas are inherently meaningful by resulting directly from our bodily experiences; that is, they have a meaning constituent that is not conceptual but experiential in nature and upon which semantic content is subsequently progressively built. This intuitive, or primitive, meaning is so fundamental that it constitutes the 'hard core' of some of our concepts (Mandler, 1992). By virtue of the fact that they are grounded in experience, image schemata are very persistent; i.e. they are the main tools that render experience meaningful. diSessa (1993) also believes that the core of intuitive physics consists of meaning carriers that constitute 'phenomenological primitives', in the sense that they render phenomenological experience meaningful. In other words, there exists widespread consensus that conceptual understanding can be constructed more effectively on a solid experiential foundation.

One of the image schemata of 'force' is that of attraction, which is acquired on the basis of experience with glue, magnets, vacuum cleaners, gravity and also by experiences of emotional attraction to others. This schema has a definite structure that includes the following features:

(a) the force is an interaction between objects;
(b) the force is directional (from the attracting body to the attracted body);
(c) the force has a source, or origin, (the attracting body) and a target; and
(d) the source is the cause of the behaviour of the target.

In so far as magnetism is concerned, the image schema (Johnson, 1987) of an attractive force gives rise to the 'pulling model' (Erickson, 1994, 92–93; see also Selman *et al*, 1982). According to this model, the magnet is viewed as an object that has a pulling capability and, thus, pulls other objects or, as children often state, sticks to other objects (Barrow, 1987; Gagliari, 1981; Selman *et al*, 1982). This conception of magnetism is thought to characterise the intuitive conceptions of children up to the age of 10.

Children's notion of causality is another constituent of the intuitive science that is important for the aims of this article. Recent findings (Bullock, Gelman & Baillargeon, 1982; Gelman & Spelke, 1981; Keil, 1989; Springer & Keil, 1989, 1991) show that children use a wide variety of causal explanations to account for biological, social and physical phenomena, and seem to observe both domain-general and domain-specific causal principles. Among the domain-general causal principles honoured by pre-schoolers is the thesis that the causes, be they agents or substrates, must resemble their effect. This similarity criterion has been called 'homeopathy' (Springer & Keil, 1991). It follows that the same causal agent must always cause similar effects since, by its nature, the effect must resemble the cause. This means, with regard to magnetism, that it is difficult for young children to grasp a causal mechanism that can cause disparate and often antithetical effects, as in the case of a magnet that can attract and repel objects.

Our discussion thus far reveals the cognitive basis of some basic notions that children are likely to have with respect to magnets. To recapitulate:

- children view magnetism as a substantial property of some objects;
- this property is conceived as the 'force' that magnets have in order to pull toward them, or 'stick to' other objects; and
- children find it difficult to understand the fact that a magnet can both attract and repel other objects, in that this violates homeopathy and presupposes the ability to co-ordinate causal schemes.

Operational definitions in science learning

Since, in the discussion that will follow, the notion of 'operational definition' is crucial, we would like at this juncture to delineate the significance of the term and discuss in more detail the specific principles that guided the design of our intervention.

We take the view that science is a human endeavour, which seeks to study phenomena and build explanatory models with predictive capability. In order to do so, we use various resources and tools. One of the more interesting and powerful classes of tools that we have developed is physical concepts. Scientific concepts are human constructs that serve the purpose of epistemological tools for clarifying and better defining specific aspects of our explanatory models. In the process of constructing and communicating new concepts, we use operational definitions.

Precise and unambiguous definitions make it possible for physical scientists to check one another's findings and to build upon the work of others (McDermott, 1990, 1996; Arons, 1997). The purpose of a scientific operational definition is to communicate the meaning of a concept as clearly and as unambiguously as possible. The operational definition of a quantity, such as mass, tells what steps or operations to take in order to obtain a numerical value for the quantity. The operational definition of an attribute such as floating or sinking specifies a test that anyone can apply to unambiguously determine whether an object sinks or floats.

Most dictionary definitions are not operational. For example, the following non-operational definition of 'area' is taken from a dictionary: *the measure of a bounded region on a plane*. This definition indicates that the concept of area is useful in describing the size of a figure. It does not, however, state how this size is to be determined. This definition leaves open the possibility of misunderstanding the exact meaning of area. Suppose we use this non-operational definition of area to compare the sizes of two squares. It would be consistent with the definition if we measured the lengths of the two diagonals. To decide whether a definition is operational, it is necessary to see whether the definition makes clear just what operations need to be done to find a particular quantity or to make a specific test.

An operational definition should conform to two criteria:
(a) it should be reliable, always giving the same result for a particular item within the class it seeks to define and,
(b), it should be stated in such a way that cannot be misinterpreted. It is worth noting that an operational definition is not required to be general in that it can describe only a subset of the class that it seeks to define. Hence, a good operational definition of an electric circuit does not have to distinguish all types of electric circuits, even though that would be an added advantage.

Apart from the epistemic role of operational definitions, children's ability to construct their own definitions can be crucial in the development of their conceptual understanding. Operational definitions can serve as standards (in the sense of rallying points) in constructing the basic physical concepts. They can also serve as a means of establishing unambiguous communication among co-operative groups of learners. Finally, operational definitions can function as useful assessment probes. Indeed, the ability of an individual to create his/her own operational definition provides undisputed evidence of deep understanding of the corresponding concept (McDermott, 1996).

The experimental study

Experimental design

The literature on the cognitive underpinnings of the pre-schoolers' background of physical phenomena and prior work on the acquisition of cognitive abilities, say, the ability to co-ordinate causal schemes, indicate that, around the age of 5, children undergo a marked cognitive change (Case, 1992; Fisher, 1980; Siegler, 1996; Siegler & Crowley, 1991). For this reason, we included subjects in three age groups: namely, pre-schoolers less than 4.5 years, between 4.5 and 5 years, and older than 5 years, with a view to examining the pattern of their performance with respect to specific science learning tasks.

The research questions in our study are the following:

(a) Can pre-schoolers be successfully instructed to construct operational definitions (ODs) of magnetism?
(b) Can pre-schoolers construct a relational OD of magnetism based on mutual attractions and repulsions among objects, overcoming persistent epistemological obstacles?
(c) Is the effective scaffolding of the learning environment a necessary condition for the pre-schoolers to construct the second, more complex, OD?

Participants (children)

The sample comprised 165 children, ranging in age from 3 years and 11 months to 5 years and 7 months (sample mean 4 and 10 months and standard deviation 6 months). Forty-five children (sample mean 4 and 6 months and standard deviation 4 months) took part in Phase I of the project, and 120 children (sample mean 4 and 11 months and standard deviation 6 months) took part in Phase II. The children were from three kindergartens in a small city and were distributed in six different classrooms. Five of the classrooms had one teacher and one assistant each. The sixth classroom was shared by two other teachers and an assistant. All seven teachers underwent training in background content knowledge, curriculum materials and classroom implementation procedures.

Description of the teaching intervention

We had designed a unit on magnetism with the aim of helping children to acquire systematic experience of the behaviour of magnets and use their experiences to formulate various operational definitions of a magnet. The underlying principle guiding our curriculum development effort is that one process in science departs from undertaking careful observations, and uses our reasoning ability to make sense of these observations to the point of generalising into rules that we can apply elsewhere. In our interventions, we explicitly encourage children to use evidence (particularly their own observations) to always support their viewpoints. We also encourage children to focus their observations, their descriptions and their thinking so that they can then explicitly relate them through examples (Lee *et al*, 2006).

The curriculum materials are very detailed in offering guidance to the teachers as to how to create an environment where children are encouraged to express themselves and every opinion is valued. The curriculum also offers detailed guidance on helping children to overcome particular difficulties and on choosing appropriate materials that will make it easier for children to respond to the underlying challenges. Some aspects of the curriculum, such as guiding children to classify objects according to material, are not trivial and the activity sequence required many trials before it could be refined to a version that was deemed effective. Below we provide a brief description of the overall outline of the unit. The unit includes 6 sequential lessons. The first two lessons are introductory, providing background experiences for the children. Lessons 3 and 5 guide the children to explore phenomena relating to the two operational definitions. Lessons 4 and 6 are dedicated to guiding the children to construct OD I and OD II, respectively. A more detailed description of the content of each lesson is given below:

○ Lesson 1: Exploring magnets

This lesson begins with a short puppet show, in which 'Aunt D' accidentally drops her pins and requests help in gathering them one by one. A neighbour offers a device for gathering the pins quickly. The children are asked what this device might be and are then encouraged to work in groups in order to explore a range of objects, which include magnets, ferromagnetic materials, plastic and wood. In this exploration phase, children are encouraged to use their materials to set up pull games and fishing arrangements.

❍ **Lesson 2: Metals and non-metals**

Children are guided to explore a number of objects made of different materials (brass, iron, aluminium, wood, plastic and polyester fabric). After identifying the objects, they are asked to work in groups. The objects are initially placed in a shallow plastic bowl on the table. The main task is to classify the objects according to material, first differentiating metals from non-metals. On every table there are coloured plates available to allow children to place each group of objects on a different plate. The lesson concludes with a whole group classification and discussion.

❍ **Lesson 3: Are all metals attracted by a magnet?**

The children now explore each class of objects from the previous lesson relating to their interaction with a magnet. The children are encouraged to predict, initially and at various stages along the way, what classes of materials they think will interact with a magnet, and how. They are explicitly asked whether any metals will not interact. After careful recording of their predictions in symbolic form by the teacher, they are asked to work in groups to find out what really happens.

❍ **Lesson 4: How can I tell if something is a magnet?**

This lesson is devoted to guiding the children to construct OD I. The children are asked to place their hands on their chairs and to sit on them. They are asked to keep their hands there for the duration of the whole lesson. (This same routine was also used in the assessment tasks). The puppet, 'Aunt D', is brought back and she needs a magnet. However, she is in the middle of a game with a person familiar to the children (usually the classroom assistant) and she cannot take off the blindfold around her eyes. So the children need to provide directions to guide her to a set of appropriate objects and then to choose the right one. This is done in a whole group setting. The children invariably sent the puppet to one of the bowls used by the groups in lesson 3. Each bowl contains one magnet and 12 other objects made of brass, iron, aluminium, wood, plastic and polyester fabric. Four of the 12 objects are very close to the magnet in weight, shape and size. The puppet actively tries to misinterpret every direction given. Children gradually learn to be precise and careful when phrasing directions. As a group, they iterate different sequences of directions until they focus on a sequence that yields a magnet. They are then encouraged to try again, this time giving directions to a person that was not hitherto present (usually the classroom assistant).

❍ **Lesson 5: Magnets with other magnets**

In this lesson we added a group of magnets as a new class of objects to those used in lesson 2 and we explored the ways in which a magnet interacts with another magnet. Once children discovered repulsion as another type of interaction, they went back and explored whether they could get a magnet to repel any of the objects in the other classes. Children were also encouraged to explore new pushing games and to see if they could set up funny fishing rods that avoid fish.

❍ **Lesson 6: Is there another way to tell if something is a magnet?**

This lesson is devoted to guiding the children to construct OD II. Again in a whole class setting, the children sit in a semi-circle and are asked to repeat the same routine, placing their hands on their chairs and sitting on them. The puppet, 'Aunt D', comes back with a different problem: she has various pairs of objects and she needs to decide which pair has two magnets. She cannot use any other materials. To make the rules plausible and more understandable to the children, they are integrated into a story of an old man who needs to trace his magnetic shoes and he is helped by 'Aunt D'. Again, the puppet actively tries to misinterpret every direction given. The children iterate different sequences of directions until they focus on a sequence that yields the magnets, which they themselves can recognise from appearance but which 'Aunt D' does not. The children are again encouraged to try a second time, giving directions to a person that was not hitherto present (usually the classroom assistant).

Our interest was in investigating children's ability to construct and apply consistently operational definitions uniquely distinguishing a magnet from other objects. The curriculum guided children to first act out (lessons 3 and 5) and then to formulate verbally, as a group, two such definitions (the first during lesson 4 and the second during lesson 6):

- Find two objects that do not attract each other. Does your object attract both of them? If 'yes', then it is a magnet. If not, then try with other objects.
- Find two objects that, when approached in one orientation, attract each other AND, when approached in another orientation, they repel each other. Both of these objects are magnets.

The words *attraction*, *orientation* and *repulsion* were not usually used by the children. Instead, they would typically use the words *pull*, *another way*, and *push*, respectively.

OD I involves identifying a candidate object and then putting it through a test. In particular, children who have understood this operational definition will test the object against other objects to see if they can find two that are attracted, without displaying an attractive property on their own. OD II, on the other hand, requires the identification of a pair of objects that demonstrate a relationship of simultaneous attraction and repulsion.

It is important to note that the children were not guided and were not expected to provide full definitions of magnetism or a magnet. An operational definition is best formulated as a series of directions; steps that describe a sequence of actions, in this case leading to the undisputed identification of a magnet among a group of other objects. In essence, the children were asked to give brief directions so that someone else could act out what they had performed themselves during lessons 3 and 5.

It is also important to say that operational definitions are a significant part of science teaching in this area. These children had, in previous unrelated science lessons, formulated operational definitions of luminous objects and opaque objects.

Validation of the curriculum materials and procedures

Prior to this project, the curriculum had been field-tested a number of times in a way that is typical of our work. Our approach to curriculum development includes an analytical methodology for sequencing learning activities in a way that explicitly addresses the conceptual, reasoning and other demands placed on the learner. In implementing this approach, we always expose the initial curriculum design to classroom testing and evaluation. The evaluation takes the form of research into student understanding and its development. This time it took two iterative cycles of curriculum – teaching – research before we felt that our curriculum was refined to the point where it could be used effectively by a wide range of teachers, following appropriate preparation (McDermott, 1990, 1996). The evaluation focused on children's understanding of operational definitions and gave us the opportunity to refine our assessment tasks prior to the start of this project.

Preparation of teacher participants

The intervention was implemented in multiple classrooms in three different schools always by the classroom teacher. Prior to the intervention, all teachers met with the researchers for four two-hour sessions on consecutive days, in order to go through the curriculum in detail, examine the materials and discuss implementation procedures. In these initial training sessions, special attention was devoted to the background content knowledge, the rationale behind the activity sequencing and the wording of appropriate questions for the children at different stages of the curriculum.

The teachers were able to try out the activities themselves, clarify what the children were expected to observe and think, and refine questions for guiding children to engage with the materials and to overcome specific difficulties. The intervention was implemented over a three-week period with two lessons every week. The lessons always took place in the morning immediately after free play in the first segment of the formal kindergarten programme.

The teachers met with one of the authors at the end of every week for another two-hour session, discussing the lessons of the previous week, the lessons of the following week and individual student progress with respect to the aims of the curriculum. These meetings helped to keep the teachers on track and encourage continued communication between them about the details of implementing particular lessons. We also tried to sustain them through the ups and downs of student development during these weeks by instilling a sense of ownership of the whole enterprise and pride in what they were achieving. The meetings also enabled us to make minor adjustments to the curriculum midway in order to cater to the needs of individual classrooms and groups of children.

Phases of the research

In the first phase of the project, we aimed to explore possible effects of age on children's ability to construct the two ODs and to test the effectiveness of the curriculum materials in the context of this project. In the second phase, we aimed to confirm the results of Phase I and examine the possible dependence of children's performance on their cognitive maturation as measured by the Raven Test. We also wanted to investigate whether OD I serves as a prerequisite to OD II. For this reason, we modified the intervention in one of the classrooms so that lesson

4 was replaced by free exploration activities with magnets and OD II was the only OD that was taught or examined. The total time of the intervention was identical for all classes of children.

In total, we worked with six classrooms of children in three different schools over a period of two school years. The classroom demographics are shown in Table 1. The interventions took place over periods of three weeks in the autumn term of 1998-1999 (Phase I) and in the spring term of 1999-2000 (Phase II). All ages are listed in reference to the last day of the intervention. This convention is upheld throughout the article. In the first phase of the project, we worked with mixed classes involving younger and older children (classes 1 and 2). In the second phase, we worked with one mixed class (class 6), one class with younger children (class 4) and two classes with older children (classes 3 and 5). Younger children were in their penultimate year at kindergarten. Older children were in their final year at kindergarten. The Phase II 'young children' were somewhat older than the Phase I 'young children', due to the difference in the time of the year. The same holds for the older children in each phase.

Data collection

The data were collected through individual interviews prior to the intervention, at the end of lesson 4 (OD I) and in the two weeks following lesson 6 (OD II). We also administered the Raven Colored Progressive Matrices intelligence test during a period of four weeks to one and a half months after the intervention. All the data were collected through individual interviews, which were always initiated with some informal conversation and play activity that had no relevance to the task at hand. Occasionally, when a child's attention wavered, the play activity was revisited for a maximum of

Table 1: Demographic characteristics of the classrooms that took part in our intervention.

School	Class No.	Phase	Number of Children	Mean age (Years: Months)	Standard Deviation in age (months)	Intervention (Lesson Sequence)
A	1	I	23	4:6	5	1, 2, 3, 4, 5, 6
A	2	I	22	4:6	5	1, 2, 3, 4, 5, 6
B	3	II	30	5:3	2	1, 2, 3, 4, 5, 6
B	4	II	31	4:5	3	1, 2, 3, 4, 5, 6
C	5	II	29	5:3	2	1, 2, 3, F, 5, 6
C	6	II	30	4:10	6	1, 2, 3, 4, 5, 6

The letter F indicates free exploration activities (or games) with magnets that were designed to replace lesson 4 while at the same time giving the children of Class 5 a total time of engagement with magnets equal to every other class.

once in the middle of the interview. The interviews were always conducted by one of the authors, not the teachers. They took place in the school premises, but in a separate room where the interviewer and child could sit alone on a carpet with the relevant materials. Not more than three interviews were ever scheduled in a row. The children were always made to feel comfortable and not rushed. They were given time to think and to modify their answers if they wanted to. While at the same time being careful not to guide the responses one way or the other, the researchers felt that this procedure weeded out inarticulate or imprecise responses and made subsequent coding easier.

○ Task 1: Pre-test interviews

In our initial (pre-test) evaluation, one child at a time was given a bowl with 10 objects comprising three magnets, two pieces of iron, two pieces of brass, one piece of wood and two pieces made of plastic, and was asked to group them on the basis of interactions between objects. The interviewer used the words *react* and *interact* interchangeably throughout these initial pre-test interviews. In the curriculum development that preceded this study, we found that the phrase *objects reacting with each other*, although scientifically inappropriate, is more commonly understood by children of this age than *objects interacting with each other*. Children were encouraged to settle on one best classification and this was recorded, both photographically and in note form, at the end of the interview. Each classification was then coded based on the criterion that the child seemed to employ.

In the same interview, we then showed each child a box with five different magnets and asked brief questions that aimed to probe prior acquaintance with magnets.

○ Task 2: Operational Definition I

In this task, children were presented with a group of 10 objects, each of which was hidden in a matchbox wrapped in white paper and sealed with Sellotape. During development of this task, we had found that children tended to shake the box and try and open it in order to come up with a guess as to its contents. In order to help children resist the temptation and to avoid irrelevant activity of this kind, we asked children to repeat the routine of sitting on their hands, and also care was taken to ensure that each object had roughly equal mass and was firmly stuck inside the box. This group of hidden objects included only one magnet. Children were explicitly told this and were then asked to give directions to the interviewer so that he/she could identify the magnet. The interviewer acted out the directions so that the child could see the result. All interviews were audiotaped. Children's responses were then coded as a 'success' or a 'failure', based on whether they could provide directions so that the interviewer could apply OD I consistently. The results were coded by three researchers independently. In 104 of the 136 cases, all three coders agreed on their evaluation. All disagreements were resolved in a joint meeting after careful examination of the protocols. The relatively large number of disagreements reflects the inherent difficulty in interpreting responses from young children.

The directions varied greatly in quality. In lesson 4, meticulous attention had been paid to how children formulated directions to each other and to the teacher. However, in grading this task the quality of the directions was deemed only indirectly relevant. We tried to concentrate our evaluation on how well children understood OD I as opposed to whether they could express it in technical terminology, or provide the directions in any pre-specified sequence. The responses of four of the children are quoted in Table 2. A set of directions was graded as 'successful' only if it specified all of the three items below:

- Finding two objects at random that attracted each other;
- Finding a third object that attracted only one of the first two; and
- Choosing the one of the three objects that was found to interact with either of the initial two.

Any response that did not include any one of these items was deemed 'unsuccessful'. Out of the responses quoted in Table 2, the top two were deemed to be 'successful' and the bottom two 'unsuccessful'. For instance, the third quote in Table 2 'fails' criterion 3. In essence, application of the three criteria enabled us to identify children who could apply the operational definition and consistently describe what they were doing.

Table 2: Typical children's responses on Task 2 (Operational Definition I).
The first two responses were classified as successful. The last two were classified as unsuccessful.

Shake them up. Find two that are pulling. Take them out and put them on the table. Then put one of them in your hand. Put your hand in the bowl and see if it pulls any other ones. When it pulls another one take them out and put them on the table. If you cannot find one then you should try with the other one on the table. When you find another that pulls you have three on the table. Find the one that pulls the other two. Now check the other two will not pull. That one is the magnet.
Find three boxes that pull. From those three now choose the one that pulls the other two. That has the magnet you are looking for.
Put your hand in there and stir them. Find the one that attracts the others. Take it out. That's the magnet inside.
The magnets are red. You cannot see them. .... No you cannot find any.

Table 3: Typical children's responses on Task 3 (Operational Definition II).
The first two responses were classified as successful. The last two were classified as unsuccessful.

Find two boxes that pull. Take them out on a plate. Try them different ways. Do they also push? They are magnets. Otherwise put them back in and find two new ones.
Stir them up and find some that pull. Take two boxes out. Check them. Do they pull? Now you know one of those two is a magnet. So try those two with other boxes and find one that pulls with one and does not with the other. So that way you know which one of the two has the magnet inside. Now find the other one the same way. When you think you found both try and see. Do they push each other some way? Try the other way. Do they pull? Those two are the magnets.
Find two boxes that pull. Take them out. Find another box from inside that pulls with one of the two that are out. Does it pull with the other? If not, then the other one has a magnet.
Find two that pull each other. Turn them around and see if they pull again. If they do, they have magnets inside.

❍ Task 3: Operational Definition II

In this task, children were presented with a set of 10 apparently identical objects wrapped in the same manner as in the first task. They were explicitly told that the objects included two magnets this time and they were asked to give directions to find both magnets in one go. The interviewer again acted out the directions so that the child could see the result. Some children spontaneously resorted to applying OD I. When this happened, the interviewer clarified once that they were to give one set of directions so that both magnets could be found simultaneously. This had proven to help some children come up with the second operational definition that was sought. Again, the directions given by children varied greatly in quality and the same approach was adopted in grading the responses as in the first task. The responses to this task from four of the children are quoted in Table 3. A set of directions was graded as 'successful' only if it specified all of the three items overleaf:

- Finding two objects at random that attracted each other;
- Testing different orientations of the two objects to see if they also repelled; and
- Rejecting one object at a time until two objects were found that both attracted and repelled.

Any response that did not include any one of these items was deemed 'unsuccessful'. From the responses in Table 3, the top two were graded as 'successful' and the bottom two 'unsuccessful'. The second and third quotes indicate that the children were resorting to OD I in order to identify the magnets. The second was graded as 'successful' because it essentially includes both operational definitions and meets all the criteria of OD II. In 124 of the 165 cases, all three coders agreed on their evaluation. Again, all disagreements were resolved in a joint meeting after careful examination of the protocols.

Raven Test

Raven's Colored Progressive Matrices were administered in an individual interview setting. All children were tested by a single interviewer. The interviewer pointed to a blank area in a rectangle filled with patterns, indicating that the blank should be filled with the one of six possible pattern selections. The task was presented as a game for finding the appropriate door, or filling in the hole, or painting the rest in, depending on how the children chose to initially identify the rectangle. The children were required to figure out the task on their own and to select the appropriate answer by pointing. After each response, the child was given positive encouragement and all responses were recorded on a worksheet with no acknowledgment as to their correctness or otherwise. The maximum possible raw score is 36 and the minimum 0.

Results

Pre-test interviews

Many children noticed the magnets but ignored them in their groupings. Forty-seven children did not recognise the magnets in their bowls. Most of the groupings were on the basis of colour, shape, heaviness, or more than one of these criteria were used simultaneously (Table 4). The responses of 32 children could not be categorised unambiguously and the criterion is listed as 'unidentified'.

Table 4: Criteria used by children (N = 165) to classify objects in their initial pre-test interviews.

Criterion	Number of children
Magnetic attraction	11
Shape	26
Colour	32
Heaviness	19
Texture	9
Material	7
Mixed	29
Unidentified	32

Classification is a skill that is emphasised strongly by all kindergarten teachers in this area. This is reflected in the relatively high occurrence of unambiguous classifications by the children during the pre-test interviews. 118 children appeared to recognise the magnets in their bowls. This number gives an indication of how many of these children remembered having seen a magnet prior to the start of our intervention. This number is also relatively high based on our experience with children of this age level. However, it should be mentioned that all three kindergartens we worked with maintained nature and science corners in each classroom and these included at least one magnet. Only 11 children noticed that there was a magnet among their objects *and* used it in any way to influence their grouping. This number provides an upper boundary to the number of children who may have been able to give an acceptable form of OD I prior to the intervention. These 11 children were distributed in 5 of the classrooms as follows: two in class 1, one in class 2, four in class 3, 3 in class 5 and 1 in class 6 (see Table 1). The 32 children who used 'unidentified' criteria were roughly evenly distributed among the six classrooms.

In the same interview, we showed each child a box with five different magnets. Three of these were bar magnets and two were horseshoe magnets. Two of the bar magnets and one of the horseshoe magnets had their poles coloured differently (red and blue). We asked the children two questions:

(a) *Do you know what these things are called?* and
(b) *Can you tell me something that I can do with one of these things?*

Only 23% (N = 38) of the children could name the box contents as magnets and only 15% (N = 24) could provide an appropriate function for a magnet (e.g. *I can use it to pick up needles*).

Both of these results showed no significant differences according to age.

Children's performance on the Operational Definition tasks

The total number of children participants is N = 165 (Table 1). The number of children who received the whole treatment (lessons 1-6) is N = 136. 90.4% (N = 123) of these children performed 'successfully' on the OD I task. Only 47.8% (N = 65) performed 'successfully' on the OD II task. Another class of children (N = 29) was only examined for OD II. The 'success' rate for this class was 41.4%, which is close to the average performance of the larger group.

One way to explain this result is that the children had some conceptual or practical difficulty with the phenomenon of repulsion. This view is not consistent with our informal classroom observations since, during lessons 5 and 6, the vast majority of children could both identify and describe repulsion events when they were guided to experience them.

We performed qualitative analysis of the children's responses. For the sake of conciseness, we only present the categories that emerged for the erroneous responses. Table 5 shows the three categories of children's errors in OD I along with a typical quote for each category. After the intervention, about one third of the small percentage of children giving erroneous responses believe that a magnet will attract all other objects (2.4% overall). Tables 6 and 7 show the corresponding analysis of errors for OD II. Table 6 includes children from the experimental group only. Table 7 includes all other children who had been taught both operational definitions. Five categories of responses were identified and a typical quote for each is given in Table 6. It is interesting to note that, as age increases, fewer children are unable to give a response or resort to features of appearance in order to define a magnet. It is also interesting to note that Category 1 *(magnets will attract all objects)* in Table 5 does not appear in Tables 6 and 7. The closest to this is Category 3 *(two objects that attract are both magnets)*. The focus on two objects as demonstrated by children's responses in OD II (Tables 6 and 7) demonstrates that at least the vast majority of the children understood the task and related it in some way to what they had learned.

Table 5: Analysis of errors in Operational Definition I.

Category	Age < 4:6 (N = 49)	4:6 < Age < 5:0 (N = 46)	Age > 5:0 (N = 41)
1	3		1
2	4		
3	3	1	1
Total No. of Errors	10	1	2

Categories

1. Children believe that a magnet will attract all other objects.
   (eg. Look for the box that attracts all the others. Yes, you can take any one and then find the box that attracts the one you have taken.)
2. Children believe that magnets can only be recognised through their appearance (eg colour) and/or extraneous properties (eg. material)
   (eg. (a). The magnets are red and blue. So you should look inside and find the ones that are red and blue. (b). The magnets are all made of iron. So if you open all the boxes you will see which ones are made of iron.)
3. Children give no response or an irrelevant response
   (eg. Open them up and you will see. You have to open them.)

Table 6: Analysis of errors in Operational Definition II (experimental group).

Category	Age < 4:6 (N = 0)	4:6 < Age < 5:0 (N = 5)	Age > 5:0 (N = 24)
1			
2		1	8
3		2	5
4			1
5			
Total No. of Errors		3	14

Categories

1. Children repeat OD I persistently

   (eg. Find three boxes that pull each other. Now put them separately. Then you have to find which two of the three do not pull. Just try them two by two and see which ones do not pull. Now take the other one and try it again with one of these two. It pulls. You should try it with the other one as well. It pulls again. That's the magnet. It pulls both these. These do not pull. {Can I try with two boxes only?} No, you will not be sure they are magnets. You need three.)
2. Children believe that two objects that attract are both magnets and that the attraction holds valid independently of orientation. Hence, they will try different orientations of the two objects to demonstrate the attractive property in multiple orientations.

   (eg. Find two boxes that pull. Turn them around. No just turn one of them around. Do they pull? The things inside are bot magnets. Try turning them another way to make sure. Yes they pull again. They are magnets.)
3. Children believe that two objects that attract are both magnets

   (eg. Find two boxes that pull. Those are the two magnets. If they stick they are magnets. {Could it be that only one of them is a magnet?} No. If they pull they are both magnets.)
4. Children believe that magnets can only be recognised through their appearance (eg colour)

   (eg. You should open the boxes up and find all the red ones. No you cannot do it without opening them to look inside. You can try cutting a hole to just have a look.)
5. Children give no response or an irrelevant response

   (eg. Find two boxes and put them side by side. Now push one of them. It pushes [with contact]. All the ones that push are magnets. {Shall we try another two?} Yes, try. They push too. They are magnets also. Maybe the magnets are not only two. Maybe they are all magnets.)

Note:
Statements or questions by the interviewer are shown in { }. Notes by the interviewer are shown in [ ].

Table 7: Analysis of errors in Operational Definition II (other groups).

Category	Age < 4:6 (N = 49)	4:6 < Age < 5:0 (N = 46)	Age > 5:0 (N = 41)
1	9	10	2
2	7	8	3
3	6	2	
4	13	2	
5	7	1	1
Total No. of Errors	42	23	6

Categories

1. Children repeat OD I persistently
2. Children believe that two objects that attract are both magnets and that the attraction holds valid independently of orientation. Hence, they will try different orientations of the two objects to demonstrate the attractive property in multiple orientations.
3. Children believe that two objects that attract are both magnets
4. Children believe that magnets can only be recognised through their appearance (eg. colour)
5. Children give no response or an irrelevant response

Typical quotes for each category are given in Table 6.

Table 8: Children's performance on Operational Definitions I and II for different age groups.

Group Age Range	N (N_{tot} = 136)	Mean Age (years:months)	Standard Deviation (months)	Success rate Operational Definition I	Success rate Operational Definition II
> 5	41	5:4	2	95.1%	85.4%
4.5 - 5	46	4:8	2	97.8%	50.0%
< 4.5	49	4:3	2	79.6%	14.3%

Table 9: Children's performance on Operational Definitions I and II.

	Operational Definition I	
	Failure	Success
Operational Definition II		
Failure	12	59
Success	1	64

In order to investigate the effect of age, we decided to separate the children into three different age groups. Table 8 presents the children's performance in the two operational definition tasks as a function of age (N = 136). The children are divided into three groups according to age (below 4 and 6 months, above 5 and in between). The percentage of children who perform 'successfully' on OD I is very high. This seems to suggest that, after appropriate intervention, virtually all children in this age range are able to construct OD I. OD II has a substantially lower 'success' rate for every age group. OD II also demonstrates a strong dependence on age. Only 14.3% below age 4 and 6 months perform 'successfully'. In contrast, 85.4% of children above age 5 are able to consistently construct OD II.

We performed a χ^2 test for OD I: $\chi^2(2) = 10.6$, $p < .005$ (Cramer's coefficient V = .28, p < .01, N = 136). This result indicates that children's performance on OD I statistically depends on age. The analogous test with OD II gave the following result: $\chi^2(2) = 45.3$, $p < .000$ (Cramer's coefficient V = 0.58, p < .005, N = 136). The Cramer coefficient indicates that performance on OD I is only weakly associated with age. In contrast, performance on OD II and age show a moderate to strong association. The difference between these two Cramer coefficients is statistically significant (t = 3.44. p < .001) (Howell, 1997).

Relative conceptual demands of Operational Definitions I and II

Table 9 shows the number of children who 'succeeded' or 'failed' in either of the two operational definition tasks. Only 9% (N = 12) of the children 'failed' both tasks. Forty-seven percent (N = 64) of the children 'succeeded' on both tasks. These values testify to the effectiveness of the teaching intervention. Forty-three percent (N = 59) of the children 'succeeded' in OD I and 'failed' in II. In contrast, only one child 'succeeded' in OD II and 'failed' in I. These findings support the sequencing of our curriculum by indicating that OD II (lesson 6) is more demanding than OD I (lesson 4).

To confirm this finding, we carried out McNemar's test for the significance of change on the sample of children that were taught all 6 lessons (N = 136): $\chi^2(1) = 54.2$, $p = .000$. The result clearly confirms that OD II is significantly more difficult than OD I.

Tables 5 and 6 do not include the performance of children in class 5 because this class received the modified intervention and was only tested for OD II. Class 5 and the group of children listed in Table 8 with ages higher than 5 years have very similar average ages. The t-test between these two groups shows that the difference in mean age is not statistically significant. In other words, class 5 is matched to the group of older children in Table 8 in age ($t(38) = -0.6$, $p > .5$). Only 41.3% of the children in class 5 performed 'successfully' in OD II. In comparison with an 85.4% 'success' rate for the older children in Table 4, this is appreciably lower. The children in class 5 performed closer to the 4.5 to 5 year-olds rather than the > 5 year-olds. The χ^2 test for OD II ($\chi^2(1) = 13.8$, $p < .005$) indicates that there is a statistically significant difference in the performance of class 5 and the older group of children who received the complete intervention. Not teaching lesson 4 and OD I seems to have influenced these children's performance on OD II significantly. This would indicate that, to some extent, OD I (and lesson 4) functions as a conceptual prerequisite to 'successful' performance on the OD II task.

Table 10: Children's performance on Operational Definitions I and II for different age groups (Phase II only).

Group Age Range	N (N_{tot} = 91)	Mean age (Years: Months)	Standard Deviation (months)	Success rate: Operational Definition I	Success rate: Operational Definition II	Mean Raw Raven Score	Standard Deviation
> 5	39	5:4	1	95.0%	84.6%	16.1	2.34
4.5 - 5	22	4:9	2	95.5%	13.6%	13.6	2.28
< 4.5	30	4:3	1	90.0%	23.3%	12.4	2.43

Raven Test

The Raven Test was administered to all 120 of the children that took part in Phase II of the project. Our analysis will focus on only 91 of the children who received the same treatment in our intervention (classes 3, 4 and 6 in Table 1).

Children's raw scores on the Raven Test ranged from 7 to 21 on the Raven scale that has a maximum of 36 (Mean = 14.3, SD = 2.85). According to the amended norms for the test, the performance of 4 to 5.5 year-olds at the 50th percentile is expected to be around 13. This compares well with our mean raw score, especially taking into account that we have more older than younger children in our sample.

The sub-group of children who took part in Phase II having received the complete intervention show the same pattern in their performance in ODs I and II as the whole sample (Tables 5 and 7). In particular, all children perform uniformly 'successfully' on OD I. In contrast, OD II shows a strong age dependence, with the older children performing significantly more 'successfully' than the youngest. The children in the middle of the range (ages 4.5 to 5) show a lower 'success' rate than the younger children. The number of children in this group is low and this would tend to increase the error of this measurement.

In addition to the performance in OD II, the raw Raven scores also indicate a clear dependence on chronological age. This pattern raises the issue of whether cognitive level might determine children's performance in OD II.

Transformation of raw Raven score to an indicator of cognitive maturation

To explore the effect of cognitive level as measured by the Raven Test on children's performance in OD II, we first transformed the raw Raven scores into a cognitive maturation index. For each child, we looked at the raw Raven performance and, using the Raven Amended Norms Table, we found the age at which the raw Raven score is at the 50th percentile. We used this age as the child's cognitive level of maturation.

Having calculated cognitive maturation indexes for all children, we then divided a number of the children into two groups. The groups were matched as to their age (Ntotal = 73, mean age = 4 years 11 months and SD = 6 months for both groups, $t(71) = -0.13$, $p > .5$). The two groups were significantly different with respect to cognitive maturation: $t(71) = -8.9$, $p < .001$. This allowed us to explore the effect of cognitive maturation on performance in OD II. To do this, we performed a χ^2 test between the groups: $\chi^2(1) = 3.96$, $p < .05$, $\phi = 0.23$, $p < .05$. Cognitive maturation significantly differentiates children's performance in OD II. This indicates that there is a dependence of performance in OD II on cognitive maturation. In particular, children with higher performance on the Raven test are more likely to succeed in OD II.

For the purpose of exploring the effect of chronological age, as measured by the time interval between the date of birth and the last day of the intervention, on children's performance in OD II, we divided a number of the children into another two groups that were matched with respect to cognitive maturation (Ntotal = 48, mean cognitive index 4:11 and 5:0, SD = 4 months for both groups, $t(46) = -1.9$, $p > .5$). The two groups were significantly different with respect to age: mean ages 4:4 and 5:1, SD = 2 months, $t(46) = -18.3$, $p<.0005$. This allowed us to explore the effect of chronological age on performance in OD II. The χ^2 test between the groups indicates that chronological age also seems to differentiate children's performance in OD II ($\chi^2(1) = 9.26$ $p < .005$, $\phi = 0.44$, $p<.005$). Hence, performance in OD II also appears to depend on chronological age. In particular, children with higher performance in the Raven Test tend to be older.

Table 11: Multiple regression analysis predicting children's performance in Operational Definition II.

Model 1	R^2	ΔR^2	F
Age	0.30		36.9**
Cognitive maturation index	0.33	0.03	3.78
** p<0.001			

Table 12: Multiple regression analysis predicting children's performance in Operational Definition II.

Model 2	R^2	ΔR^2	F
Cognitive maturation index	0.20		21.04**
Age	0.33	0.13	16.91**
** p<0.001			

Table 13: Standardised coefficients Beta for the two independent variables.

	Standardized coefficient Beta	t
Cognitive maturation index	0.21	1.94
Age	0.44	4.11*
* p<0.05		

The values for the coefficient ϕ appear to indicate that there is a stronger dependence on chronological age than on cognitive maturation. To explore this further we worked out a regression model.

Hierarchical multiple regression analysis

To separate the effect of cognitive maturation and chronological age on performance in OD II, we performed multiple regression analysis on student performance in OD II with respect to chronological age and cognitive maturation. Table 11 presents the first resulting model that shows that chronological age accounts for 30% of the variance and cognitive maturation was not a significant contributor to the variance. In contrast to cognitive maturation, chronological age is found to be a significant predictor of student performance in this model.

If one reverses the order in which the independent variables are entered into the multiple regression equation, the resulting model is presented in Table 12 on page 17. The cognitive maturation index now appears to account for 20% of the variance and chronological age in turn for 13% of the variance. In this model, both cognitive maturation and chronological age are found to exert significant influence on student performance in OD II. The discrepancy between these two models is explained by the confounding of the two variables (mental and chronological age).

Examining the standardised coefficients beta that are independent of the order in which the variables are entered into the multiple regression formula, and hence are identical for Models 1 and 2, we find that only the coefficient for chronological age is statistically significant (Table 13 on page 17). Hence, it would appear from this result that cognitive maturation is not a significant contributor to the variance of student performance in OD II.

Discussion

In this article, we sought to examine the following issues:

(a) Can pre-schoolers be successfully instructed to construct ODs of magnetism?
(b) Can pre-schoolers construct a relational OD of magnetism based on mutual attractions and repulsions among objects, overcoming persistent epistemological obstacles?
(c) What do pre-schoolers, who have successfully constructed the two ODs, actually learn?
(d) Is the effective scaffolding of the learning environment a necessary condition for the pre-schoolers to construct the second, more complex, OD?
(e) Is the ability of pre-schoolers to construct the more complex definition determined by their chronological age, or rather could it be attributed to cognitive maturation?

Our study shows that the answer to the first four issues is affirmative, and that cognitive maturation is not the main determinant factor that shapes the performance pattern of these children.

(a) With respect to the first issue, it is evident that, even though the children across all ages could not initially categorise magnets as a class of bodies with a specific property that other objects do not have, the appropriate didactic intervention led them to construct OD I. Our study shows that 79.6% of the first age group (4 to 4.5 year-olds), 97.8% of the second age group (4.5 to 5 year-olds) and 95.1% of the third group (children older than 5 years of age) succeeded in constructing the first operational definition.

The nature of the first definition explains the success rate across all ages. This definition was formulated in such a way that it did not contrast with the infants' basic intuitions regarding magnetism. Some objects attract others, whereas some other objects do not. Attraction was the only factor to be taken into account. The definition did not clash with children's conception of magnetism as a substantial property of objects, nor with their view of causality as a homeopathy. Finally, it was consistent with the image schema of attracting force and the pulling model, according to which a magnet is a body that has a pulling capacity.

(b) The second operational definition yields markedly different results. Only 14.3% of the first group 'succeed' in constructing it. Fifty percent of the second group and 85.4% of the third group 'succeed' in the task. Thus, only children older than 5 years of age 'succeed'. Almost all younger children and nearly half the children from the second group 'fail'.

In the second definition, objects that are to be categorised as magnets sometimes attract and sometimes repel other objects. In this case, there are two factors to be taken into account, in that the information these two factors provide must be combined in order for successful categorisation to be achieved. In other words, the causal property of magnets to both attract and repel should be co-ordinated. Other researchers have also found a lack of capacity in children less than 5 years of age to combine and integrate information from two independent sources (Fisher, 1980; Halford & McDonald, 1977), and to co-ordinate two causal schemes (Demetriou & Valanides, 1998).

From the perspective of OD II, the phenomenon of repulsion further complicates matters. Homeopathy seems to be violated, in so far as the same object can attract and repel other objects and, consequently, the causal patterns that could explain the phenomenon become more complex and beyond the comprehensive abilities of the younger children.

Furthermore, our study reveals the gradual character of the acquisition of the cognitive resources that are required for the successful construction of the second definition. The children between 4.5 and 5 years of age are 'halfway' towards 'success'. The acquisition of the cognitive resources is not an all-or-nothing matter; instead, it occurs gradually and culminates at around the age of 5 (in full agreement with Halford & MacDonald, 1977 and Fisher, 1980).

(c) But what exactly have children, who have successfully constructed OD I and OD II, learned? To examine this issue, one has to analyse the children's responses when they were trying to construct the two operational definitions (a sample of these responses is given in Tables 2 and 3). The analysis clearly shows that children of all ages who 'succeeded' in constructing OD I have understood that an object is a magnet if it can attract other objects and know how to use this information to determine whether an object is a magnet. In fact, some among them believe that attraction is both a sufficient and necessary condition for an object to be a magnet, in so far as they state that, if an object attracts others, it is a magnet and, if it does not, then it cannot be a magnet. Furthermore, they also know that not all objects are susceptible to the magnetic pull. The few children who 'failed' have missed the significance of attraction, and categorised objects based on the colour similarity between these objects and the magnets with which they had been initially trained, or thought that an object is a magnet if it attracts all other objects.

The analysis of responses with respect to OD II shows that the older children and those few among the younger children who constructed OD II know that magnets attract some objects and that a magnet can attract or repel another magnet depending on the orientation. This can be inferred from the fact that, not only do these children know how to manipulate the objects to determine that something is a magnet, but they are also aware of the criteria that guide their actions. Children's responses show that most of the children of all groups who 'failed' to construct OD II did so because they occupied themselves only with attraction and failed to take into account repulsion. The rest used analogical reasoning and claimed that, in order to determine whether an object is a magnet, one should look at its colour, since the magnets encountered during the instruction were red.

(d) In discussing the experimental design, we argued that successful learning requires that the learner does not process the full complexity of the problem from the very beginning, but faces, instead, a simpler version of it. If this scaffolding does not occur then learning becomes problematic, the reason being that scaffolding results in the simplification of the problem space, so that a heuristic search of it is possible and effective. The learning system has the opportunity to learn first the domain's basic features and regularities. These basic regularities provide the learning system with a code that will allow it to recode the information pertaining to the complex problem. This recoding, as we have said, may lead to a successful reformulation, and solution of the problem.

To test this, we bypassed lesson 4 and the first operational definition with a group of 29 students (replacing it with free exploration activities with magnets), proceeding directly to the second operational definition. The study shows that only 41.4% 'succeeded' in constructing the second definition, in comparison with 85.4% of the pre-schoolers of the same age (the third group) that succeeded in the second operational definition after the full sequence of activities. Our study thus confirms the decisive role in successful learning of diminishing the cognitive load (for a similar finding, see Merrill & Reiser, 1994). In the case of our study, the ordered presentation of the two ODs purports to accomplish this scaffolding.

In Clark and Thornton's (1997) account of learning, problems can be divided into two categories: those whose solution requires the finding of the surface structure of the data; that is, of first order regularities, or phenomenological laws; and those whose solution requires finding the deep structure of the data; that is, the more abstract regularities (for a similar analysis see also Dennett, 1994; Dominey *et al*, 1998). Clark and Thornton (1997) call the former cases problems of type-1 and the latter problems of type-2.

Problems of type-1 can be solved relatively easily by means of an inductive search of the relevant problem space that can extract the basic statistical distributions in the data. Statistical procedure cannot be applied directly to type-2 problems. Problems of type-2 could be solved if transformed to type-1 problems. The first operational definition is a typical case of a type-1 problem. It requires that the children limit themselves to examining only information regarding the phenomenon of attraction between bodies. When the first definition is understood, the children 'know' that those bodies that can attract others are to be categorised as magnets, all other factors (such as shapes, colours, etc.) becoming irrelevant to the problem.

Tables 2, 3 and 11–13 are revealing, in that they show exactly how the children, focusing on attraction, arrive at constructing the first definition and then the second. The property to attract other bodies becomes the recoding schema based upon which they will attack the second definition, which is a type-2 problem. Once other factors have been eliminated and only 'attraction' matters, then those children that have the appropriate cognitive resources include in the picture information regarding mutual repulsion (see Table 3) and eventually understand the second operational definition too.

Of the 58.6% of the children in the experimental group who did not 'succeed' in constructing OD II, the majority (16 out of 17) 'failed' because they concentrated their efforts on establishing attraction as the salient magnetic property and completely ignored repulsion. Since they were instructed to try different orientations to see that two magnets can both attract and repel one another, some of them (9 out of 17) incorporated the instruction regarding orientation in their attempt to establish attraction, did not consider repulsion, and claimed that a magnet attracts objects in various orientations (Table 6). The rest (8 out of 17) completely ignored the instruction concerning different orientations. In contrast, the third group of children, who had been taught OD I, did not spend any time on establishing attraction and proceeded directly to examine whether two objects that are attracted could repel one another in a different orientation (Table 7).

(e) Finally, concerning the Raven Test, the regression analysis shows a stronger dependence on children's ability to construct operational definitions on chronological age rather than on cognitive maturation. This indicates that chronological age, and not cognitive maturation, is the more decisive factor that explains the patterns of performance in the tasks. The continued development of language and other skills with chronological age may go some way towards explaining this dependence. An issue that we have not explored is that of the retention of the ability to reconstruct an OD after a period of time. Such data would enable us to make more conclusive claims about the effectiveness of the teaching intervention and the nature of the transition that children undergo around the age of 5 with respect to this ability.

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Making sense of the natural world: seeds and plant germination

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Abstract

The aim of this article is to describe the teaching and learning situations that occurred in elementary schools as observed by the authors as they supervised teaching practice during the *Experimental Science for Primary School Teachers Programme.*

Over the past few years, efforts have been made in Portugal to invest in the training of early years teachers in experimental science education, one such case being this training programme funded by the Portuguese government. The programme aims to improve the teachers' practice in experimental science, supported by classroom activities that contribute to children's scientific literacy, in order to make sense of socio-scientific issues.

In this article, the authors present and analyse some of the ways that children (from 6 to 8 years of age) find to explain the natural world, as well as examples of strategies used by teachers to help the children to understand scientific ideas, here illustrated through the theme of germination. Data were collected during the course of supervision work by the authors.

Keywords: experimental science; primary school; learning; teaching; germination.

Introduction

Teacher education is the key factor determining the quality of science education that schools can provide. No resources can ever be effective if teachers are not able to fully understand and use them. A view of the experimental sciences, as part of literacy promotion in the broad sense, introduces a further factor to the recognition of the importance of quality training for primary science teaching (Harlen, 2004; Sá & Varela, 2007).

Over the past few years, efforts have been made in Portugal to invest in the training of early years teachers in experimental science education, with project development and training programmes funded by the Portuguese government. The *Experimental Science for Primary School Teachers Programme* (Martins *et al*, 2006) is one example of such a programme. This kind of initiative aims to improve the school teachers' practice in experimental science, working on such themes as *floating in/on fluids; dissolving in fluids; seed, germination and growth; shadows and images; electrical phenomena;* and *changes of physical state* or other topics listed in the National Curriculum.

The topic *germination* is part of the primary school curriculum, which suggests conducting experiments on and the observation of the reproduction methods of plants, specifically the germination of different kinds of seeds. Teachers are encouraged to plan activities with students, enabling them to identify environmental factors that affect plant life, such as water, air, light, temperature and soil.

Beyond methodical work, there are also important attitudes that science can promote, such as persistence, patience and taking care. The theme of *germination* is a perfect way to illustrate these skills, since we must 'sow to reap at the right time'. To do this, it is necessary to plan, wait, look after and cherish the hope that all factors, internal and external to the seed, gather for the embryo to slowly come out of its dormancy and commence a more intense metabolic activity. Germination happens when the reserves so permit, giving rise to a new plant, which starts its growth when its photosynthetic organs are able to start producing organic compounds, providing food for itself and, together with other plants, to the ecosystem. The question of time, cycle, sustainability, conservation and diversity is very important to keep in mind and children should be encouraged to discover new meanings, reflecting on the world of science and its language and attempting an appropriation of the real world in a more holistic and systematic way.

We describe ways that children use to understand germination and the development of plants, and approaches that teachers have developed to help them in the process of thinking and constructing knowledge, during a period of training carried out by the authors with these teachers. Our attention focuses especially on the *meanings*, and how meanings are generated and mediated in the classroom. We support a teaching and learning perspective of science that emphasises knowledge construction and reflective thinking in a social context of communication and co-operation, where the activities are personally relevant to the child and induce socio-emotional and intellectual development (Harlen, 1992; Howe, Davies, McMahon, Towler & Scott, 2005; Oliveira *et al*, 2009).

The Experimental Science for Primary School Teachers Programme

The in-service training programme in *Experimental Science Education for Teachers in Primary Schools* was an initiative of the Ministry of Education, which took place between 2006 and 2010 in Portugal, and its implementation was conducted by several higher education institutions, including the University of Évora. The training team consisted of university teachers who undertook the training and monitoring of one or more groups of up to 12 student teachers.

The training programme had as its primary purpose the improvement of education in experimental science in primary schools, through the development of good practice for teaching and the learning of basic experimental science. The objectives of the programme were to deepen and develop the skills of primary teachers in the following areas:

- Understanding the importance of an adequate science education for all and developing an innovative intervention in science education in their schools;
- Developing an attitude of interest, appreciation and liking for scientific knowledge and the teaching of science;
- Knowledge of educational content in the teaching of science in the early years of schooling, taking into consideration the current curriculum guidelines for the teaching of basic physical and natural sciences, technical education and the study of the environment, as well as recent research on teaching of science;
- Exploration of teaching situations for the teaching of science in primary education; and
- Conception, implementation and evaluation of practical science, laboratory and experimental activities in primary education.

To achieve these objectives, a training plan was developed to span two academic years, supported by booklets, covering six themes: *Exploring Objects ... Floating in Liquids, Exploring materials ... Dissolving in Liquids, Exploring Seed and Plant Diversity, Germination and Growth, Exploring Light and Shadows ... images, Exploring electricity ... lamps, batteries and circuits*, and *Exploring Changes in the physical state of matter.*

These themes, though connected to the curriculum, can be considered as external modules that have been inserted both in the context of the overall programme, and in the area of natural and physical sciences.

In each year of training, the programme lasted approximately 30 weeks and included:

- Five plenary sessions, attended by all the trainers and trainee teachers, and held at the institution responsible for training (the University of Évora). The first session corresponded to the beginning of the training and the last to the end; the remaining sessions had the purpose of introducing each new topic and making an assessment of the previous theme.
- Ten group sessions (8 to 12 trainee teachers per group), with three sessions for each subject and a working session to prepare the final assessment. These sessions were dedicated to the analysis of the booklets, and to the preparation and discussion of the practical activities to be developed in the classroom.
- Three individual sessions for monitoring the classroom activities of the teacher trainee. Each of these sessions lasted approximately two hours, and was followed by a discussion of about one hour. Student teachers could choose to plan different activities, either from the booklets or from those presented in the group sessions.

In the end, each teacher trainee would have received 63 hours of training. Apart from formative assessment in all sessions (plenary, group and individual), an individual assessment of trainee teachers was carried out. This consisted of a presentation of a portfolio representative of the training pathway of the primary teachers, in order to evaluate the outcomes and the processes for obtaining them.

Teaching and learning science

Science activities allow children to expand knowledge and understanding of the physical and biological world. These activities have the potential to extend the knowledge of pupils, stimulating their natural curiosity and desire to learn and understand the natural phenomena that occur in their daily lives, and the factors that influence these phenomena (Driver *et al*, 1994). Children build knowledge and values about themselves and the world in social contexts, through the relationships and interactions with others (Vygotsky, 1986).

There is now consensus amongst the scientific community that learning is based on socio-constructivist processes. Research has shown that, when children come to school, they bring knowledge about subjects with which they are familiar, but also representations about content in different areas, such as biology, geology, chemistry, physics and others. It is thus very important to focus a child's attention on evidence, in a climate of interaction with peers and adults, in order to develop the child's observational acuity, to settle relationships between observations and thereby build new mental representations of reality (Harlen, 1992; Sá & Varela, 2007).

Recognition of the importance of how children incorporate the external world and construct knowledge, along with the consideration that thinking is strongly linked to concrete action with objects in the first years of schooling, seems to reinforce the need for primary school programmes to enable children to study and manipulate objects in the physical environment.

However, as Vygotsky (1986) claims, children's spontaneous knowledge interacts with integrated systemic organisation and this conceptual systematisation should be ensured through connecting the pupils with the scientific concepts that will give them the means to a deliberate and conscious control of their entire conceptual system.

The importance of science education for children lies not only in the content, but also in the thinking skills and competencies it develops (Harlen, 2004). This means that content in science should not be seen as an end but rather as a means, given that processes are more important than results when children are trying to make sense of the world and explain it.

According to Hodson (1998), science education should be developed in three different areas: *learning science, learning to do science* and *learning about science.* Children in primary school should acquire basic scientific ideas, appropriating processes and procedures, and develop scientific attitudes, aiming for the formation of scientifically literate citizens. Activities should be based on children's interests and explore situations where they have to interpret or solve problems, taking into consideration the students' ideas about the topics (Lakin, 2006).

The teacher's role is to create meaningful situations in which children can express their ideas and discuss them with others, confront these ideas using the information available as well as experimental evidence, and realise that there are different ways to explain the same phenomena and that some are better than others (Cosgrove & Osborne, 1985). The teacher needs to help children to make explicit their ideas, through questioning, observing their actions, their drawings, conversations with peers, and so on.

Questioning is a scientific procedure that should always be present in the teaching and learning of science. The way that the teacher asks and answers questions has strong implications for cognitive and emotional development. While carrying out activities, it is important to keep the dialogue going, posing different types of questions that can help reflection and knowledge construction, and the teacher should give time for children to think about the answers (Black & Wiliam, 1998; Black & Harrison, 2004). Children should also be encouraged to ask questions and the teacher should avoid giving immediate answers. Instead, it would be better to rephrase the question and make it more intelligible, respond with questions or propose new tasks (e.g. search for books, conduct an experimental activity) to allow children to find the answers. These strategies depend on the nature of the issue, the interest aroused or the relevance and complexity of the questions (Black *et al*, 2002). The teacher assumes the role of children's learning mediator as he/she organises relevant activities, tasks and discussions and, as he/she helps and supports the pupils, contributes ideas, provides clues, gives suggestions and asks questions.

We may consider different types of activity in primary schools depending on the maturity of the children and the kind of objectives to be achieved. One type of activity could be planned *sensory experiences,* based on vision, smell, taste, touch and hearing in order to foster the ability to observe, and focusing on relevant issues. Observation of these will allow the grouping of objects and materials according to different criteria: observable characteristics (rough/ smooth, hot/ cold, big/ small), and properties (floating/ not floating, dissolving/ not dissolving, permeable/ impermeable). It is very important that children interact freely with objects and materials, making and testing predictions.

Illustrative experiments are designed to illustrate concepts, relationships between variables or to introduce a specific skill. Activities are prepared by the teacher, who provides the materials and guides the children in order to help them understand the subjects.

Finally, *investigative experiments* start with a problematic question, the answer to which is not known by the child. These questions can be more or less demanding depending on the characteristics of the group and on the objectives to be achieved. They allow children to work on their own ideas, make predictions, test hypotheses, conduct experiments and solve problems. As Goldsworthy and Feasey (1997) argue, investigating is an important activity in primary science because it makes children aware of the scientific processes in the classroom and leads them to a better understanding of science.

Whatever the type of activity, we encouraged the trainee teachers to carry out the following: register children's ideas before, during and after the activities; encourage predictions and explanations *(What will happen? Why has it happened?)*; promote the use of different types of records (text, drawings, graphs) and involve children in deciding the form and content of records; and discuss the results and review the steps taken, so that they can make better sense of the way in which the natural world works.

The topic *Seeds, Germination and Growth* was chosen because it is a curricular topic in the Portuguese primary school and corresponds to the subject area of expertise of the authors.

Investigating seeds and germination

The main aims of the activities were as follows: to recognise the wide variety of seeds in respect to some of their characteristics as well as differing behaviours when placed in water; to understand that the germination of a seed gives rise to a new plant; to recognise that the germination time is not the same for all types of seeds; and to understand the influence of some environmental factors on germination (Martins *et al*, 2007).

What do these children think about seeds and germination?

Children do not understand growth as needing materials; that food provides the materials and energy for the process of respiration. They see both growth and germination of plants as needing light. In this research, germination is understood to mean the early stages of plant growth from the latent state of life, a seed or a spore. When a seed germinates, it starts to consume oxygen and liberate carbon dioxide. This is the sign that respiration processes have begun, that the chemical reactions that mobilise the energy contained in the reserve substances for growth and development of embryos are taking place.

What do children say about seeds?

As at first the notion of diversity amongst the children was limited, the activities included the observation of a great variety of seeds in order to construct the concept. The topic was planned to start with a sensorial activity, to demonstrate the existence of seed diversity and to distinguish seeds in

Figure 1: Observing seeds.

terms of some of their characteristics (colour, shape, size and texture). Children were stimulated to observe and freely explore various types of seeds – they selected and classified seeds according to different criteria, using a range of tools including magnifying glasses and rulers.

Children were asked to group the seeds according to a range of criteria and to record their choices. Criteria included colour, size, shape or weight (using a digital scale).

Children's preconceptions about seeds were then explored through language. The pupils (aged 6 to 8 years of age) first explained their understanding of seeds in their own words (the following quotes are the most representative collected during the class observations):

'Inside the seed are leaves, flowers and very little roots'
'The seed has a leaf and a lung to breathe'
'The seeds have no life'
'The seeds have a special type of life'
'It grows a little something in there that opens the skin and leaves, grows and gives rise to a plant'
'It will give rise to a plant of the same species'

The sentences show the effort that children make to explain and make sense of what they see. As can be inferred from their responses, some of the ideas are quite naive and others reflect an anthropomorphic view. Many children demonstrated difficulty in distinguishing 'seed' from 'plant'. However, some pupils showed some knowledge, not only around the representation of a seed, but also about the germination process. Indeed, the processes occurring in nature are

Figure 2: Drawing seeds.

continuous and the boundaries that we set for better study and understanding are artificial, naturally causing difficulty for children.

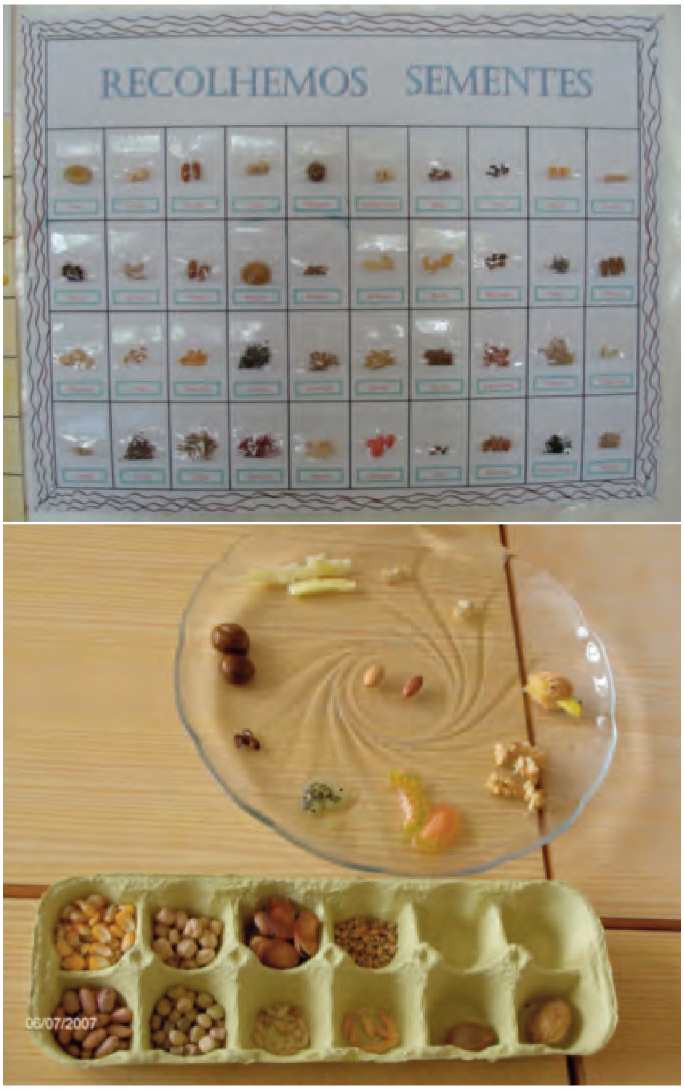

Figure 3: Display of seeds.

To develop the children's ideas, some seeds were placed in water for 24 hours, so that they could open easily and their insides seen. Children observed large seeds, such as broad beans (see Figure 1), so facilitating the identification of the seed coat, cotyledon and embryo.

At this stage, they were encouraged to make drawings of what they were seeing (see Figure 2).

Teachers found different ways of helping children to better construct the concept of a seed, as shown in Figure 3.

What do children say about germination?

To observe what happens to the seeds after they are placed in water, some simple devices were made available to enable easy observation of the changes occurring and the emergence of the seedlings (see Figure 4). Children were thus able to observe the bursting of the seed coat, the emergence of the radicle, the decrease in size of the cotyledons, the formation of the aerial parts of the new plant and the emergence of the green colour, indicative of its photosynthetic capacities.

Children were encouraged to make regular observations of seed germination and record these observations in tables, diagrams and drawings in order to be aware of the ongoing changes.

Figure 4: Seed-plot.

The children observed:

'There is a very tiny seed that opens and goes out'
'The root grows down to the ground to hold the seed and feed'
'The stem grows upward because it goes in search of the sunlight'

As these quotes highlight, children had the notion that the seed would result in a new plant, but their theories were not clear about the process of how the seed becomes a plant.

The next activities consisted of planning and preparing devices where several seeds could germinate and verify the conditions under which seeds do or do not germinate, and why. The pupils made predictions regarding the effects of water and light on the germination of bean seeds and set up devices with small greenhouses that allowed them to observe the germination under different conditions of light and humidity, to highlight the importance of the control variables, in order to be able to draw conclusions. We recorded the following statements made by the children as they carried out the different experiments:

'Seeds germinate better in the presence of light'
'First germinated the seeds that were warmer, the other took longer because they were cooler'
'The soil provides heat, food and shelter to the seed'

Among the pupils' ideas on germination, we emphasised in our teaching those related to the need of light. A possible explanation for the inclusion of light as a requirement for germination could be a lack of discrimination between seed germination and plant growth. In fact, the two processes occur in nature on a continuum that is only separated for study purposes, and this disjunction is hardly perceived by children. Moreover, many of the experiments previously carried out by the pupils had always been in the presence of light and this may have fostered the idea that light is necessary for germination. This is an example of an idea that emerges from the interaction with the experiences in schools and embeds itself as an alternative conception (Giordan & Vecchi, 1987).

Germination appears to be a concept that the child does not associate spontaneously with his/her everyday knowledge of seed germination in soil. The models used in school and in soil systems are thought of as separate concepts. Hence, it is important to relate the absence of light during germination with everyday life: seeds germinate in the soil in the absence of light.

Taking into account the ideas children had about how a seed turns into a plant, some classes were directed to explore that topic. By observing, some children recognised similarities between the embryo and the structure and morphology of a plant, which made them think that the little 'plant' will grow into a big plant. The initial theory was then modified towards a higher-level understanding, which has its foundation in a better knowledge about the constitution and structure of the seed.

There was also diversity of meanings and, in co-operative interaction with peers and teacher, new meanings were discussed, selected and shared. Experimental evidence thus generated ideas and questions about the phenomena being studied, which expanded the existing meanings after discussion, negotiation and critical selection.

During the activities – observation of seeds, germination of different seed types, study of some factors influencing the germination – the children's interest in and enthusiasm for observations, experiments and measurements was evident.

In conclusion, activities were characterised by the following:

- Exploitation and appreciation of children's preconceptions, sometimes more complex than they seem
- Encouragement to observe and show curiosity
- Focus on careful recording of predictions and observations
- Development of important skills (questioning, discussing, observing, previewing, experimenting)

There are no results yet of the impact of the programme on children's learning in global terms. Data from the national report (Martins *et al*, 2010) indicate however that, in the opinion of trainers, children have developed thinking skills, including making predictions, making observations, drawing conclusions and communicating. The report also mentioned an improvement in formulating questions and planning investigations, including the control of variables, and an improvement in procedures such as taking measurements; manipulating instruments and handling laboratory supplies.

Reference to the engagement in science and the development of pupils' autonomy was also made by teachers, with improvement in co-operation between students, in particular in the context of group work, noted. The report also records that the trainee teachers expressed a high degree of satisfaction regarding the *impact of training on improving practice* in all the following categories: diversification of teaching strategies; improvement in quality and quantity of experimental activities; bigger and better use of them; and better evaluation of experimental components (Martins *et al*, 2010).

Conclusion

The idea of these activities was that the programme contents were converted into educational settings, where children were actively involved in thought and action, in order to mobilise, transform and integrate knowledge.

We believe that a scientific approach of the physical world around the child is of huge importance as, without the opportunity to think and act on it, thinking about reality is limited to a world of subjective impressions that can thus remain for life. With the activities undertaken, children could improve the quality of their ideas, through reflective thinking strategies in social interaction, raising their levels of thinking. In this process, the children's awareness of their ideas, the verbalisation and ability to think about these ideas in co-ordination with data emerging from their experiments, along with other ideas, particularly those introduced by the teacher, played a critical role.

The global results show a very positive impact in terms of the programme, as attested by trainees and trainers; improvement in the practice of experimental teaching was reflected in an improvement in pupil learning across procedural and conceptual dimensions. Thus, notwithstanding the limitations of the available data, evidence pointed to the fact that the main purpose of the training programme was achieved: the improvement of experimental science education in the schools concerned, through the development of better practices for teaching and learning science.

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Building scientific meanings through the Solar System Project

■ Maria Helena Blasbalg ■ Agnaldo Arroio

Abstract

This article aims to increase the discussion, within science education, about children in early years of schooling. A socio-cultural perspective of science education informed this research. Seventeen children, aged from 5 to 6 years of age in a first grade class, participated in this research. A qualitative research design was used to investigate how children construct scientific meanings. The pedagogical activities were planned as an interdisciplinary project, providing opportunities for children to construct representations on matters discussed according to the three different forms of representation established by Bruner (2007; 2008). The data analysis indicates some important aspects about the process of constructing scientific knowledge by this age group. It reiterates the necessity of offering children opportunities to represent their scientific experiences in different ways and in the multiple contexts of everyday school life.

Keywords: Early science education, interdisciplinary project, systems of representation

Introduction

A wide range of research in early science education confirms the fundamental role of this area of knowledge in child development (Harlen & Rivkin, 2000; Vega, 2006; Bruner, 2007; Deighton, Morrice & Overton, 2011; Johnston, 2005, 2011a; Campbell, 2009; Carvalho, 2004, 2007, 2008; Sasseron & Carvalho, 2007; Capecchi, 2004; Vygotsky, 1962). These studies, based on a socio-cultural perspective, stress the role of science education in the formation of citizens who can be enabled to perceive science and technology as an inherent part of their lives and who understand the implications of this knowledge in the development of human life and the planet's future.

However, research performed by Monteiro and Teixiera (2004), Fourez (2003), Jiménez-Aleixandre, Roberts and Duschl (2000), Driver and Newton (1997), suggested that teaching science to young children is a complex task for teachers, as it requires an integrated understanding of the prevailing current teaching concepts in this area of knowledge, and the learning processes through which children of this age attribute meanings to the school curricula. It is the teacher who is faced with the enormous challenge of articulating these aspects in their teaching practices, and integrating them into subjects for this age group.

This article intends to contribute to the discussion of the understanding of meaning-making processes through an interdisciplinary project, *Solar System*, which was implemented in a first grade class of 5-6 year-olds.

Theoretical framework

The socio-cultural perspective of science education is supported by the assumption that the particular characteristics of human social life are reflected throughout the knowledge process of internalisation (Vygotsky, 1994). Through this approach, science teaching should go beyond the act of memorisation of concepts to create opportunities for the children to build contextualised explanations, related to their everyday lives. In this way, science is seen as a culture with its own rules, language and values (Carvalho, 2008; Capecchi, 2004; Lemke, 1998; Driver, Asoko, Leach, Mortimer & Scott, 1994). Therefore, teaching science should enable the reflexive engagement of children in scientific issues, based on their own interests and concerns, in order to encourage them to participate critically and consciously in contemporary society. For this, it is necessary to furnish children with opportunities to discuss topics related to scientific culture, technological innovation and environmental problems, which may affect their lives (Sasseron & Carvalho, 2007).

The teaching of science in the early years of schooling can and should be planned and designed in order to avoid simple memorisation of scientific concepts, rather encouraging reflection on different aspects of scientific culture through experimentation, search for explanations and, when appropriate, the introduction of terms used by the scientific community (Deighton, Morrice & Overton, 2011; Johnston, 2011b; Carvalho, 2004; Roth & Lawless, 2002; Candela, 1999; Driver *et al*, 1994; Lemke, 1990).

Science education in the early years of schooling

John Dewey was an important supporter of the teaching of science in the early years of a child's education. According to Dewey, the study of science is especially valuable once children develop the ability to interpret and control their past experiences, enabling the process of understanding everyday environmental phenomena (Dewey, 1980).

The concept of experience and its fundamental role in the process of teaching and learning was extensively discussed by Dewey (1980), who claimed that the subject, the core element of experience, attributes, in a subjective manner, qualities to the objects according to the child's own experiences, which are due to their social and cultural interconnections.

The subjective combinations that children perform during the attribution of processing meaning have also been studied in depth by Vygotsky (2003). According to Vygotsky, the human brain is not simply an organ capable of storing and reproducing past experiences, but also one capable of combining and re-elaborating past experiences into new approaches. Related to their experiences, needs, interests and social traditions, children reproduce their experiences by re-elaborating the past experiences with new combinations that reflect aspects of their time and environment. Therefore, the richer the experience, the greater the possibility of establishing meaningful new knowledge.

In a convergent way, Johnston (2005, 2011a) discusses the importance of developing science education from early childhood education and highlights the importance of the practical scientific experiences for child development. According to Johnston, attributing scientific meaning develops as children construct knowledge and solve problems arising from exploration and experience of the phenomena of everyday life.

Considering that exploration is an important part of the learning process, it is necessary to provide opportunities for children to explore a large variety of sources. Through a range of experiences, children have the opportunity to check and verify the operation of the objects and the cause and effect of day-to-day phenomena. As children build hypotheses to understand their environment, they re-elaborate the information obtained and consolidate the learning of the scientific concepts involved (Vega, 2006).

It is important to emphasise that science teaching using this approach should seek not only to understand the scientific concepts, but also to develop attitudes and abilities related to them (Johnston, 2011a). From this perspective, science education should aim to promote opportunities for children to be in contact with several aspects of the scientific culture, from the social interaction and handling of the material provided by the school (Vega, 2006).

The studies of Jerome Bruner (2008) also highlight the importance of the systematic teaching of elementary notions of science and mathematics in early years education. This knowledge can encourage a better understanding of some concepts that will be worked in later grades. However, teaching performed in such a framework is only possible when the curriculum revolves around major issues, principles and values that society considers worthy of interest.

According to Bruner (2008), children build 'representations' to appropriate aspects of the environment. This process involves more than just storing memory of past experiences. It involves a coding and processing system able to, when applicable, recover the relevant information in order to achieve a higher level of understanding of current information.

Bruner (2007; 2008) recognises that humans, in developing intellect, use three systems or modes of processing information in the construction of models of reality. Such systems are called according to their nature: *enactive representation*, *iconic representation* and *symbolic representation*. This means that one can learn through motor responses, arising, for example, from manipulating, from image, or from symbolic meanings such as language. According to Bruner (2008), the development of human intelligence necessarily depends not only on the integrated use of the three systems of representation, but also on the transposition preserved by each one.

Design and procedure: the science education in the *Solar System* project

This present research involved a primary first grade class in an independent private school in São Paulo. This class comprised 18 children, aged from 5 to 6 years of age. Since the focus was to study, in depth, the context of research development, a qualitative research method was selected, whose design is underpinned by theoretical hypotheses in which meaning and process are central concerns when understanding human behaviour (Bogdan & Biklen, 2003). Data were collected in order to explore the formal situations of the science teaching and context of the everyday activities of first grade to encompass the three systems of representation *(enactive*, *iconic* and *symbolic)* (Bruner, 2007; 2008). The enactive representations were acquired through photographs and notes recorded in a field notebook. The iconic representations were obtained from drawings designed by the children, with the aim of recording and systematising the themes studied during the project, from free time drawings and drawings from other activities. Lastly, the symbolic representations were gathered using circle time filming and its transcription, and through collective texts designed to organise the ideas studied through interviews with the researcher.

Considering the curricular expectations of children of this age, and also the assumptions of a socio-cultural perspective of science education, the theme 'solar system' had been systematically studied during the school year through an interdisciplinary project (Edwards, Gandini & Forman, 1995) originated by the concerns of the group.

The *Solar System* project started with a conversation about a globe brought to school by a child. As the globe created great interest, children began to take books, toys and news pieces about the topic to school. Such interest resulted in an interdisciplinary project, with special focus on the construction of scientific meanings. From this, pedagogical activities were planned based on curriculum objectives, providing opportunities for children to experience aspects of scientific culture and for the construction of representations of those experiences throughout the three systems of representation (Bruner, 2007; 2008).

Thus, a weekly routine of study was established, consisting of two stages. In the first stage, books, newspaper articles and surveys conducted by the children using the Internet were read and discussed during circle time conversation. In addition to providing opportunities for the development of symbolic representations, the circle time conversations are considered essential routine activities due to the importance of oral language in written language acquisition, the main objective of the Brazilian schools' first grade. It was agreed with the group that, in each session, only one component of the Solar System would receive special attention, starting with the Sun, until all planets were covered. After sharing new information, materials were provided for the children to explore freely, enabling the development of enactive representations through manipulation. Aiming to broaden the children's contact with scientific culture, an overhead projector was used to show images from and about space.

The second stage of the project included a verbal presentation of information studied so far, followed by the elaboration of symbolic representations of the concepts raised through a collective text written by the teacher. Since the children in this study are at an early stage of literacy, the development of collective texts is considered a very important practice, not only for science education, but also for the consolidation of skills associated with the writing code.

In order to establish a creative space of re-elaboration of the themes previously studied, each child produced a graphic (iconic) representation, that they deemed more interesting. They freely chose materials and techniques with which to perform their recordings. After completing their work, the children explained individually the content of their representations to the researcher. The discussions were concluded with the development of an individual representation about the concept *Planet*, based on the planets already studied. At the end, each child explained to the researcher his/her personal impressions about the *Solar System* project.

As the plan was to use the different elements to compose a book as part of the curriculum goals, each child gathered all the graphic recordings made and designed his/her own book about the Solar System.

Findings

The activities outlined in this research were planned based on a socio-cultural perspective of science education and were intended to identify relevant aspects in the process of meaning construction of subjects related to science.

As illustrated in Figure 1, it was found that children commonly created their iconic representations as combinations of the studied concepts and elements of their everyday lives, including their interests or concerns about friends and family.

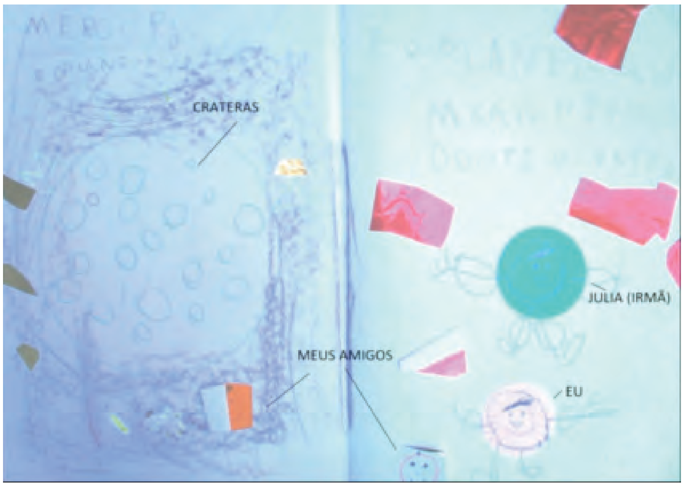

Figure 1: Record of the Planet Mercury with everyday life elements made by BS *(eu)*, her sister *(Julia)*, her friends *(meus amigos)* and the characteristic craters of Mercury *(crateras).*

According to Vygotsky (2003) and Dewey (1980), these combinations are an integral part of attributing meaning to processes and enable children to transform new concepts into familiar ones endowed with a unique and personal meaning.

It was also observed that the development of representations about the scientific concepts studied during the project went beyond the formal learning moments, extending to other contexts of everyday school life, such as in free time, play in the break time (Figure 2) and during other activities in the classroom (Figure 3).

Figure 2: Children drawing the Planet Earth on a chalkboard in the schoolyard during break time.

Figure 3: Flag produced by GC to decorate the June County Fair, with the message *'A clean world'.* (He reported to the researcher that what was drawn was the Planet Earth, Venus, a meteor and the Sun).

Besides elaborating on representations of the topics studied in various situations of everyday school life, the data showed that children concomitantly used different forms of representation as established by Bruner (2007, 2008) to assign meaning to a concept. This fact has been observed frequently, mainly in situations where oral explanation of the concepts proved to be difficult. Table 1, based on the transcript of RC's interview, illustrates how this student turned to other forms of representation to overcome the difficulty in adequately preparing a symbolic representation of the concepts while trying to explain his ideas to the researcher.

Table 1: Transcript of the interview between RC and the researcher.

Turn taking	Oral transcript (symbolic representation)	Enactive representation	Iconic representation
1	RESEARCHER: Did you like to study about what goes next to the Solar System?		
2	RC: Loved it!		
3	RESEARCHER: Why?		
4	RC: Because I discovered lots of things.		
5	RESEARCHER: Tell me what you discovered.		
6	RC: I didn´t know that the Sun was a star. No! I knew that the Sun was a star. I knew nothing about Mercury. And now I know that is the planet that is closest to the Sun, and the Moon looks like it because it has a lot of craters. Venus has clouds of sulfur, is very beautiful, looks like a star and has zero moons. It is the stinking planet because it has sulfur clouds.	Opened a book and searched for the page related to the Sun. Searched the book.	Observed the drawing he had made to represent the Sun. He looked closely at the illustrations prepared for his records.
7	RESEARCHER: That´s it.		
8	RC: Earth … it has many countries, a lot of water and people and cities and it goes around the Sun. The Moon goes around the Earth. Now I'll do it. It's very difficult because you have to make the Earth rotate around itself. I know she turns around itself. Remember when MR invented that we have headaches because the Earth is spinning? *Read the written text on his record:* Mars has water, giant volcano, two moons; it is known as the red planet. Craters, volcanoes, water, two moons. Ah, Jupiter! If you fall into Jupiter you will float…a part is missing *(referring to his work)*. No problem, later I will find it. It has a very thin ring. It has 63 moons! Red spot. It's gaseous, is the second largest, has at least… 50 moons. Its rings are made of ice and dust.	Searched the book. Handled the articulated model, built on record about the Earth. He made circles with his finger in the air imitating the hurricane and turned the page.	Checked if the two moons drawing was in his work. Observed calmly the drawing of Saturn
10	RC: *Read the notes on Neptune.* Neptune: It is a gaseous planet, has 13 moons. He has a hurricane called Great Black Point. It is the eighth planet away from the Sun.	He pointed to the Black Point, making a circular motion with the index finger to simulate the movements of the hurricane.	
15	RC: Planet Disco: The moon is like a disco ball. He has a ring of the same colour, so you cannot see the ring.	He pointed to the ceiling and turned the index finger in the air, referring to the mirrored globe in clubs.	

Table 2: Transcript of the interview between RR and the researcher.

Turn taking	Oral transcript (symbolic representation)	Enactive representation	Iconic representation
1	RESEARCHER: Did you like to study about the Solar System?		
2	RR: Yes.		
3	RESEARCHER: Why?		
4	RR: Because I discovered lots of things.		
5	RESEARCHER: Tell me what you found out.		
6	RR: I did the Sun, the Earth, on Jupiter. It has Neptune. The Earth rotates around the Sun? I got it, I got it! Neptune is a gaseous planet, isn´t it?	He picked up his book and flipping through it, began to describe his findings to the researcher... Handled the articulated model, built on record about the Earth. Continued manipulating his book calmly...	Slowly observed the illustrations in his works. Observed calmly the drawing of Neptune.

The filming of RC´s report shows that this student needed to observe his book illustrations or read the symbolic representations arising from collective texts before answering the questions. Sometimes he needed to complement his speech with hand movements.

Similarly, the student RR resorted to hand movements, the handling and observation of the figures in his book to answer the researcher's questions (Table 2).

According to Table 2, it was hard for RR to tell the researcher what he already knew about the Solar System. Once he began to manipulate his book, he managed to report the names of the subjects studied, without however describing other concepts. Turn 6, in which RR asks whether the Earth rotates around the Sun, revealed that the student knew the name of the elements studied, but the concept of translation was still rather vague. However, when designing an enactive representation by manipulating the articulated model, RR immediately had his doubts clarified.

The spontaneous transposition of a system of representation into another was also seen in the games that took place during break time. The play that occurred in the sand pit after the study of the characteristics of Planet Mars (Figure 4) is a good example of how children use the different systems of representation in the process of acquiring meanings. During this game, the children built an enactive representation of the volcano, *Olympus Mons*, already studied in the circle time conversation and systematised through collective text (symbolic representations) and the respective graphical record (iconic representation).

Figure 4: Children building the *Olympus Mons* volcano during break time (Researcher: *'What are you playing?'* RR: *'This is a "mega" volcano!'* GC: *'It is the Olympus Mons').*

These examples seem to indicate the progress of the development of meaning by the student in which the use of articulated systems of representation and transposition of one form to another are key parts of this process (Bruner, 2007; 2008).

Although the children had difficulty in presenting their thoughts verbally, there was enormous interest in new words emerging from the science, and the meaning of the more difficult words. This became very evident, not only in the circle time conversation, but also in the elaboration of collective texts in which these words were inserted naturally.

Considering that construction of the concepts begins with the verbal definition and its spontaneous application (Vygotsky, 1962), the interest in the meaning of new words and their natural application in different contexts, as illustrated during the construction of the volcano, *Olympus Mons*, is an important indicator that the process of building concepts is ongoing.

Throughout the project, it was also possible to note the strong presence of imagination and fantasy during the development of representations. In fact, it was found that, generally, children experienced incredible adventures in games of make-believe arising from the handling of the overhead projector images (Figure 5), the drawing activities (Figure 6) and in the play activities during break (Figure 7). In these adventures, they were either accompanied or alone, transformed into astronauts, scientists or superheroes.

Figure 5: Student MA playing with the overhead projector, pretending to be an astronaut in his rocket.

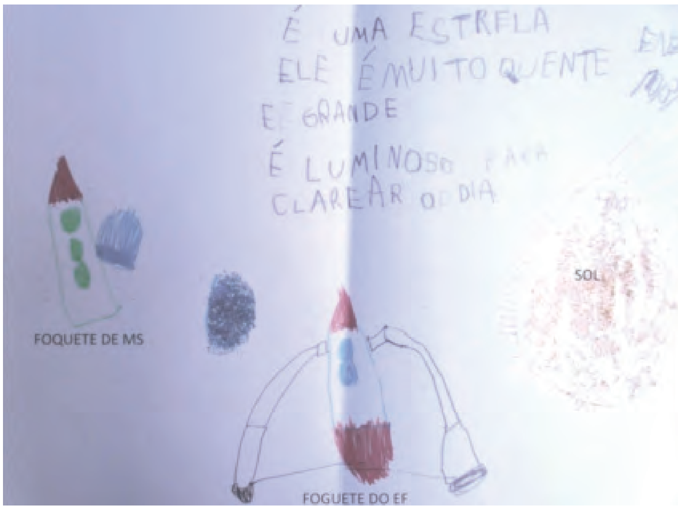

Figure 6: Record of the Sun made by EF. (During this activity, EF played with his hands as the rocket trajectory, making sounds. When questioned by the researcher, he said: *'I made my rocket (foguete do EF) and MS´s (foguete do MS). I also made the Sun (Sol)'.*

Figure 7: BS and RC playing during break with the 'rocket' made out of paper.

According to Vygotsky (2003), playing forms a major part in the process of meaning construction, since it allows the child to combine imagination and fantasy with elements taken from reality. Indeed, the representations made during play seemed to give the children opportunities to experience aspects of scientific culture through other forms of action, expression and interpretation of reality.

As the project developed and planets were studied, it was noted in the circle time conversation that the children showed a special interest in the number of moons, rings and unique characteristics of each planet, expressing their initial attempts to develop criteria for the characterisation of this concept. Despite the ability to formulate true concepts, which, according to Vygotsky (1962), emerges only during adolescence, children show from a much earlier age the processes that contribute to the development of this ability, such as the capability of grouping objects, ideas or information, in order to create criteria that are closer to those used by adults.

As shown in Figure 8, Student CK expressed the concept of planets through the association between moons and rings, elements present in several of the planets studied, and balls and other elements of football. In his drawing, it can be seen that the spherical shape, most evidently a characteristic of planets, gives rise to the symbol of his football team.

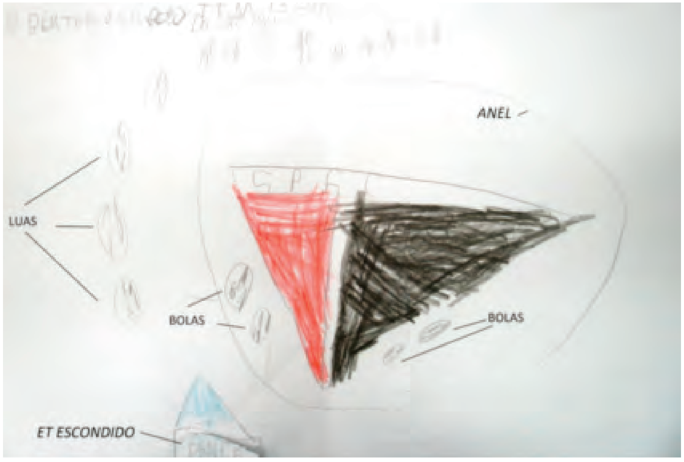

Figure 8: *Planet São Paulo Futebol Clube.* (This has four balls *(bolas)* inside the planet, as well as the symbol. It has 13 moons *(luas)* and a ring *(anel)*).

The analysis of symbolic representations shown by children in comments such as: *'Was this photo taken by Hubble?'* (GC), *'I think Saturn will have more moons than Jupiter'* (MS), *'We get a headache because the Earth rotates?'* (MR), *'On the dark side of Saturn it is the night and on the clear side should be day'* (MS), indicates that the activities promoted not only the comprehension of some basic concepts, but also an awareness to look at other issues related to science education; for example, the specific procedures of science in constructing knowledge, interest in formulating hypotheses and seeking explanations, as well as the perception that science is a part of their daily lives. These, and many other representations, indicate that the planned activities were able to trigger a reflexive process arising in children's curiosity about science topics and the implications of this knowledge for their lives.

Conclusion

The results obtained from this research indicate that children construct scientific knowledge through combinations of the elements present in their daily lives and the new elements studied in the classroom (Vygotsky, 2003). These combinations illustrate children's first attempts to approach these concepts and give them a unique and personal meaning.

This reiterates the importance of considering science education at each stage of child development and understanding the way in which children construct knowledge. In order to reach the goal of constructing scientific knowledge, it is necessary to consider the teaching of science in its broadest sense and seek not only the comprehension of basic concepts, but also to understand the cultural context (Johnston, 2011a). Science education, understood in this perspective, should enable children to develop new visions of the world while establishing relationships between language and the specific practices of the scientific culture, within the everyday lives of those children (Sasseron & Carvalho, 2007; Capecchi, 2004; Carvalho, 2008; Driver *et al*, 1994; Lemke, 1998).

Johnston (2005), Dewey (1980) and Vega (2006) argue that this approach requires the careful planning of activities, to provide students with experiences of issues related to science, and opportunities to represent them in different ways and at different times (Bruner, 2007). Thus, the pedagogical process should be planned to take into account the different systems of representation through activities that promote discursive interactions: written texts, drawings and collages, the handling of materials, make-believe play and drama.

On the other hand, it should also be considered that spontaneous representations developed outside of the school context might provide clues as to how the issues discussed in the classroom are being assimilated by the students. Therefore, the mediation of the teacher must be also extended to encourage students in a fuller discussion and reflection on matters related to science.

In conclusion, there are important implications for early science education when providing children with opportunities to build scientific knowledge from the extraction of facts and laws present in everyday phenomena. These experiences, elaborated and re-elaborated under the three systems of representation proposed by Bruner (2007; 2008), will form the basis of children's first scientific concepts.

It is important to highlight that the concepts constructed in this way are those as validated by the scientific community and structured by the subjective impressions of the child; children take what is taught and make sense of it in light of their own experiences inside and outside school. It is expected that these temporary concepts will be gradually replaced by more elaborate ideas, as students develop and have more formal taught experiences.

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The new primary science curriculum: a new Programme of Study for science – a reason to be cheerful!

■ ASE Primary Science Committee

This article appeared in the ASE house magazine, *Education in Science*, in the May 2013 issue. The Editors of *JES* are very grateful to the ASE Primary Science Committee for their willingness to allow this article to be slightly revised and reproduced for readers of *JES*.

The draft National Curriculum was published for consultation in February 2013 and the final version is now published, with schools busy preparing for implementation in 2014.

Primary Science Committee (PSC) members were delighted to see the changes made since the first draft published in June 2012. This was the result of real consultation; science was one of the few subjects where the ministers really did listen to the experts – and, fortunately, primary science has some great experts in its corner! The authoritative critical feedback compiled by SCORE from the professional science education bodies, including ASE, was fully acknowledged. Anne Goldsworthy and Brenda Keogh were nominated by PSC to help the Department for Education (DfE) mandarins in the final writing stage of the draft and we owe them both an enormous thank you for all their hard work, expertise and wily tact in getting a better deal for primary science. Thanks to Brenda and Anne, their PSC colleagues and all who contributed to the SCORE consultation, the February 2013 draft Programme of Study (POS) has a clear progression in both conceptual and procedural knowledge, and working scientifically is embedded throughout, in both the statutory content and the guidance.

ASE's influence ensured that, in the draft POS published in February, science retained the practical element that is an essential strategy for helping children to develop their conceptual understanding: *'Practical work is always going to have a key role in science teaching. The challenge is to continue to find ways to make it as effective a teaching and learning strategy as possible, while retaining its clear, and refreshingly evident, affective value.' (Abrahams & Reiss, 2010)*

The aims of the new curriculum reflect the message of the ASE/Millgate House publication, It's Not Fair. Both sources recommend that children engage with a wide range of science enquiry types to answer questions about the world around them. It is very exciting to see the influence of ASE's work on science enquiry on such an important document for schools. How wonderful to think that the fair test will no longer be the only way that children answer scientific questions about the world, and that observing over time, looking for patterns, identifying and classifying and researching using secondary sources will be taking place in every primary classroom.

There have been some changes to content. There has been some concern expressed that Key Stage 1 (age 5-7) appears to have fewer topics than previously. However, the requirement to get to know and regularly observe a wide range of living things in the locality offers a fantastic opportunity for teachers to take the learning outside every week and really deepen and broaden children's understanding of the natural world. Also, it builds seamlessly onto good practice from the Foundation Stage. Evolution and inheritance are new additions to Key Stage 2 (age 7-11) and will present some challenges, but also brilliant opportunities for children to really engage with some of the big ideas of science and the implication and applications of these. A slimmed-down POS, which is what we now have, is a wonderful opportunity for teacher autonomy. The non-statutory guidance reflects the good practice that exists in so many schools and offers clear advice and examples of how teachers can ensure that children engage with the content by working scientifically. However, they are only guidance – teachers can and will develop more good lessons and activities themselves, building on the needs and ideas of the children in their classes. Just as they always have!

And ASE will be here to help you do that. Representatives of other subjects in primary schools have asked us how we ended up with such a positive POS for science, when their subjects did not fare so well. It may have been luck, but we think it is down to the fact that primary science has a strong subject association, which represents the views of its expert members well. Although, at the time of writing, we are still awaiting news about future assessment requirements for science, PSC members feel optimistic about the future of science in our primary schools and look forward to working with members to ensure that good practice and good learning prevail.

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Notes & News

ASE conferences

If you read this in time, the *ASE Summer Celebration Conference – The Future for Science Education* will be held at the University of Hertfordshire from 27th to 28th June 2013. At time of writing there are still places left so why not visit www.ase.org.uk and book?

The ASE Annual Conference 2014 will be held from 7th to 11th January 2014 at the University of Birmingham. There is always a strong early years and primary strand in this conference programme, so keep an eye on the Conferences area of www.ase.org.uk for more details.

More information on all ASE activities, including membership options and news from the world of science education, can be found at www.ase.org.uk

ESERA (European Science Education Research Association) Conference 2013

The ESERA Conference 2013 will take place in Nicosia, Cyprus, from 2nd to 7th September 2013. There is a strong early years strand and an active Early Years Special Interest Group (SIG).
More information and details of how to book can be found at http://www.esera2013.org.cy/

WorldSTE2013 Borneo

The International Council of Associations for Science Education (ICASE), in official partnership with UNESCO, is hosting the 4th World Conference on Science and Technology Education in 2013 (WorldSTE2013) on Borneo Island in the city of Kuching, Malaysia, from 29th September to 3rd October 2013.
The conference is entitled *Live Science, Love Learning, Create Change.*

The 5-day conference will be attended by up to 2000 delegates from all over the world and will host an exhibition with over 100 exhibition stands.

More information and details of how to book can be found at http://worldste2013.org/

Creative Little Scientists Project

Creative Little Scientists: Enabling Creativity through Science and Mathematics in Pre-school and First Years of Primary Education is a European Commission's 7th Framework Programme research project. The research is being carried out over a two-year period in nine European countries, chosen because they represent a wide spectrum of educational, economic, social and cultural contexts, as well as a wide spectrum of practices regarding science and mathematics education in general, science and mathematics education in early years, and creativity in education.

The project has recently completed fieldwork that looks at both pre-school and primary school practice in creative science and mathematics and is beginning to consider the implications for teacher education.

More information about the project can be found at http://www.creative-little-scientists.eu/home

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SEVENTH FRAMEWORK PROGRAMME

Resource Review

ASE Guide to Research in Science Education by Oversby, J.P. (Ed.). Published in 2012 by ASE, Hatfield, price £21.00 (to ASE members) and £27.00 (to non-members).
ISBN 978 0 86357 429 0

The book is divided into two sections; the first a review of current research in science education, and the second a guide to carrying out research. Most of the chapters in both sections are relatively short, with one or two main ideas that are clearly explained and summarised. There is plenty to immediately grab the attention of an early years teacher, including chapters on how primary-age children think, creativity in teaching science (and what we mean by creativity!) and discussions about formative assessment, summative assessment and assessment for learning.

Unlike some books that I have read, this book did not leave me feeling as if I could never be as effective as the teachers I found between the pages. Just one example is John Black's discussion about dialogic teaching in his chapter about formative assessment, which I found particularly heartening; in the past, my own attempts at dialogic teaching have had varying degrees of success (I find myself resorting to nodding sagely and muttering *'mmm... I wonder...'* quite a lot). How lovely then to read that this is a skill that needs to be learned, as opposed to being something that is enjoyed naturally by a gifted few! Moreover, by the time I had read this chapter, I felt more confident about what my own next steps should be.

I also found that the chapters which, on the face of it, had nothing to do with early years teaching were not only very readable, but gave valuable insights into the teaching and learning process. In Chapter 4, for example, Amanda Berry describes how an experienced chemistry teacher helps Year 7 (aged 12) pupils begin to understand Particle Theory. She describes how she not only impacts on their current understanding of the theory, but also how she prepares them to be able to take on more ideas in the future, when they are more mature and experienced. I was surprised by how similar this process was to my own recent experience of helping children investigate the effect of putting a coat on a snowman, appreciating that it will be some years before they are able to understand about insulation but, nevertheless, knowing that the experience that I am providing for them, and encouraging them to think about, is helping to prepare them when the time comes! Berry's description of this process shows the strong interplay between her own subject knowledge, her knowledge of how children learn, and her experience of what activities will be effective in extending the children's learning.

The second section, mainly written by Jane Johnston, is a guide to carrying out research. It is divided into seven sections, each tackling a different part of the research process such as conducting a literature review or analysing data. When talking about assessment for learning, we are often referring to how we share information about the learning process, and what the next steps are with the children we teach; this section was very much about enabling the reader to realise where they are in their own process of becoming a researcher and what the next steps are. Particularly interesting is the table comparing the differences between the skills of one person operating at Masters' and another at Doctoral level. I also enjoyed the description of different phases of research, in which one could find out if one was at the 'Sheep phase' or the 'Squirrel phase', for example. Again, this was particularly useful, as it not only gave information about where the reader is now, but also what steps are needed to move beyond the current phase. In each chapter, there are also 'Reflective tasks', which help the reader to not only consider their current level of understanding, but to move beyond it.

I began looking at this book with an assumption that I would have to glean from it chapters and passages that would be relevant to my own situation as an early years teacher; I ended with a much greater understanding of the underlying similarities in the teaching and learning experience, not only between pre-school and secondary pupils, but also with children and adults.

I would definitely recommend this to other early years teachers. If you want to be a better teacher and better understand how the children in your care think, you will find this book not only a useful, but also a particularly accessible resource. If you want to carry out research of your own, or work towards a Masters' level qualification, this book will be invaluable.

Jane Winter, Foundation Stage, Year 1 teacher and science subject leader, Kirkby la Thorpe Primary School