Science in the early years

PAPER 2
Science inquiry skills

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Introduction

This is the second paper in the *Science in the early years* series that reviews current research into science learning and monitoring in the early years. The aim of this series is to provide early years educators with an insight into current research; highlight how research findings relate to children's science learning; look at the current understandings about early years science monitoring; and provide examples of how early years educators can incorporate this research into their practices.

This series defines 'early years' as the two years prior to school and the first three years of primary school, which in Australia generally includes children aged three to eight years. Children in the early years may attend early childhood centres, kindergartens or primary schools. Educational expectations for children of this age range are covered by the Early Years Learning Framework (EYLF) for preschool children, and the Foundation to Year 2 Australian Curriculum (AC) for school students.

This paper focuses on the importance and value of providing learning experiences that support the development of science inquiry skills (SIS) in the early years. The paper describes how developing children's SIS are integral aspects of both the EYLF and the Foundation to Year 2 AC, and emphasises the importance of incorporating science contexts and content in the early years within an inquiry-based approach in which children conduct investigations into aspects of the world around them.

The *Science in the early years* series reviews Australian and international research to highlight aspects of the learning and monitoring of science in the early years that are significant to Australian children and their educators.

What are science inquiry skills?

Science isn't just about learning facts, it is a way of thinking and developing skills so that we can understand the world. In order for young learners to do this they need to develop and practise the inquiry skills involved in science. In the early years, SIS are sometimes referred to as *sciencing* in an early years context (Wilson, 2007).

Science inquiry skills used in early years contexts can be varied; however, they tend to cover similar skills, which are:

- observe
- predict
- check
- record
- communicate.

These skills are referred to as SIS in the AC: Science, but may also be called *science process skills* (Peterson & French, 2008) and the *nature of science* (Akerson & Donnelly, 2010; Akerson, Buck, Donnelly, Nargund-Joshi, & Weiland, 2011). These skills provide processes for children to learn and follow and a structure for understanding science content (Wilson, 2007). For the purpose of this paper, we will refer to such skills collectively as *science inquiry skills*.

Table 1 compares different definitions of SIS from the literature to those noted above and to the AC: Science.

Table 1: Science inquiry skills

Observe	Predict	Check	Record	Communicate	Source
Questioning and predicting	Questioning and predicting	Planning and conducting	Processing and analysing data and information Evaluating	Communicating	Australian Curriculum: Science, 2016
Observation		Comparison Measurement Classification		Communication	Charlesworth & Ling, 2003 as cited in Gallenstein, 2005
Observing	Predicting	Classifying Comparing Inferring	Concluding	Communicating	Croft, 2000 as cited in Tu, 2006
Observing	Predicting Hypothesising	Experimenting Classifying		Communicating	Conezio & French, 2002
Observing	Predicting	Classifying	Representing information	Language skills to talk about the processes and their outcomes	Peterson & French, 2008
Engage		Explore	Evaluate	Explain Elaborate	Australian Academy of Science, 2018
Observe	Predict	Check	Record	Communicate	Gelman & Brenneman, 2004
	Formulating questions and hypothesising	Planning and conducting investigations	Developing explanations Critiquing investigations Evaluating explanations		Hess, 2010
Observing Describing	Questioning Predicting	Comparing Experimenting Cooperating		Reflecting	Nayfield, Brenneman, & Gelman, 2011
	Hypothesis generation	Experimentation	Evidence evaluation		Klahr, 2000 as cited in van der Graaf, Segers, & Verhoeven, 2015
Observe	Predict	Explain			Kallery, 2015
Questioning	Predicting	Planning Collecting data Looking for patterns and relationships	Recording data Organising experiences	Sharing	Worth, 2010
Observing	Predicting Hypothesising	Experimenting Classifying		Communicating	Wilson, 2007

Note: Although these are common SIS the order in which some authors include them in the science methods varies. We have aligned the key SIS in the order of observe, predict, check, record and communicate to highlight the commonalities.

Why are science inquiry skills important?

Science inquiry skills are interlinked with young learners' understandings of science content as they provide the structure and processes for which science content can be covered. Science inquiry skills are fundamental to the learning of science content, and science content allows students to apply, practise and develop their SIS. With instructional support, children in the early years can develop a sound understanding of SIS (Akerson & Donnelly, 2010; Samarapungavan, Mantzicopoulos, Patrick, & French, 2009). It has also been found that the use of SIS can help children develop science knowledge (Gelman & Brenneman, 2004) as they provide a common structure and way of thinking during science activities.

Recommendations have been made to reduce the amount of science content covered in the early years so that more time can be devoted to developing science inquiry and thinking skills (Akerson & Donnelly, 2010; Rutherford & Ahlgren, 1990 as cited in Gallenstein, 2005). With a greater emphasis on SIS, young learners can find out about the world around them through investigations (Wilson, 2007). Introducing, developing and applying SIS does not need to make science more complicated in an early years' context, instead these skills provide young learners and educators with a repeatable way of thinking and structuring their scientific explorations. Once SIS have been introduced to children, play-based and creative activities can foster the development of SIS, providing a foundation that children can build on in later years (Andersson & Gullberg, 2014; Department of Education, Employment and Workplace Relations, 2009). Ensuring that all science activities have a focus on SIS skills (as well as science content) highlights the importance of the process of science to young learners by reinforcing that science is not just about the learning of science content. Science inquiry skills developed in one context should be transferable to other science activities as SIS are a way of thinking scientifically so they should be applicable to all science learning, regardless of the content.

It is believed that before children start kindergarten they have started to reason and think in ways that support science understandings (Duschl, Shouse, & Schweingruber, 2007). Children are active learners making meaning from their experiences. Focusing on the development of SIS in the early years ensures that science is more than just doing an experiment to entertain and amaze young students: it is about developing skills and understandings (Gelman & Brenneman, 2004).

Science inquiry skills in the EYLF and the AC

The importance of SIS is recognised in both the EYLF and the AC. Outcome 4 of the EYLF (Department of Education, Employment and Workplace Relations, 2009) states ‘Children are confident and involved learners, with a key component of “Children develop a range of skills and processes such as problem solving, enquiry, experimentation, hypothesising, researching and investigating”’. Such skills are fundamental to the SIS strand that is embedded in the AC: Science (ACARA, 2016).

The AC: Science (ACARA, 2016) has a specific strand: SIS. This requires that these skills are specifically taught from Foundation. At Foundation, the SIS strand consists of four outcomes:

- Pose and respond to questions about familiar objects and events [ACSIS014].
- Participate in guided investigations and make observations using the senses [ACSIS011].
- Engage in discussions about observations and represent ideas [ACSIS233].
- Share observations and ideas [ACSIS012].

Each subsequent year's SIS are further developed. For example, the outcome Compare observations with those of others [ACSIS213] is introduced at Year 1. As noted above all of these early aspects of inquiry, are supported by Outcome 4 of the EYLF.

Strategies for introducing science inquiry skills in the early years

Children need to be provided with a wide range of contexts within which to develop and use SIS, as the development of these skills might be highly context dependent during the early years (Saçkes, 2013). One way of developing the set of skills in the early years is to use an inquiry-based approach, which highlights specifically the skill or skills being used. Regardless of the context in which learning is occurring, it is important to teach SIS to young learners using a consistent approach across varying concepts as a way of building and developing skills, understandings and knowledge. Programs such as Primary Connections (Australian Academy of Science, 2018) use the 5E Instruction Model as a consistent approach regardless of the science content being covered. The 5E model has five phases and follows the structure of engagement, exploration, explanation, elaboration and evaluation. In the Primary Connections program, science is integrated with literacy, and includes investigations, embedded assessment and collaborative learning as well as significant professional learning support for educators. While Primary Connections has been developed for K–6 students, the 5E model could also be applicable in early childhood contexts to provide a common structure to science learning.

Children in the early years should be encouraged to question, think critically, problem solve, and make well-informed decisions, all essential skills in the 21st century. Children who engage in inquiry by designing and conducting investigations participate in similar activities to scientists (Altman, Stires, Weseen, & Bank Street College of Education, 2015; Gallenstein, 2005). The link between SIS (also referred to as process skills) and science content (concepts) relevant in the early years suggests the inquiry strategy of 'observe, predict, check, record' for young learners (Gelman & Brenneman, 2004) as an appropriate way of scaffolding activities that can address both process and content. Science at this level should also include activities in which children can experiment to test their ideas, measure, collaborate and communicate. Through an inquiry-based approach, children could have the opportunity to design and conduct scientific investigations so that they can understand the world around them (Lind, 2005 as cited in Gallenstein, 2005).

How to support science inquiry skills

Educators can support the development of early years SIS in a number of different ways. Teaching should be intentional and explicit when introducing young learners to the range of SIS (Akerson & Donnelly, 2010; Samarapungavan et al., 2009). The supplementary materials provided in this series highlight how SIS can be developed through early years science activities. It is also important to highlight to children that by using SIS they are undertaking tasks similar to those of scientists (Altman et al., 2015; Gallenstein, 2005). This can help students see themselves as scientists and successful science learners. Below we have used the AC: Science, SIS from Foundation to Year 2 to show how these skills can be developed.

Questioning and predicting

Young children are great at wondering what might happen if…? How can I get it to do…? Will this work if I …? Such wondering and thinking are important inquiry skills to foster and develop in the early years especially as they can form the start of a science investigation. Question asking can be thought of as the process of trying to find out more and requesting specific information (Jirout & Klahr, 2011). Educators can support children's questioning and predicting skills by asking them to explain what they think might happen (Peterson & French, 2008) and by stimulating further investigations (Andersson & Gullberg, 2014). As part of a science inquiry, it is wise to give young children the chance to explore and play with materials first to get them wondering and sharing ideas (Worth, 2010) that can then lead to more informed questioning and predicting. It has also been found that preschool children can benefit from explicit instruction and modelling to improve questioning (Jirout & Klahr, 2011). Educators can assist children with developing their questioning skills by highlighting trends children might observe during science based activities (Siry, 2013) so that they start to see patterns and question why.

Questioning by educators might assist children to see the science in their everyday activities, such as painting and cooking. For example, while children are painting, educators could ask children what they think will happen when they mix different colours of paint. Or, does the thickness of the paint have an effect on how long the painting will take to dry?

Pre-existing knowledge should also be discussed and considered (Piekny & Maehler, 2013) when children are questioning and predicting and educators could support children by asking them to think about what has happened before and what might happen in different scenarios based on what they already know. Young children are used to making predictions as they are often asked when reading stories, 'What do you think might happen next?' Predicting is an important skill to introduce in the early years as it leads to hypothesising. During science activities it is important for educators to use the terms 'questioning', 'predicting', 'hypothesising' so children can label their actions and be more conscious of what inquiry skill they are using.

Planning and conducting

Following questioning and predicting comes 'planning' and 'conducting' of experiments and investigations in an attempt to answer questions that have been raised or to support predictions made.

In the early years, care should be taken when young learners are designing, planning and conducting their own experiments as it has been found that this will not necessarily improve their scientific understanding (van der Graaf et al., 2015). In the AC (ACARA,

2016) *participation in guided investigations* are learning outcomes for children in Years K–2. In Years 3 and 4 the learning outcomes require investigations to be *planned and conducted with guidance*. It is not until Grade 5 that the learning outcomes require students to plan and conduct their investigations on their own.

While there may not be a requirement to have children in the early years develop and conduct their own investigations, it has been found that children from as early as Grade 2 can conduct independent inquiry (Akerson & Donnelly, 2010), that is, work by themselves to investigate a phenomenon or to answer a question about the world around them. During the conducting of investigations, where conclusions are based on evidence and reasoning, the more specific aspects of SIS such as inference, are best supported by explicit instruction, with a focus on real-world objects (Akerson & Donnelly, 2010). The role of the educator is central in explaining the scientific concepts as well as in guiding the development of specific behaviours of the children as is the importance of whole-class and group discussion during experiments (Kallery, 2015).

During investigations, observations may be made by using scientific equipment such as scales, microscopes, rulers or informal methods of measurement where appropriate. It is essential for educators to scaffold and support young children's use of scientific equipment, it is not enough to just have such equipment available for use (Nayfeld, Brenneman, & Gelman, 2011). New equipment might need to be introduced with the sole intent of learning more about it before it is used to develop observations, as young children can get distracted by the novelty of the equipment (Johnston, 2009a). For example, an introductory session where children explore the use of magnifying glasses or scales should precede any sessions where such equipment is used as part of the observation process for the first time.

Sufficient time should be allocated to support children to develop observation skills as these lead to other inquiry skills such as predicting and hypothesising (Johnston, 2009a). Interaction and communication with other children and adults is also important when developing observation skills and other process skills (Johnston, 2009b) as this communication can provide young learners with different perspectives from their own. For example, in a study which looked at the benefit of providing young learners with

a number of ways and times to develop their observation skills, children were presented with an unfamiliar animal, the New Zealand tuatara. The children observed the tuatara on a number of occasions and over time their attention to detail to the features of the animal increased (Cowie & Otrel-Cass, 2011). The children produced a sequence of gradually more sophisticated drawings and models of the animal. Providing sufficient time for children to explore new ideas, make careful observations and use their new knowledge to represent and talk about the tuatara's features was essential to developing their observation skills.

To ensure that children develop their observation skills they should be taught to observe with *all* their senses (Lind, 1998) not just to rely on what they can see. When using drawings to record observations it is important to emphasise that they should be an accurate representation of what the children observe rather than a creative drawing (Russell & McGuigan, 2016).

To show a development over time and just as scientists do, young learners should record and date their observations (Gelman & Brenneman, 2004).

In the early years there is a strong emphasis on developing young children's observation skills, as observation is a vital aspect of processing and analysing data and information (Russell & McGuigan, 2016). Like other SIS, observations can be developed through structured activities (Johnston, 2009a). Asking children to describe what happens during their investigation is an important way to help children develop these skills (Peterson & French, 2008). Recording and communicating observation allows children to value and further develop their observation skills.

Processing and analysing data and information

When looking at the data and information gathered as part of any experiment or investigation it is important to note whether it supports or contradicts the initial prediction/hypothesis (Piekny & Maehler, 2013). It has been found that primary school children can understand that experiments are used to find out information and not to necessarily produce a predicted result (Piekny & Maehler, 2013). Emphasising the investigative nature of science helps to ensure that children see science as a way of finding out about the world not just learning facts.

Evaluating

Evaluating investigations includes looking at what worked and what didn't (Conezio & French, 2002), comparing what has happened to what children thought might happen and reviewing their questions, predictions and hypotheses. To help young learners evaluate their findings they can compare their results with others, which can be done in small or large groups. Discussing their findings will assist young learners to think about what they have found (Worth, 2010) and to recognise patterns.

Communicating

Communicating findings from scientific experiences has been found to be undervalued in the early years (Ravanis & Bagakis, 2006). Communication is an important science skill and highlights the integration of science and literacy skills. Just being able to describe their findings can be a significant event for preschool children (Chien, Hsiung, & Chen, 2009). As with recording observations, depending on the age and abilities of the children in the early years, communication could include drawings, verbal reports, and written text: scribed by an educator or written by the child. Strategies that engage young learners and provide experiences that promote thinking and communication, such as drama and puppetry, could also be used (Gallenstein, 2005).

If children are expected to reflect on and articulate their observations and experience then they must have this modelled and be given time to practise these skills. The science activities involved do not need to be complicated, they could be as simple as mixing paint, blowing bubbles or finding insects. The practice should allow children to develop their science communication skills by learning to support their ideas and observations with reasons and evidence: a central part of science communication (Russell & McGuigan, 2016).

Content and contexts to support science inquiry skills in the early years

An emphasis on inquiry skills is important; however, it is also vital that 'science content' (topics) and 'concepts' (understandings and relationships) are introduced in early years science learning. The content and concepts provide the contexts within which learners explore and play. Contexts support young learners to develop inquiry skills in situations that are meaningful to them. In other words, the science content allows children to learn SIS in a meaningful context rather than having them introduced independent of content. Research into young children's conceptual understandings have been undertaken across all science content areas: biology, physics, chemistry, earth and space science. The following sections outline some of the common topics and includes some cautions when introducing these to young learners.

Biology

The classification of living things, in particular, the classification of animals and non-animals is a common topic in the early years. Classification is an important skill for young children to learn and is closely linked to the inquiry skill of 'observation'. Observation, as previously noted, is a vital scientific skill for young children to practise and develop.

Classification and inquiry skills

Misconceptions are inevitable as learners develop a scientific understanding of the concept of classification. It is likely that children learn this new concept in steps, sometimes taking a direction away from scientific views. It is important that early years educators recognise that these steps 'constitute progress, not problems' (Carey, 2000, p. 18), but to avoid such misconceptions arising, an emphasis on physical (anatomical) features as the basis for classification in teaching activities is recommended when classifying animals.

Young children can learn to classify animals using a number of different characteristics, including physical ones, the means of movement, and knowledge of common animal categories such as birds, fish, insects, reptiles, amphibians and mammals. It has been found that younger children tend to make fewer errors when classifying animals than older children, as they tend to rely on physical features of animals when classifying them into different groups (Allen, 2015). As the basis of formal scientific classification is anatomical (physical difference), the younger children made decisions based more closely on this principle. Older children made decisions based on the animals' general habitat or means of locomotion, which is not as scientifically correct. This highlights the fact that scientific learning is not linear and that as children's knowledge increases there may be a chance that they apply this knowledge incorrectly.

The scientific meaning of the term *animal* encompasses humans. Preschool children often have a concept of *animal* and they can accumulate extensive knowledge about different kinds of animals. However, preschoolers' understanding of the concepts of *person* and *animal* change throughout childhood (Carey, 2000). They can distinguish animals from non-animals, and make inferences based on similarities between the kinds of animals. However, the basis for these abilities is an intuitive conceptual framework, as they think of an animal as a variation of a person.

Biology can be used to help children develop their classification skills. In a study where preschool children were provided with examples of unfamiliar animals such as a pangolin, and novel artefacts, such as a taiffle (which is used for stretching shoes) the children tended to ask questions about the function of the novel artefacts (i.e. questioning based on the purpose of the objects) or individual body parts of the animal, and to also ask questions about where the animals were found and their habits and reproduction (Greif, Kemler Nelson, Keil, & Gutierrez, 2006). Although the preschooler children in this study might not have been able to verbalise how they were applying an abstract thinking process to categorise non-living objects and living things, the evidence indicates that they were aware of patterns that distinguished between the categories of objects and animals.

Anthropomorphic language: Some cautions

The use of anthropomorphic language (attributing human features to non-human animals, such as a talking pig that expresses emotions) as a teaching strategy has direct relevance to biological concepts. The use of anthropomorphic language when teaching preschool children has been found to both hinder and facilitate scientific learning (Thulin & Pramling, 2009). Employing a teaching strategy in which non-living things are spoken about in human terms can be a helpful when used as a device to connect children's experiences with conceptual understandings such as identifying the purpose of animal behaviour. Relating these to human behaviour can be suitable, but educators ought to be aware that the use of such language should be seen only as a tool for 'bridging the gap' between children's experiences and the learning of scientific concepts. Educators must move past speaking in the *human domain*, and instead need to move on to use more formal, scientifically correct language. For example we should move from statements such as 'The lizard is happy when it is sitting in the sun' to 'The lizard is sitting in the sun because it will warm it up'. The Thulin and Pramling study (2009) study found that these children rarely introduced anthropomorphic speak themselves, and so it should not be assumed that they will speak or think this way because of their young age.

Physics

While physics may seem beyond the capability of young children, research suggests that they have extensive understanding of the concepts of physics such as pushing and pulling (introduction to forces), colour-mixing, light and shadows, electrical circuits, mirror reflection and movement of objects such as toys (e.g. Johnston, 2009b). All of these topics are appropriate for young learners as they can be linked to the children's everyday experience as a starting point for learning about the underlying concepts, and can support the development of inquiry skills. The topic areas of 'pushing and pulling' and 'light and shadows' are discussed below.

Pushing and pulling

In Brown's 1990 study, young children are able to select from a range of tools (sticks and strings with different attributes, such as length and shape) to investigate how to move an object using pushing and pulling. Children tended to pay more attention to the surface features of objects and were indifferent to colour and shape when making decisions about the scenarios, but they did consider attributes such as length and rigidity. This is significant because these attributes determine whether a push or pull force is likely to be effective. The key teaching implication from this research is that children may have this specific understanding at an early age so they should be extended by opportunities that allow them to apply this knowledge, and begin to consider *why* pushing and pulling occurs in certain scenarios. This is an example of how inquiry skills and conceptual knowledge are interlinked.

Light and shadows

Natural phenomenon that are part of young children's everyday experiences are appropriate topics for young children to help develop their SIS. A number of studies has focussed on light (Gallegos-Cázares, Flores-Camacho, & Calderón-Canales, 2009), shadows (Delserieys, Jégou, & Givry, 2014) and colour-mixing (Peterson & French, 2008). These studies suggest that learners are able to produce explanations of the outcomes of short, simple tasks incorporating physical materials. That is, the children can go beyond descriptions of what they observe and begin to explain behaviour, for example, objects positioned to block light from a light source and create shadows.

Chemistry

For chemistry, there were several topic areas commonly identified in the research literature: liquids and gases, floating and sinking (density), the properties of water, and mixtures (including solutions). The topic areas of 'floating and sinking' and 'solutions' are provided as examples of how these topics link to SIS development.

Floating and sinking

One research study showed that when children were allowed to study the phenomenon of floating and sinking in a playful and creative manner, they developed a positive experience of the concept of density that can be built on later (Andersson & Gullberg, 2014). The children were not expected to explain why the objects floated or sank but were asked to communicate what they found.

Case studies of open-ended activities around floating and sinking (Siry, 2013), demonstrated that science concepts shifted and developed from play-based experiences, and children were empowered by this approach: they began to express their ideas about buoyancy, and began to experiment to change *sinkers* to *floaters*. This experimentation could be a result of the children's observations of what happened and their application of the knowledge they gained to a new context, which is an important part of predicting.

Exploring mixtures

When exploring mixtures such as solutions (e.g. dissolving substances in water), one study described children's learning where children were given bottles, buckets, pumps and a number of substances: vinegar, bicarbonate soda and leaves to grind (Fleer, 2009). It was found that providing the materials alone for children to play with independently did not result in the formation of scientific concepts, highlighting the need for an educator to support and scaffold the activities.

Earth and space sciences

For earth and space sciences, the research conveyed a focus on astronomical topics, in particular the behaviour of Earth and its movement in space. These concepts are abstract, but should not be avoided as preschool children can understand these with the appropriate support.

In general, abstract concepts about the relationship between the Earth, moon and sun should be presented in association with concrete materials (Doğru & Seker, 2012), such as a basketball to represent the sun, a tennis ball to represent the earth and table tennis ball to represent the moon. Children are capable of showing their understanding by making observations and drawings, for example, but the activities should not exceed the attention span of the children. Teaching advice for such activities is that they should be short and repeated often. Specific concepts identified as being appropriate for children aged four to six years in relation to earth and space sciences include the spherical shape of the Earth, and that day and night are the result of the spherical Earth's rotation on its axis (Kallery, 2011).

Summary

Early years science shouldn't just be learning facts about the world; it should also develop the skills young children need to be able to understand the world. Science inquiry skills provide the structure and processes for which science content can be understood. It is essential that the SIS such as observing, predicting, checking, recording and communicating are taught in the early years of science. Both the EYLF and the AC recognise the importance of such skills and the fact that young children are able to successfully learn them. There are many suitable contexts and topics in all of the science content areas with which children in the early years can engage, and through which they can develop their inquiry skills with the support of educators. Educators should make young children explicitly aware of the SIS they are using and practising, and emphasise that using SIS is what scientists do, in order to encourage young students to see themselves as scientists and successful science learners.

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