Educational Research

The interplay of context and concepts in primary school children's systems thinking

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There is growing recognition of the importance of helping children to develop an ability to think about biological and environmental issues in terms of systems interactions and impacts. Several progressions have been published that suggest how their conceptual understandings may develop over time. However these are not necessarily as informative for teachers as for researchers or specialist resource developers, nor do they take account of 'moment in time' interactions between an individual's contextual and conceptual knowledge. This research aimed to develop examples to support assessment for learning by helping teachers recognise students' next learning steps in relation to interactions between the components of an ecosystem (both conceptual and contextual) with which the children had varying degrees of familiarity.

Introduction

This paper describes an exploratory investigation of one aspect of children's systems thinking. Assaraf and Orion (2005) identified this as an important type of thinking to develop if science learning is to prepare students to become responsible citizens – an outcome that most science education researchers would surely see as important. The American 'Project 2061' also identified systems thinking as one of the most powerful ideas in science and recommended beginning the development of an understanding of systems from the kindergarten grade (Rutherford and Ahlgren, 1990).

Developing an understanding of important biological and environmental issues requires children to have opportunities to learn about systems interactions and impacts (Assaraf and Orion, 2005). Learning about systems, in turn, challenges educators to help children experience the real-world stories behind conceptual knowledge (Mayer and Kumano, 1999) – that is to bring contextual and conceptual knowledge into a rich interplay with each other. Mayer and Kumano recommend more fieldwork, a focus on both parts and wholes, and greater attention to narrative and contextual description (Mayer and Kumano, 1999). The latter is a challenge that can be easily overlooked (Hipkins, 2001) since curriculum planning traditionally focuses on 'facts' (or maybe concepts) to be learned. But how does such content development interact with children's knowledge of, and familiarity with, the context of the system in question?

The potential of ecosystems as a study topic

Ecosystems are a commonly studied topic in the New Zealand primary school curriculum, and hence provided an opportunity to explore children's systems thinking in a familiar type of learning situation. Field trips to the ecosystem of choice are typical and traditional components of the learning provided. Studies of the rocky shoreline, or of one of the many rivers and streams that cut across the geologically active land, are perennial favourites.

The study of rivers and streams is well supported by an initiative called 'Waterways' managed by the Royal Society of New Zealand. The initiative aims to promote proactive care of our rivers and streams, both by direct actions such as riparian planting and water quality monitoring, as well as by educating children about these environments as dynamic but vulnerable ecosystems.

This initiative provided the research team with an opportunity to investigate the interaction between growing contextual familiarity with a waterway and children's understanding of the targeted concepts of direct and indirect relationships between components of the chosen ecosystem. One emphasis of the initiative is on understanding that what an individual does may impact on a waterway out of sight and awareness (for example putting toxic substances such as oil or paint down street-side storm-water drains – which in New Zealand tend to enter waterways without first passing through treatment plants, in contrast to grey water and sewage). Here one action could begin a series of events, some of which might be predicted if relationships between physical water quality and the living things in the ecosystem are understood. Effects that flow on from the initial perturbation also require an understanding that change to the population of one living thing can impact on other species. Typically children first encounter this via the systems concept of food chains, and these too are a common focus of ecosystem learning in the New Zealand primary school.

Supporting the development of systems thinking

Several progressions have been published that suggest how, given appropriate learning experiences, understanding of systems interactions may develop over time. Assaraf and Orion (2005) propose eight stages in the conceptual development of children's systems thinking, while Project 2061 proposes four broadly similar stages of development (American Association for the Advancement of Science, 1993).

Assaraf and Orion's first level is "naming parts and processes".

Next they specify the identification of "processes that create relationships between parts". Feeding relationships would probably be a simple beginning point for developing this concept in the context of a waterway as an ecosystem. Third is "building up a framework of relationships" such as food chains and webs. The fourth step of the progression is "making generalisations about relationships", for example knowing that all food chains must start with a plant. Next comes "understanding that some relationships can impact on other relationships" – the "indirect relationships" component of the Waterways resource. The sixth step is "knowing there can be hidden dimensions that affect the system", for example the role of microscopic decomposers or, in a waterway, microscopic producers. The final stages have temporal dimensions: "understanding that many systems go in cycles" and "recognising that systems can change over time, sometimes slowly and sometimes quite quickly". At every stage rich contextual knowledge is potentially added, and many more possible links can be identified, along with increasing complexity of concepts.

With the level of detail to be remembered, such progressions may not be as informative for teachers as they are for researchers or specialist resource developers. Furthermore, while these indicators of progression are certainly helpful, the explicit focus is largely on concepts, once the necessary contextual groundwork has been laid. But teachers need to be able to relate ideas about progression to the actual work children produce and such work seldom fits neatly into pre-planned categories; indeed it is likely to show messy contradictions between conceptual understandings and contextual familiarity.

In any case, if children's work is to provide evidence for making judgements about next learning steps, as is widely proposed in the formative assessment literature (see for example Black and Wiliam, 1998), the *learning* implications must be the teachers' decision-making focus. However this intent may be easier said than realised and has been seen by some as the 'Achilles heel' of the formative assessment reforms (Olson, 2005). With limited time and a whole class to attend to, the teacher needs accessible, practical curriculum guidance that allows planning for the whole class, not just for each separate individual (unless the class is exceptionally small). Producing such practical advice was the focus of this research.

The research questions

This paper describes an investigation of year 7 and 8 (ages 10-12) children's ideas after taking part in the Waterways project. The researchers worked with one classroom teacher to explore the following questions:

- are there identifiable patterns in the ways children express their understanding of relationships between the components of a familiar ecosystem in drawing and in words?
- is there evidence that their contextual knowledge about the ecosystem interacts with their level of conceptual understanding of relationships?
- is it possible to identify helpful next learning steps that take account of any such interactions, whilst still providing practical teacher guidance on supporting children to extend their learning?

Method

The method used to address these questions was itself "strongly influenced by systems theory" (Boulter, Reiss and Tunnicliffe, 2003). The researchers explored how children's personal narratives about an ecosystem and its component parts (their contextual knowledge) interacted with their learning about *relationships* between the components of that ecosystem (their conceptual knowledge). The findings reported here are part of a wider study that investigated a range of teaching strategies and assessment questions. The focus here has been narrowed to one class, and indeed largely to three students in that class, so that the complexity of concept/context interactions can be described in some detail.

The research tools

Following a method described by Assaraf and Orion (2005), the children in one chosen class (around 25 students in all) added details to a simple outline sketch that represented several familiar elements of a stream and its surroundings (see the figures that follow). The children also wrote answers to three short questions about relationships they could see in their drawings:

1. From your picture, describe a relationship between two things in the water.
2. From your picture, describe a relationship between one thing on the bank and one thing in the water.
3. Describe some ways human activity can upset relationships in and around this waterway.

This phase of the research produced sets of drawings annotated by the children, with accompanying answers to the short questions. A small sample of students was subsequently interviewed by two of the researchers. They talked about what they had learned and why they had drawn what they did. These interviews added useful additional insights into the children's thinking at the data analysis phase.

Data analysis

Each child's drawings and written responses formed one data set. Using the available progressions as a broad theoretical reference, the researchers explored various ways of grouping the children's responses to identify characteristic indicators of the overall level of understanding of concepts and awareness of contextual detail that each child showed. The researchers' emergent reasoning was checked against what the interviewed children had said, and later checked with the classroom teacher, who had a much better knowledge of the children as individual learners.

The analysis revealed mismatches between children's conceptual understanding and their familiarity with (ability to describe in words or images) the context of the waterway. At first the individual data sets seemed to comprise a bewildering array of idiosyncratic narratives, combining concepts with varying contextual detail in as many different ways as there were participants. After some hours of intense exploration of different suggestions for patterns, the researchers finally identified three broad types of understanding amongst the children in the group. These are illustrated next, via the work of three specific children.

How concepts and contexts interact in children's work

Although existing research on progression informed the analysis, the focus here was somewhat different. The researchers wanted to know how concepts and contexts interacted in this ecosystem, at this moment in time. Thus an important caveat to the descriptions of the three broad patterns that follow in Section 4 is that the researchers see these as snapshots of learning, at this point in time, in this context, and not necessarily as indicators of some overall forward progress or 'development' each child had made. While in-the-moment and overall learning development are obviously not unrelated, the focus here was to find ways to support teachers as they make formative comments that prompt each child to focus on what to attend to next, not to report on overall learning progress across time.

Emergent awareness

Some children produced busy pictures, seemingly impressive at first glance, that actually gave very little indication that they understood the concept of relationships between the naturally occurring components of an ecosystem. Figure 1 illustrates this with Leona's drawing. It was accompanied by the following written ideas about relationships:

1. *The Duck feeds on the bread*.
2. *The sheep drinks the water*.

In response to the third question about the impact of human activity on relationships, Leona again had plenty of ideas to share. Connections between human actions and possible impacts on the naturally occurring components of the ecosystem were hinted at but not fully developed:

Went swimming and lost a shoe.

Washing the car with the hose.

Went pinicing [picnicking] and spilled some juice to cause the stream to change colour.

Farmer feeding sheeps [sic] and looking after them. The sheeps having waste.

Leona's contextual knowledge of the waterway is very general. This knowledge allowed her to identify a number of parts to the ecosystem in her drawing, but possible relationships were implied rather than explicit. The identification of a hole in the tree for possums implies a shelter relationship between the possum and the tree. A feeding relationship is implied in the placement of the caterpillar on the leaf, but again this is not elaborated. By identifying that bread is food, Leona implied that some human actions are positive for other species.

Like most of the children, Leona identified more parts from the surroundings than in the stream itself. She had only a very general awareness of specific types of animals (e.g. waterbugs, seagulls or birds) and may not develop a more focused understanding of the concept of relationships until she knows more about the actual things between which such relationships could potentially form. Thus, her lack of a rich contextual knowledge of the naturally occurring components of the ecosystem may well be a barrier to the intended conceptual learning.

Leona's written response about a picnic illustrates an interesting link between holding a rather generalised understanding of the context and a misrepresentation of the scale of the effects described. This resonates with Boyes and Stanisstreet's (1996) findings concerning the sweeping generalisations children are likely to make about the effects of pollutants if they over-generalise these – for example by talking about 'air pollution' rather than a specific pollutant. In this research project, even children who could correctly describe some relationships in the ecosystem could misconstrue the scale of effects if they did not have a sound awareness of contextual detail.

Direct relationships can be described

Figure 2 shows Zoe's drawing. Compared with Leona, she has accurately identified more naturally occurring parts of the ecosystem, including plants, animals and inorganic components, together with some processes and direct relationships. She is more aware of specific life forms in the water (eels, freshwater crayfish). She shows some awareness that the water cycle will impact on the stream – an idea that very few children introduced.

Zoe's written responses were as follows:

1. *The fish eats the water bugs that also live in the water*.
2. *The dead leaves have fallen off the tree into the water*.
3. *People can tip paint or oil down the storm water drain and*

Figure 1. Leona's drawing is busy but lacking in specific ideas about relationships.

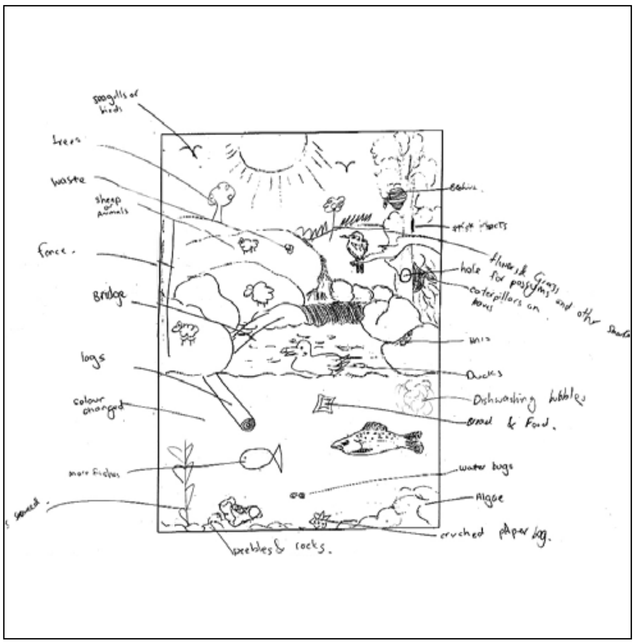
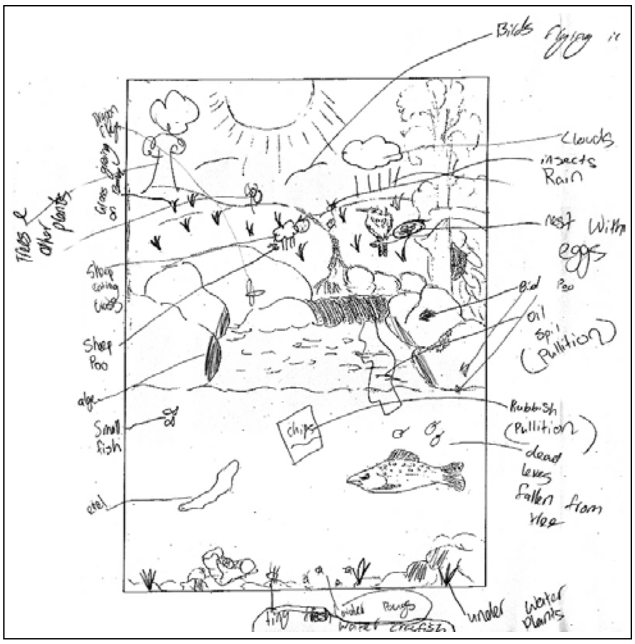


Figure 2. Zoe's drawing shows more accurate awareness of contextual detail.



it could end up in this stream. People who are taking a walk down the river might drop some rubbish and it can be blown into the stream. Both of these pollut [sic] the stream and can kill the wildlife.

The direct relationship is correctly described although again it is general rather than specific in its contextual detail. A fish of some sort eats water bugs of some sort. While Zoe is aware of a simple interaction between plants on the riparian edges and the waterway itself (which is an explicit focus of the Waterways learning activities and interventions) she does not extend this to describe a dynamic effect. Again the comments about pollution are over-generalised and Zoe makes no distinction between the consequences of a potentially very damaging action and a rather more innocuous one.

More advanced conceptual understanding with weaker contextual knowledge

Compared to the above examples, Matt's drawing named a wider range of specific animals and plants found in and around the waterway (tree frog, trout, water spider, kingfisher, reeds) and he included some of the 'hidden' components (algae, leeches). The placement of the leeches near the legs could be inferred as a suggestion of a feeding relationship. Like most students Matt named more animals than plants. He indicated some technological elements that impact on parts of the ecosystem, for example the factory, although he was not clear about how this would impact.

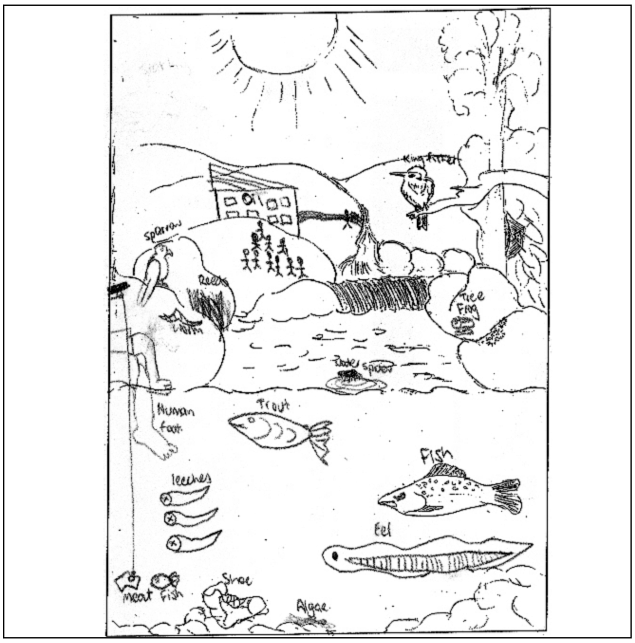
Matt wrote clear descriptions of direct relationships in response to the first two questions:

1. *The algae is eaten by the eel.*
2. *The rainbow trout feeds on the reeds*.

Although Matt clearly understands the concept he was asked to exemplify, both relationships are incorrect in their contextual detail. Neither eel nor trout are herbivores. Similarly, Matt was able to describe a complex, dynamic change to the waterway that included a chain of events as the result of one human action:

3. C*ompanies by water drop oil waste into waterways therefore killing the trout and other fish. The reeds will overgrow, algae will spread and this will cause blockage of drains.*

Figure 3. Matt's interesting selection of waterways components.



Here Matt demonstrates that he understands the impacts on plants (and therefore the ecosystem) when animals that feed on them are removed. His response is a conceptually ambitious attempt to describe dynamic relationships, combined with an inaccurate knowledge of the actual feeding relationships that are possible in the stream. There is an implication that "trout and other fish" all eat reeds and/or algae. Trout are of course insectivores that live in fast flowing waters, not in brackish areas where reeds would be found. Herbivorous fish are not common in New Zealand waterways (the ecological consequences were potentially disastrous when an attempt was made to control introduced waterweeds by introducing koi carp, for example).

Contextual knowledge may need more attention

Overall, the children's work suggested that contexts are indeed in need of explicit attention when teaching for systems thinking. The children shared a poor contextual knowledge of:

- *relatively common New Zealand birds*: the kingfisher was included in the drawing outline and named in the instructions but some children assigned this label to the large fish already drawn in the stream
- *freshwater fish species*: apart from eels, few fish species were named
- *the difference between freshwater and salt water species*: crabs and seaweed featured in some drawings. Ironically, the research team made a mistake of this sort too. Not until it was pointed out by the director of the Waterways project did the team realise that the fish in the provided drawing outline had fins more typical of sea species than a freshwater species. This may have confused some children. Additionally, the interviews revealed that the overall structure of the drawing led some children to conclude that the foreground represented the sea
- *plants that live in freshwater*: many children did, however, include algae, which obviously caught their imagination during the Waterways unit;
- *non-living components*: few students mentioned erosion and those who did generally referred to cows trampling the banks. There was little reference to water temperature despite the Waterways focus on the importance of summer shade provided by trees, and elements of the water cycle were addressed in very few students' work.

Educational implications

This moment-in-time snapshot of children's learning in a rich ecosystems context revealed the three broad patterns described above. There was an apparent interplay between conceptual and contextual understanding as each child described direct and indirect systems relationships. And each pattern implied a somewhat different immediate learning challenge, with associated potential 'next learning steps'.

Next learning steps

Tables 1 to 3 summarise aspects of children's work that could prompt teachers to provide formative feedback that is manageable in the classroom moment.

The advantage of a broad set of patterns of concept/context interactions such as those shown in these tables is that teachers are supported in knowing the sorts of things to attend to as they quickly check for both conceptual understanding and contextual accuracy – assuming of course they have the

Table 1. Emergent concept/context relationships and next learning steps.

Pattern of concept/ context interaction	Examples
Some contextual elements identified.	*The bird is staring at the fish.*
Relationships are implied but not explicit	*The dead leaves have fallen into the water.*

Implications for next learning steps

Both conceptual and contextual understanding may need strengthening. Modelling a range of examples of relationships and discussing the type of relationship shown by each – e.g. feeding, habitat requirement – could help.

necessary knowledge of the ecosystem for the latter critique. Even if they do not, awareness that they can direct children to check contextual details for themselves may be sufficient.

Paying greater attention to contexts in systems thinking

The findings reported here support Assaraf and Orion's contention (2005) that "naming parts and processes" underpins learning for systems thinking when it provides a firm contextual foundation on which to build. Each new context that is encountered will need to be a specific focus of learning, and will have its own challenges for the accurate transfer of concepts. It may be that teaching children to ask specific questions about how an idea applies in a context could alert them to the aspects to which they will need to pay attention. For example, once they know about food chains, they could think about which specific animals might be herbivores, knowing what role these play, then check if they are correct.

Nevertheless, it is of particular interest that children's conceptual development was *not necessarily* impeded by a lack of accurate, rich contextual knowledge. While some children did not appear to be ready to move forward until they could name and describe more ecosystem components, others were well able to think more abstractly about relationships, notwithstanding their accurate lack of contextual knowledge.

The findings also challenge the idea that temporal dimensions represent the final stage in a series of progressive developments of systems thinking. Any change in an ecosystem implies a temporal dimension. Something happens, something else follows. Even when children did not join their ideas into coherent chains of consequent actions, it was evident

Table 2. Direct concept/context relationships and next learning steps.

Pattern of concept/ context interaction	Examples
A wider range of plants and animals can be named.	*Alge [sic] gets eaten by macroadnvertebrates [sic].*
Simple direct relationships are described.	*The trees shade the water.*

Implications for next learning steps

Conceptually, the range of types of relationships could be extended (e.g. not just feeding relationships).

Contextual knowledge can be enriched and extended and exploratory use of interesting new vocabulary (as in the first example) consolidated.

Table 3. Dynamic concept/context relationships and next learning steps.

Pattern of concept/ context interaction	Examples
At least one concept such as a food chain is sufficiently well understood that impacts of changes can be proposed.	*The humans can eat the fish so the kingfishers etc won't have much to eat.*
A dynamic relationship where one change that influences another is described.	*People fishing makes the algae grow more because fish aren't eating it.*

Implications for next learning steps

Conceptually children have a grasp on the intended learning. However there may be aspects of the context that need to be revisited:

- Check for and challenge misconceptions in the scale of effects (e.g. thinking one small change will cause widespread pollution)
- Encourage children to check the accuracy of the contextual details in their examples.

that they were aware of temporal dimensions (as in Leona's description of spilling her drink in the stream). This suggests caution is needed when interpreting children's responses to a task such as the one discussed here. Systems are complex and sometimes contradictory. So, it seems, is children's thinking about them.

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