Wānangatia te Putanga Tauira

National Monitoring Study of Student Achievement

Key Competencies 2017

REPORT 2:

Disciplinary meaning–making in science

2

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National Monitoring Study of Student Achievement

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Introduction:	The NMSSA approach to assessment of key competencies
Report 1:	Developing a theoretical framework for a retrospective analysis of achievement in the key competencies
Report 2:	Disciplinary meaning making in science
Report 3:	Disciplinary meaning making of static visual images in English
Report 4:	Disciplinary meaning making in mathematics and statistics
Report 5:	Disciplinary meaning-making: Synthesis of findings from a retrospective analysis

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REPORT 2: Disciplinary meaning–making in science

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Table of Contents

Figures

1. Introduction

The big-picture vision of the *New Zealand Curriculum* says it is important to foster students' dispositions to learn and to contribute as active members of society. The key competencies directly support this vision. NZC describes them as "capabilities for living and lifelong learning" (p.12).

A 'capability' is something that is demonstrated in action. It is what students show they can do—and are willing to do—as a result of their learning. If the envisaged capabilities are sufficiently demanding, students will need to bring aspects of all or most of their key competencies to bear as they work to complete assigned tasks. In other words, capabilities *remix* aspects of all the key competencies and weave them together with important knowledge and skills.

A focus on capabilities provides a practical and helpful way to assess whether and how students are developing their key competencies within the learning areas of the curriculum. If they show they can do things that require increasingly challenging capabilities, we can infer that their key competencies have developed and got stronger.

One potential fish-hook in this argument is that many capabilities are needed for "living and lifelong learning" – more than we could possibly name or focus on. But it is possible to identify some capabilities that are so commonly needed that we can see them in action right across the different curriculum learning areas. They might play out differently but in essence the capability is the same.

The wider project to which this report contributes has investigated whether and how key competencies have been assessed in the first round of National Monitoring Study of Student Achievement (NMSSA). We analysed a range of NMSSA questions from across the many different assessments to identify a small set of capabilities that are almost always needed. The three described from this preliminary analysis are:

- Critical inquiry
- Perspective-taking
- Disciplinary meaning-making

This report has a primary focus on the capability of disciplinary meaning-making and a secondary focus on capabilities needed for critical inquiry.[1] We begin by outlining particular meaning-making challenges in the discipline of science. Next we explain how we analysed the 2012 science assessment called *Knowledge and Communication of Science Ideas* to look for evidence of whether and how Year 4 and Year 8 students demonstrated these capabilities as they responded to the assessment items. We then report on relationships between these capabilities and students' knowledge of science concepts.

Finally, the report returns to the big picture, by discussing how disciplinary-meaning making capabilities in science might contribute to the NZC vision of preparing our young people to be active and informed citizens in their futures.

[1] This idea subsumes three of the "science capabilities for citizenship" (gather and interpret data, use evidence to support ideas, critique evidence) as outlined on TKI: http://scienceonline.tki.org.nz/Science-capabilities-for-citizenship/Introducing-five-science-capabilities

2. The scope of disciplinary meaning-making as a capability in the context of science

Making meaning in discipline-specific ways requires students to take the ‘perspective’ of disciplinary experts (to think like a scientist, mathematician or literary critic for example). In turn, this implies being able to think critically and to manage the various texts that are appropriate to the discipline area.

Meaning-making is essential for accessing the ideas of others, as well as expressing understanding and ideas, and creating ideas. It is complex and multifaceted. The most direct key competency links are to *Using language, symbols and texts* and to *Thinking.*

Disciplinary meaning-making in science

There are signals in the science learning area of the New Zealand Curriculum (NZC) that developing meaning-making capabilities is an important outcome of science learning.

The Nature of Science (NOS) strand is the ‘overarching’ strand in the science learning area and the only compulsory one. *Communicating in Science* is one of four sub-strands of this NOS strand. The specific achievement objectives do not differentiate between levels 1 & 2, or between levels 3 & 4. These achievement objectives are shown in the bullet points below. Note that there are two specific achievement objectives for *Communicating in Science* at levels 3 & 4:

- Levels 1 & 2: Build their language and develop their understandings of the many ways the natural world can be represented
- Levels 3 & 4: Begin to use a range of scientific symbols
- Levels 3 & 4: Engage with a range of science texts and begin to question the purposes for which these texts are constructed.

The final part of the third achievement objective above suggests a need for an explicit focus on the texts of science *as texts*.

The general features of science texts

Science texts typically value *precision* and *clarity* of communication. These texts are constructed so that new data and explanations about the natural world can be communicated and understood by interested parties (especially but not only by other scientists) anywhere in the world.[2]

To streamline and aid precise and clear communication, science inquiry communities sometimes invent specific *conventions* on which they all agree. One classic example is the way in which ecologists use arrows to convey energy relationships in an ecosystem, both in food chains and food webs. A common sense use of arrows might capture the eating action (e.g. rabbit → grass). However an arrow has a specific meaning in this ecological context. It signals the direction in which energy flows through the ecosystem. This means it reads as grass → rabbit because energy comes from the sun, via photosynthesis carried out by plants. Although this seems like a small detail, it is not possible to draw accurate conclusions about what is being communicated by a food web model unless you are aware of the convention.

Empirical inquiry is an important part of science. Scientists aim to gather data that build a convincing case that will not be overturned by critique from their peers. For this reason, clarity and precision in data gathering and in its presentation are highly valued. *Tables and graphs* are important texts in science. They

[2] Some science studies theorists attribute the rapid spread of scientific ways of working to this very ability to reduce the complexity of the natural world to carefully assembled inscriptions on paper that can be ‘read’ by other members of an inquiry community anywhere in the world. In this way, they link the rise of science to the advent of the printing press. See for example Latour, B. (1990) Drawing things together. In M. Lynch & S. Woolgar (eds.) *Representation in Scientific Practice*, Cambridge (Ma) & London, MIT Press, pp. 19–68.

come in many forms, each with its own conventions. Young learners are typically only expected to interact with simple tables (no more than four columns say) and simple line, bar or pie graph forms.

The ultimate aim of empirical inquiry is to build more robust explanations for the natural world. The shaping of such explanations is aided by drawing *diagrams* (again often with specific conventions in different inquiry fields) and building physical or theoretical *models* that enable comparisons to be made between the familiar and the new. A food web could be seen as part model/part diagram as it has some features of each.

Explanations in science are typically causal claims, and the conditions in which any one claim holds true are carefully specified. Writing this type of explanation demands the use of *conditional clauses* that children can take time to master. They need to learn to use words and phrases such as 'because' or 'as a result' in precise ways that link their evidence to the claim being made.

Explanation is also aided by clear precise use of *specialist vocabulary*. In science complex processes are often reduced to a single word or phrase (condensation, dissolving, and global warming are just some examples). This creates a challenge for teaching, learning and assessment because students sometimes use these words appropriately in context, yet with little real understanding of the underlying processes or complexities. Terms specifically invented to describe natural phenomena often have Latin roots that are metaphors for the phenomenon being labelled. This can make the language of science arcane and hence difficult for students.

Finally students can be challenged by the need to avoid using *non-specific or value-laden* words and phrases that will almost certainly be a common part of their everyday speech. For example 'cute' tells nothing observable about a specific animal.

How we analysed meaning-making in science

The 2012 NMSSA assessment *Knowledge and Communication of Science Ideas* had an explicit focus on the NOS strand called Communicating in Science. Some items tested knowledge so that the relationships between knowing and communicating could be explored. Year 8 students completed a test booklet with 22 questions and Year 4 students were given 19 questions. A small number of questions were in both test booklets. Some questions had multiple parts. We use the term 'items' to discuss these parts individually.

The plan to use a small number of capabilities as a framework to assess students' demonstrations of their key competencies was not developed until 2015. This means it came after the science results had been analysed and reported.[3] For this new round of analysis we went back to the test booklets and identified all the instances where we could see that students needed to draw on science ways of meaning-making to complete the items. Seven specific types of meaning-making were evident across the mix of questions in both tests:

- Making detailed observations from images
- Interpreting models
- Reading and interpreting diagrams
- Creating or adding to diagrams or models
- Reading and interpreting tables
- Reading and interpreting graphs
- Writing causal explanations

[3] The report of the 2012 science round can be found here: Educational Assessment Research Unit & New Zealand Council for Educational Research. (2013). *National Monitoring Study of Student Achievement: Science 2012*. Wellington: Ministry of Education. Retrieved from http://nmssa.otago.ac.nz/reports/2012_Science_ONLINE.pdf

We then looked at the marking schedules to find out whether and how meaning-making impacted on the way achievements were scored. From this analysis we developed brief descriptions of the disciplinary meaning-making demands of the selected items.

Next we made predictions about the comparative difficulty of different items, based on our own knowledge of challenging aspects of meaning-making. Then we went back to the data from the original analysis to see if our predictions were correct. In a few cases they were not correct and this challenged us to think about why not. Some descriptions needed to be adjusted at this point.

Finally the descriptions were collated as shown in figures 2–8, and the associated findings were outlined.

3. Are students making progress in disciplinary-meaning-making in science?

The figures in this report unpack the various ways in which the 2012 *Knowledge and Communication of Science Ideas* assessment evaluated aspects of students' meaning-making capabilities in science.

The 2012 statistical analysis of the *Knowledge and Communication of Science Ideas* assessment generated the scale shown at the left-hand side of figures 2–8. Each individual item in the assessment was located on this scale based on the analysis of students' answers. An item's location indicates its relative difficulty compared with the difficulty of all other items in either the Year 4 or the Year 8 assessment. The higher up the scale an item is located, the more difficult it was for students to answer the item correctly.

Each participating student was also given a position on the scale, depending on how many questions they answered correctly, and how easy or difficult the overall mix of those questions was. We don't show the individual students in most of the figures in this report because our focus is on the items. However we can say that students located at the *same place* as an item (in figures 2–8) will have a 70 percent chance of meeting the demands of that question. Figures 9 and 10 do show student locations because they explore the correlation between students' science knowledge and their meaning-making capabilities in science.

In figures 2–8 each box briefly describes an item in terms of its meaning-making demand. The brown tab to the left of each item box is positioned to show the difficulty of that item. Dichotomous items (questions to which responses were either right or wrong) have blank tabs, and they are positioned on the scale where students would typically be meeting the demands of the question. Polytomous items (those marked on a partial credit scale) have two brown tabs showing the comparative difficulty of achieving a partial score versus a full score. These tabs are numbered 1 and 2 respectively.

While the scale generated by the analysis of the test items shows their comparative difficulty, it cannot, per se, make links to the different curriculum levels of NZC. The method used to do this is described in detail in Appendix 3 to the 2012 report. In brief, a team of eight science education experts worked with booklets of selected items ranked in order of difficulty (as completed by students and statistically modelled by the assessment team). Over the course of a full day workshop these experts individually decided, and then collectively debated, the placing of 'cut points' at which one curriculum level ended and the next began.

Figure 1 is taken from the 2012 report. It shows overall achievement of the whole cohort at Year 4 and at Year 8. This graph compares the relative achievement of the two cohorts, as assessed by the *Knowledge and Communication of Science Ideas* assessment. Notice that there are no hard and fast distinctions between level 1 and 2, or between level 3 and 4. The curriculum does not differentiate between these levels so the science education experts felt they could only make broad distinctions between emergent and developed knowledge and capabilities.

The graph shows that at Year 4 students are broadly on track in making progress against the NZC levels but by Year 8 many are falling behind where they would ideally be. In the sections that follow, it will be apparent that not making the shift from using every day meaning-making conventions to using science discipline-specific conventions contributes to this lag in progress at Year 8.

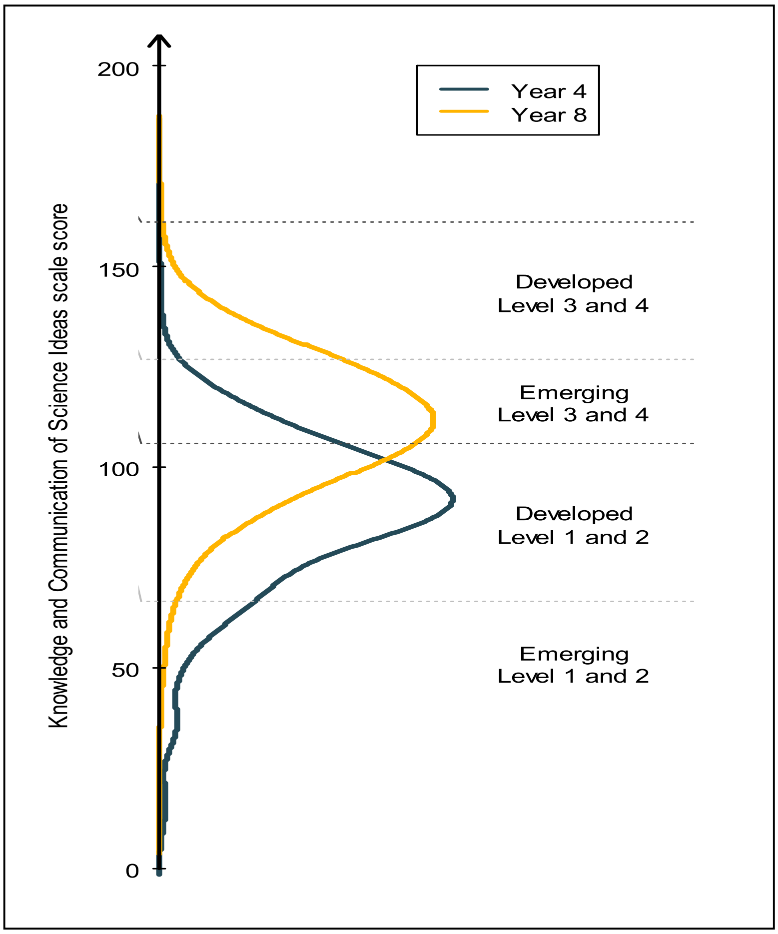

Figure 1. Comparative progress as measured by the science GAT in 2012

In figures 2–8 the colour grading shows the change between curriculum levels. The pale blue lower on each figure represents a developed level 1 and 2 display of disciplinary meaning-making. The darker blue at the top shows what developed disciplinary meaning-making looks like at levels 3 and 4. The green in the middle is emergent disciplinary meaning-making at levels 3 and 4.

4. Making detailed observations from visual images

Precision and lack of ambiguity are valued aspects of meaning-making in science. Several items tested this aspect of the capability by asking students to make observations from provided images. Each item was framed in a way that required careful attention to detail and precision in the use of descriptive language. Figure 2 (over the page) describes the patterns of difficulty of these items.

Links to critical inquiry

Gathering and interpreting data is one of the science capabilities.[4] More generally it is an important aspect of critical inquiry across the curriculum.

The emphasis in the questions selected here is on making observations and writing these down. The related aspect of making inferences is not assessed by these items. If students did describe something they had inferred but could not actually see they would have scored 0. Knowing that there is a difference between observation and inference —and how to tell which type of disciplinary meaning you are making in the moment—is an aspect of critical inquiry.

Interpreting the patterns

Year 8 students were given fewer support cues than Year 4 students. One of their observation questions was more open and the other was more abstract. The difference in scale locations for these two items, compared to the other items shown in figure 2, suggests that openness increased the meaning-making challenge.

To complete the more open observation question, students needed to decide what to pay attention to, and why. They needed to observe multiple differences because one observation would almost certainly be insufficient to make the requested differentiation. If students had known how to write a precise description for a specific communication purpose, this question should have been easier on average than it proved to be. There were 21 scale score points between those students who did provide a sufficiently clear description and those who gave a more generic answer. This represents about the width of emerging level 3&4 band, and about two thirds of the developed levels 1&2 band on the graphic.

It was more obvious what needed to be described for another Year 8 observation item. But this was also a more abstract representation and a clear description required the use of precise directional language.

Year 4 students completed one question with two parts. Each part was marked by partial-credit scoring. To gain full credit students needed to use appropriate comparative language and avoid non-specific similarities or differences that could equally well apply to a wide range of other animals (e.g. both have legs as an example of a similarity). They also needed to ensure they described features that could actually be observed. The animals were familiar and some students inferred differences that could not be seen. A difference of 12 scale score points highlights that some students were able to use appropriate, clear meaning-making capabilities while others made vague but basically correct observations. Overall, clearly describing a difference was harder than describing a similarity – the relative scale scores were 118 and 95.

The questions with partial-credit scoring clearly show that using *appropriate* science conventions for written meaning-making is a challenge. If students had understood what the questions actually entailed in the context of science, more of them would have been able to complete them as intended, given that no specific science knowledge was required and many of them were able to write generic descriptions.

4 http://scienceonline.tki.org.nz/Science-capabilities-for-citizenship

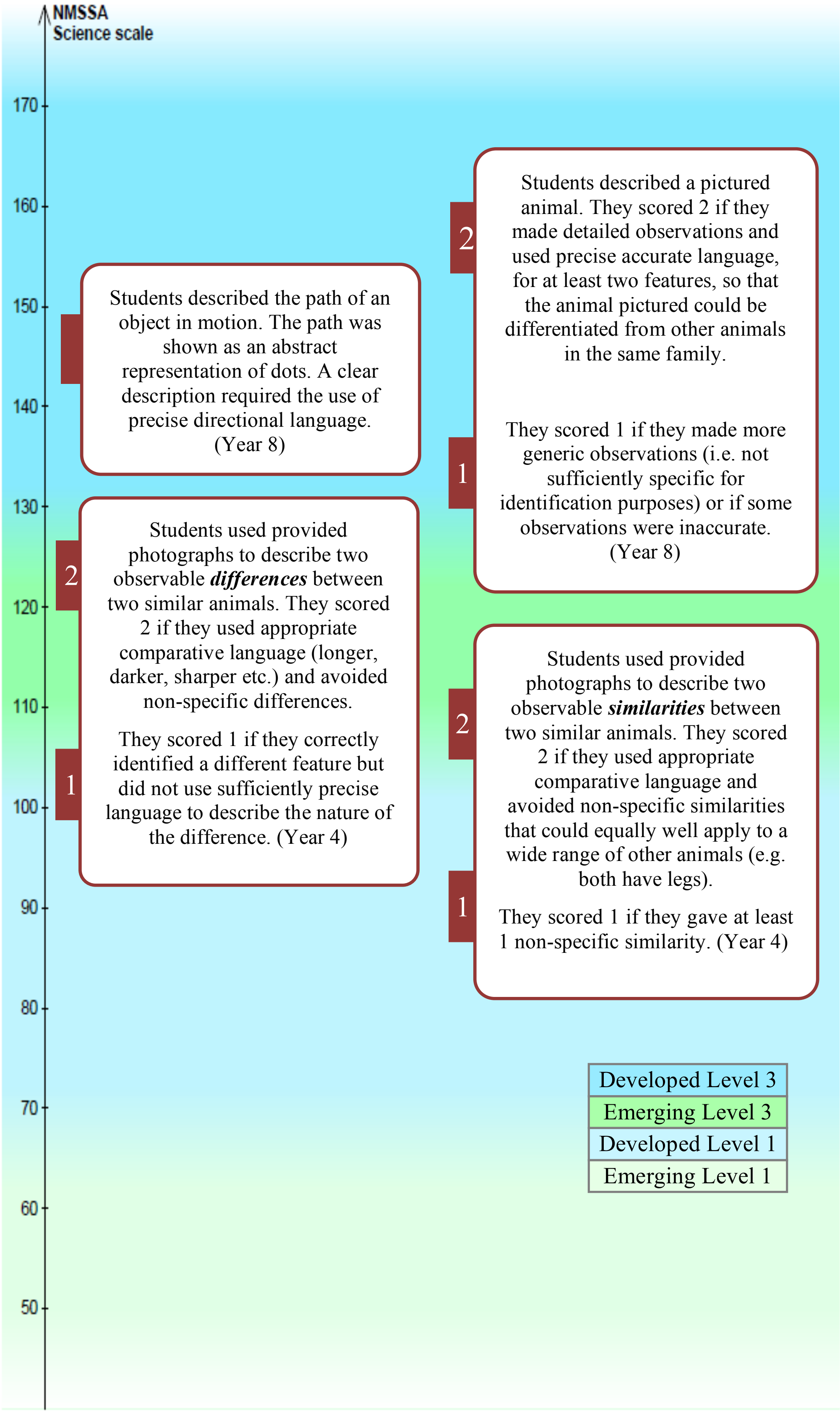

Figure 2. Features of items that required students to make scientific observations

5. Interpreting a model

In science, a model is a representation of an idea, an object or even a process or a system that is used to describe and explain phenomena that cannot be experienced directly. Models are central to what scientists do, both in their research as well as when communicating their explanations. *https://beta.sciencelearn.org.nz/resources/575-scientific-modelling*[5]

In all of the following ways, models are an important component of disciplinary meaning-making in science. Models are variously used to:

- make abstract ideas more accessible
- probe the adequacy of current explanations, to strengthen or reject them
- make predictions in order to develop 'next questions' and testable hypotheses.

Figure 3 (over the page) describes items that assessed students' capabilities in using models for meaning-making.

Links to critical inquiry/perspective taking

Describing possible outcomes of an action demands critical thinking and often also requires an element of perspective-taking (see the theoretical framework report in this series). Linking cause and effect also requires that students demonstrate aspects of both these types of capabilities. Predicting the consequences of changes to food webs invokes both of these aspects of critical thinking.

Thinking from a systems perspective is a specific type of critical thinking. The analysis suggests that taking a systems perspective was something that many Year 8 students did not seem able to do – or perhaps they did not see the need to do this in order to *critically* complete the question. To build this aspect of critical inquiry they need to learn to ask themselves if there might be more than one possible and plausible way to think about changes to even quite simple models.

Interpreting the patterns

Food webs are part-model, part diagram. If Year 8 students knew the convention for use of arrows in food chains and webs, the questions in one item were not particularly demanding. However, as for a number of other items, it seems that lack of knowledge of this science-specific aspect of meaning-making was one aspect that made the questions comparatively difficult.

One of the food web questions was scored on a partial credit scale. In addition to needing to know which way to read the meaning of the arrows, students needed to take a 'systems' perspective on the highlighted part of the model. There were multiple possible impacts and they needed to describe at least two. The substantive difference of 42 scale scores points between those who could describe one impact and those who could describe more than one possibility suggests that making a more complex reading of a model is something with which the vast majority of Year 8 students are not familiar. (42 scale score points represents more than one curriculum level – a pretty big difference.)

No comparison with Year 4 can be made because there were no items that assessed Year 4 students' facility with using models to communicate in science.

[5] This quote is taken from a longer Science Learning Hub resource on the use of models in science.

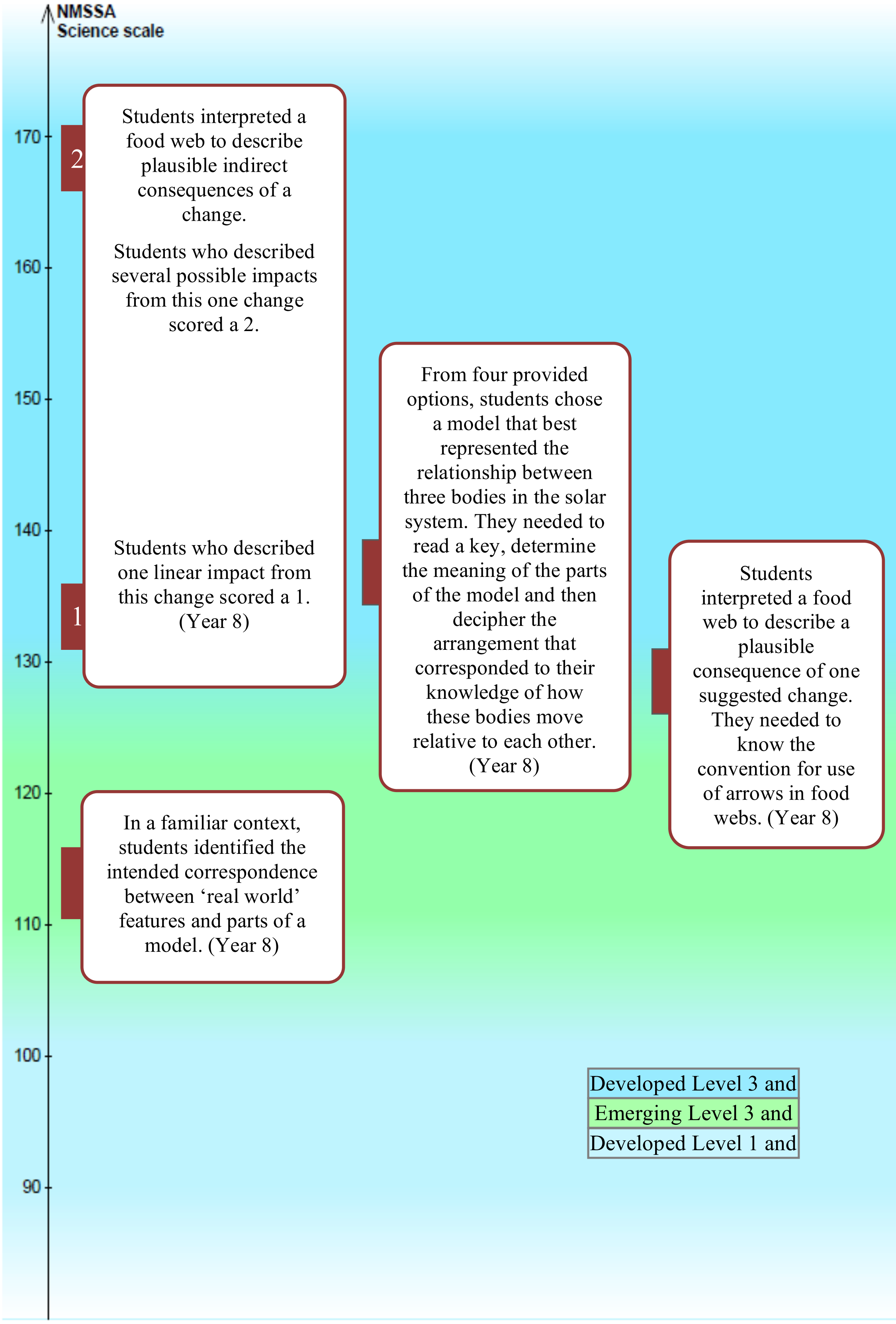

Figure 3. Features of items that required students to make meaning with scientific models

6. Reading/interpreting a diagram

Diagrams are another widely used meaning-making tool in science. They come in a wide variety of formats and often employ specific conventions. Some diagrams convey salient features of a real phenomenon and others are more schematic. The latter type might capture the essence of a pattern for example.

Arrows can mean quite different things in different types of scientific diagrams (for example, as already noted, food webs could be called a type of diagram or a model and their arrows have a very specific meaning).

Figure 4 describes items that assessed students' capabilities in making meaning from diagrams.

Interpreting the patterns

The figure shows that diagram interpretation was one of the easier aspects of meaning-making for students to demonstrate. However there was more scaffolding for some of these items – three of them were in a multiple choice format. This format could have provided meaning-making prompts for some students.

One Year 4 item in this set had partial-credit scoring. Compared to other items scored this way, there was a comparatively small difference between students who could write two clear statements from the diagram and those who could only write one. Again there were prompts. The question specifically asked for two statements. Spaces numbered 1 and 2 were provided so students did not have to make their own decision about how much information constituted an adequate response.

While the multiple choice questions did require student to make a choice between options, the critical thinking demands of these items were not as high as for those that required systems thinking or similar.

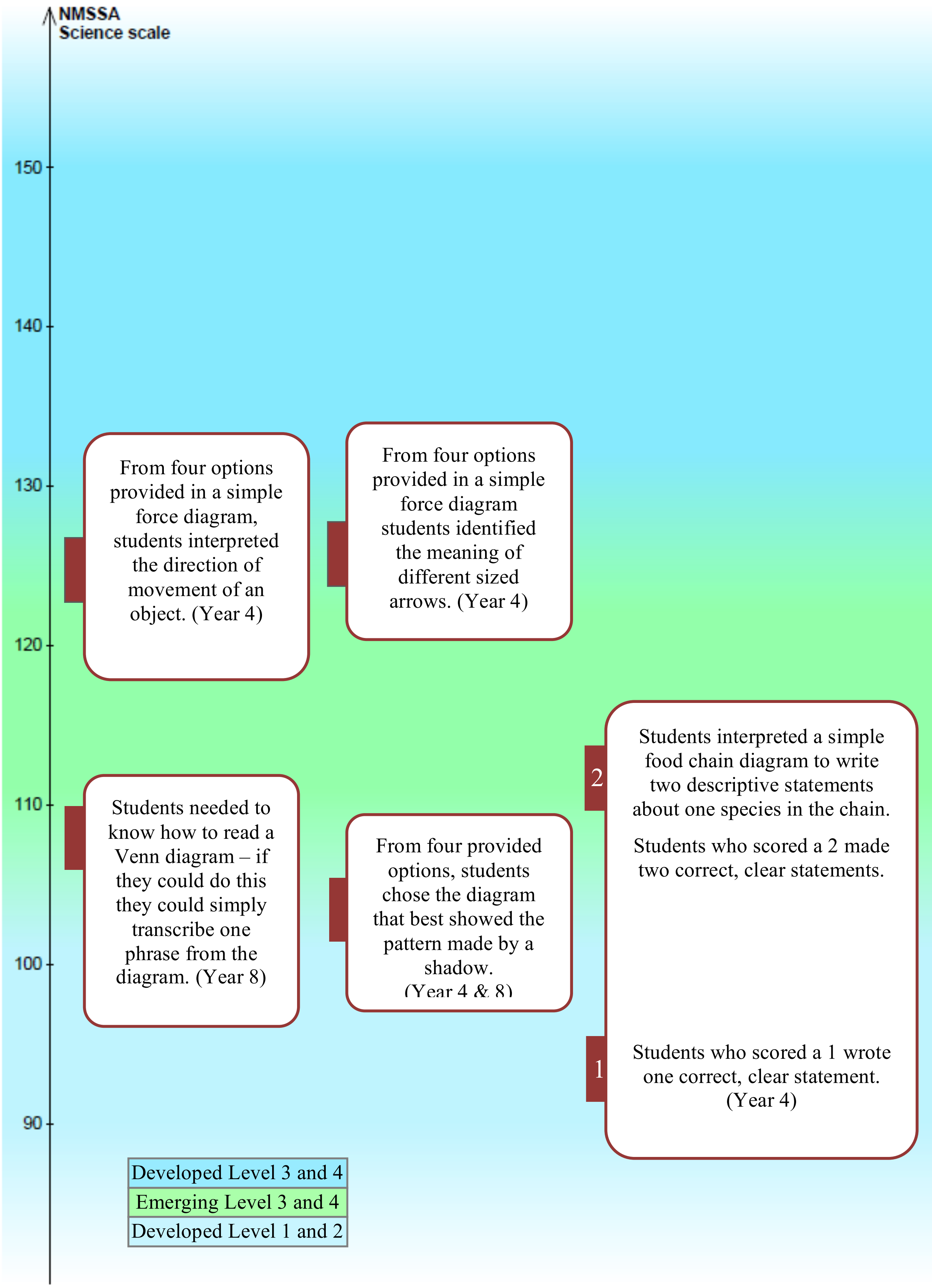

Figure 4. Features of items that required students to interpret diagrams

7. Creating/adding to a diagram or model

Like models, diagrams include features that are important for the communication purposes they serve. Other features are often left out in the interests of clarity and precision. Thus diagrams are not 'pictures' in an artistic sense (though construction of complex diagrams can require considerable artistic abilities). This focus on directing attention only to the desired aspects of a phenomenon creates considerable challenges for students when they are asked to construct diagrams, as opposed to making an interpretation of a diagram constructed by someone else. Figure 5 describes items that assessed students' capabilities in drawing scientific diagrams as a form of meaning-making.

Interpreting the patterns

A comparison of the location of these items with those in figure 4 supports the hypothesis that it is more difficult for students to construct diagrams than to interpret them. If they did not understand the purpose for which diagrams are constructed, or the associated conventions, they were likely to draw pictures and/or leave out critical elements such as arrows, and/or not pay attention to the importance of accurate sequencing of events or relationships.

Year 8 students needed to be aware of all the appropriate conventions to complete their drawing as an appropriate approximation of a life cycle diagram. Drawing skills per se were not assessed and in any case they only needed to draw eggs from their own general knowledge. The support materials provided the other images needed, but students did need to make a connection between the relevant images and parts of the text. There was a difference of 24 scale score points between being able to use these conventions and understanding what was needed but not using appropriate conventions.

By contrast the item for Year 4 students provided more scaffolding and the animal was likely to be more familiar. The difference in scale score points between being able to do the drawing using appropriate conventions and not using these conventions was only a little smaller than at year 8 (19 scale score points).

Transforming information from one medium (written text) to another (a specific type of diagram) requires critical thinking. Students must identify relevant information, and reshape it in the specific format requested. As Figure 5 shows, doing this without some form of scaffolding is demanding for Year 8 students.

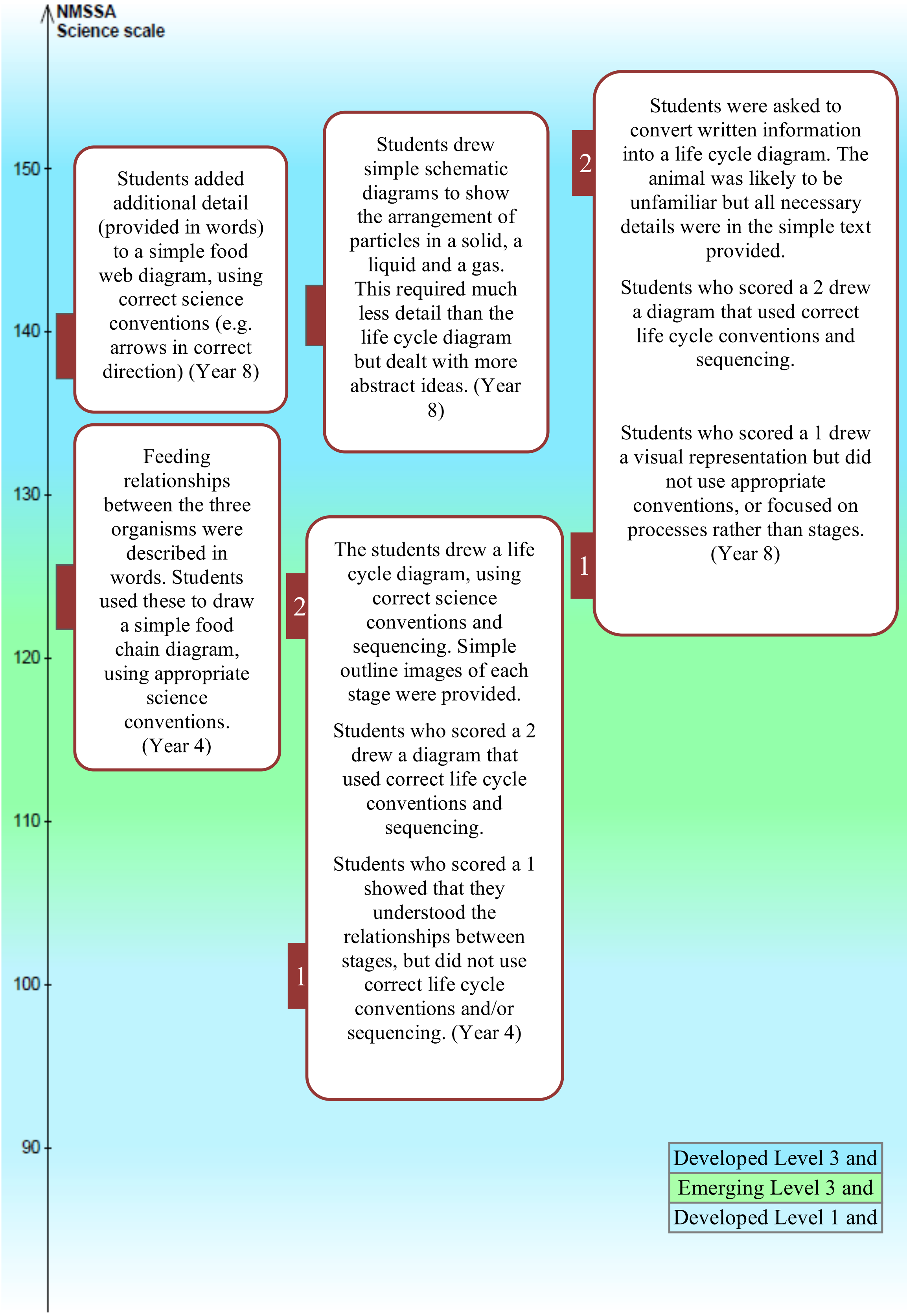

Figure 5. Features of items that required students to draw, or make additions to, diagrams or models.

8. Reading/interpreting a table

> *Researchers and scientists often use tables and graphs to report findings from their research. In newspapers, magazine articles, and on television they are often used to support an argument or point of view. ……. It is easy, if students are not skilful at reading graphs and tables, to interpret them incorrectly. They can make wrong decisions because they are basing them on false inferences. When constructing graphs and tables, it is also possible to misrepresent the data. Research suggests that students often regard tables and graphs as an end in themselves. Few refer to them as a source of evidence, or as a way of exploring patterns and relationships in data or information.*
> *https://arbs.nzcer.org.nz/tables-and-graphs*

This quote from the Assessment Resource Banks site provides a very brief overview of why tables and graphs can be problematic forms of meaning-making for young learners.

Although they are used in many areas of the curriculum, there are some specific challenges for using them in science. Tables are widely used to organise empirical data from science investigations. This can entail the use of specialist vocabulary. Specific units of measurement are also important – the numbers in the table are essentially meaningless without these. Use of succinct labels and titles is another important convention (although this was not tested in this particular assessment). Figure 6 describes the patterns of difficulty for items that required students to make meaning from tables.

Interpreting the patterns

It appears that reading data from simple tables is an established capability for many students at both year levels. Some Year 4 students did not seem to know that they also needed to provide the correct unit of measurement to complete their answer. There was a very big difference of 41 scale score points between answering with the unit of measurement and answering correctly but without this unit. This simple convention is one way in which precision and clarity are valued as aspects of meaning-making in science. Patterns for reading a graph, discussed next, will show that this was also a challenge for Year 8 students.

For Year 8 students, successfully demonstrating the two-step reasoning/estimating process was considerably more difficult than simply reading data from a table or recognizing a pattern in data.

Reasoning backwards from data to infer the question that generated the data was challenging for many Year 4 students. Some students could make a relevant inference but did not shape a clear concise investigable question.

Links to critical inquiry

Making and justifying inferences is an important aspect of critical inquiry. The specific science capability implicated is ‘gather and interpret data’.

Making inferences from a succinct data summary (i.e. a table) requires careful reasoning and logical thinking. Students need to decide what the data pattern can and cannot tell them, in the specified context.

Shaping questions (as opposed to answering questions asked by others) is another important aspect of critical inquiry.

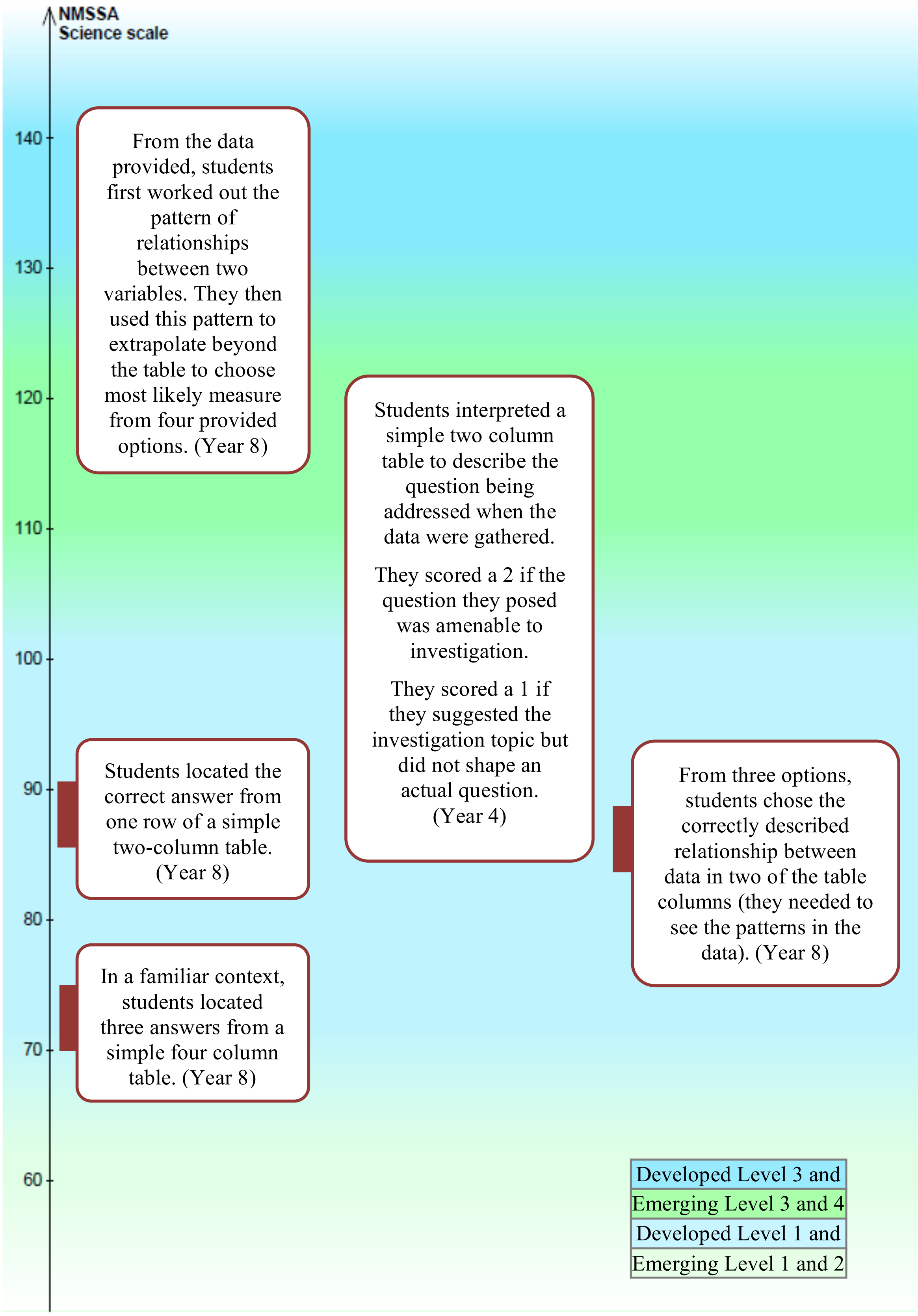

Figure 6. Features of items that required students to interpret a table

9. Reading/interpreting a graph

Like tables, graphs are widely used to organise empirical data from science investigations. All the same meaning-making challenges apply. The researchers who work on developing Assessment Resource Bank items have found that students can have difficulties with: reading scales; answering questions that involve calculations; and interpreting an overall shape or trend. We also found examples of all these challenges in the *Knowledge and Communication of Science Ideas* assessment. Figure 7 describes the patterns of difficulty for items that required students to make meaning from graphs. Note that the phrases in italics signify different aspects of critical inquiry.

Interpreting the patterns

Comparing figures 6 and 7 it is tempting to conclude that interpreting graphs is more difficult for students than interpreting tables. However the graph questions were arguably more demanding. For example one item with a focus on reading a table required students to *make a simple estimation* but four possible answers were provided. By contrast students needed to mentally divide a rather coarse scale on a line graph to arrive at a suitable estimation for one of the graph questions. (Note that students do not encounter line graphs in mathematics until Years 5 & 6.) This question was clearly very difficult to answer, even though a wide range of estimates was allowed by the markers. Once again the difference in scale scores between achieving a full score for this question (scale score 156) and achieving a partial score (scale score 122) resided in using the correct unit of measurement.

Writing a *simple evidence-based argument* in their own words was difficult for Year 8 students, even if they had successfully read the three-column bar graph provided for one item.

The critical thinking demand was also high in the item that required Year 8 students to draw on their personal knowledge of a very familiar geological phenomenon. Students would almost certainly have seen this phenomenon in person, or at the very least seen vivid images on TV. They needed to connect this everyday knowledge to the provided information and then draw on this experience to *make an inference* about the meaning of a sharp peak on the provided graph. Then they needed to explain this meaning in words, making a *simple cause and effect claim*. There was again a very big difference between being able to do this with clarity and precision (169 scale score points) and using less precise language that did not clearly link cause to effect (137 scale score points).

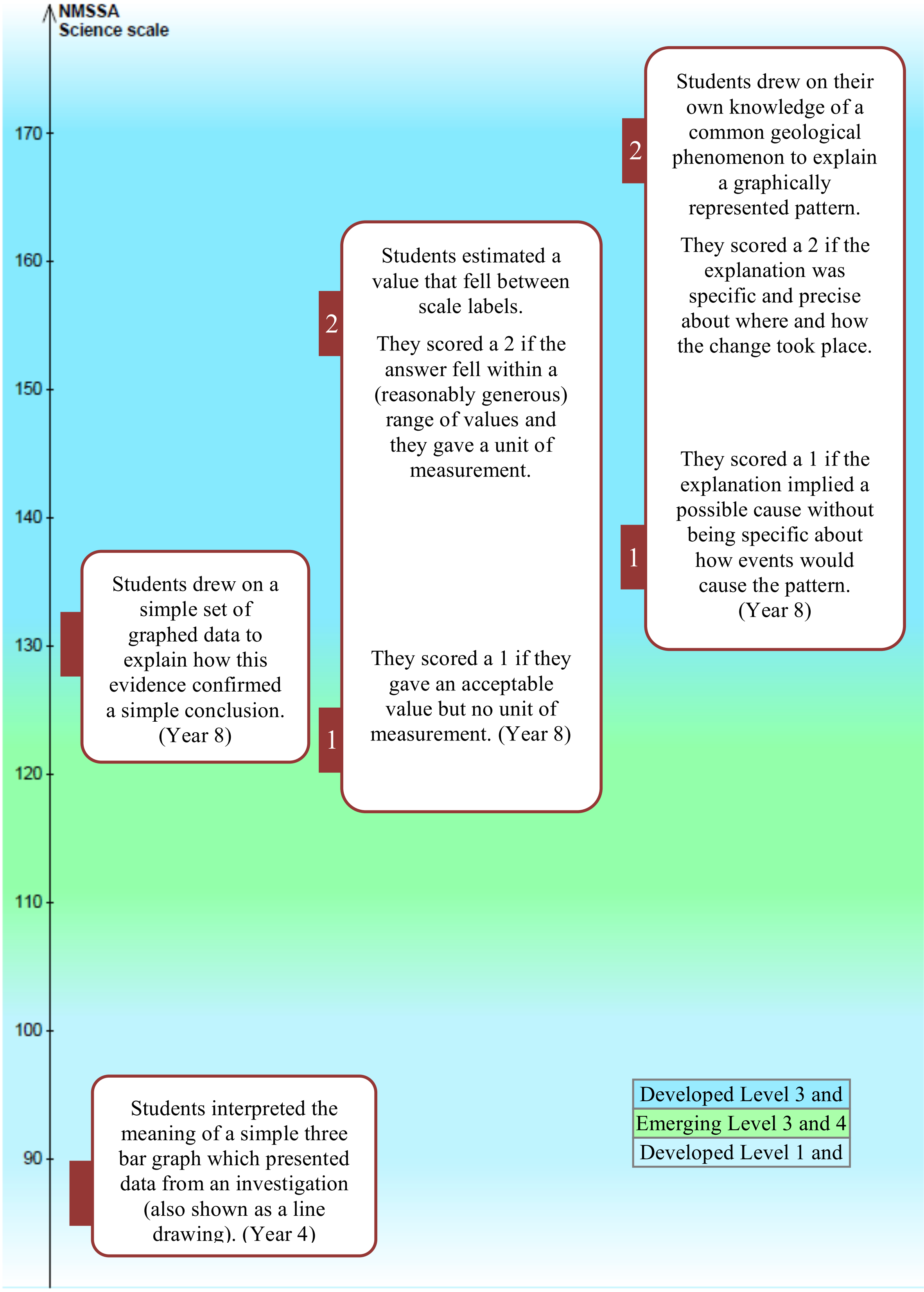

Figure 7. Features of items that required students to interpret a graph

10. Writing a causal explanation

Figure 8 describes patterns of difficulty for items that assessed writing causal explanations as a meaning-making activity in science.

Interpreting the patterns

It appears that writing scientific explanations can be a deceptively challenging form of meaning-making for both Year 4 and Year 8 students. While some items appeared to be comparatively easy, others were much more difficult even though the core activity—i.e. writing a simple explanation—was essentially the same in all cases.

What accounted for these differences? The marking schedule provides one clue. Students needed to establish clear links between the thing being explained and the science idea that provided the link. In other words, clarity in communication was important.

The familiarity of the context doubtless contributed to difficulty levels. This is clearly seen in one item in common between the two tests. Year 4 students wrote two explanations and scored more highly when writing about a more familiar animal, as did Year 8 students who wrote three explanations. For the older students, explaining a plant adaptation was more difficult than explaining an animal one.

Note that several of the items that have already been discussed could also have been repeated here. A number of explanations required students to first interact with other specific forms of meaning-making in science (tables, graphs, diagrams). If doing that was challenging then they would be unlikely to arrive at a clear explanation regardless of their writing ability. Notably the items towards the lower end of figure 8 were less likely to require this dual meaning-making.

The knowledge that students brought to their explanations included both everyday knowledge and knowledge of science concepts. The partial-credit questions where students could score a 2 or a 1 highlighted the additional challenge when an explanation requires the use of science concepts. Some Year 8 students could draw on particle theory to shape an explanation (scale score 152). Others knew what they wanted to explain but could not use particle ideas concisely or clearly (scale score 124). Some Year 4 students could provide an explanation of a change using their own words (scale score 137) while others resorted to vague or incorrect explanations but at least tried to say what had happened (scale score 111). Again the differences between partial and full scores represent more than one curriculum level, or around two year's growth in learning.

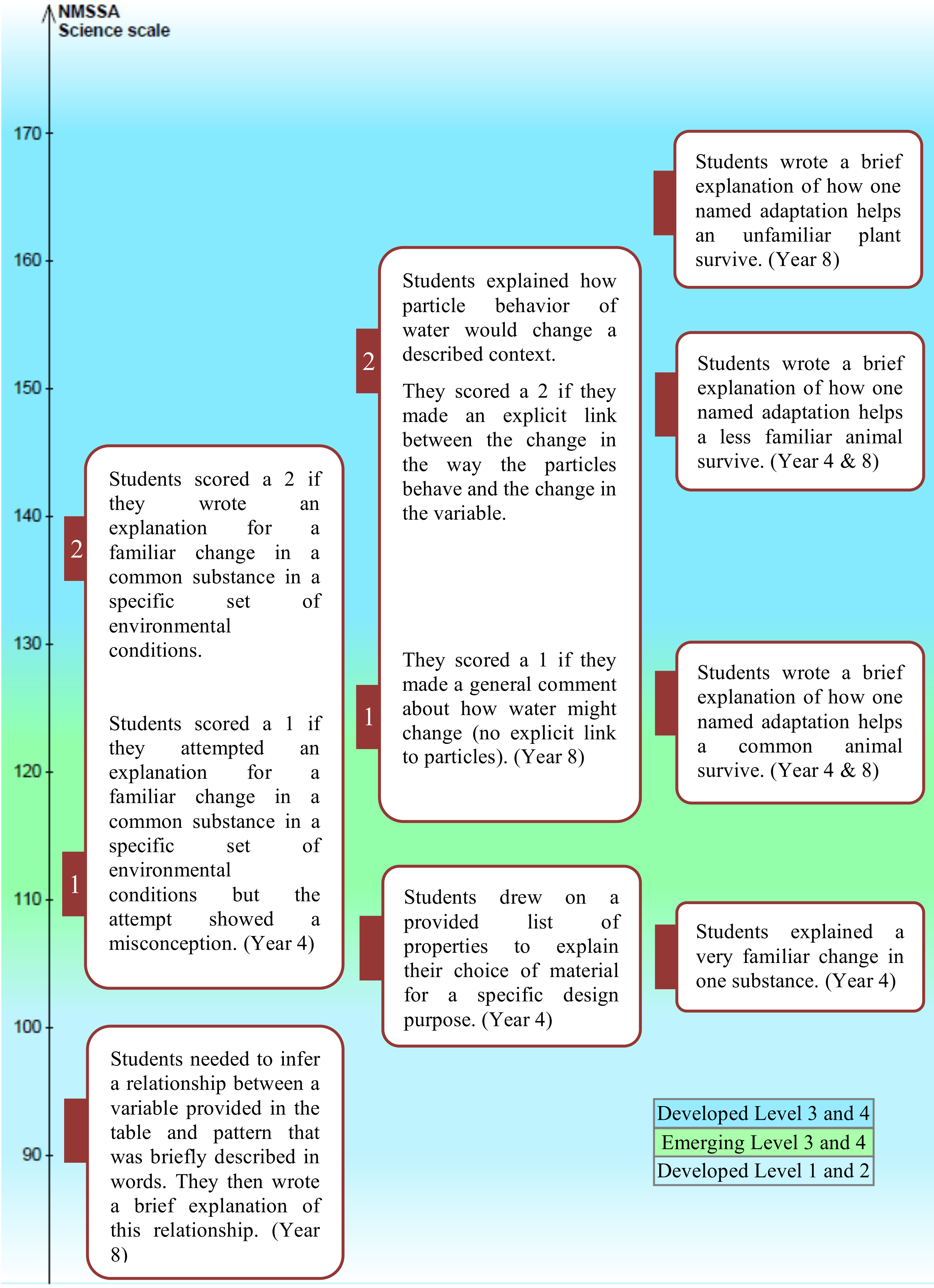

Figure 8. Features of items that required students to write a causal explanation

11. Is conceptual knowledge correlated with disciplinary meaning-making capabilities?

A small number of items in the *Knowledge and Communication of Science Ideas* assessment had a focus on science knowledge but did not otherwise require a demonstration of capability. In other words these were more traditional 'test' items. This was done so that we could investigate the relationship between knowing some basic science ideas and being able to draw on and display appropriate disciplinary meaning-making capabilities. Figures 9 and 10 show the results of this investigation.

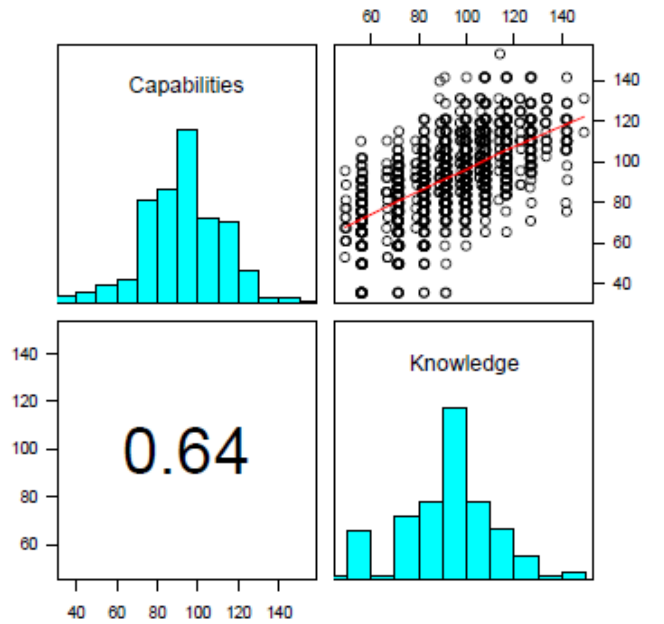

Figure 9. Correlation patterns between knowledge and capabilities at Year 4

Each dot in figure 9 represents one Year 4 student. The black patches indicate that many students are located more or less at the same point. A correlation co-efficient of 0.64 shows that for many students at Year 4 knowledge was indeed correlated with the specific capabilities being investigated (i.e. disciplinary meaning-making and critical inquiry). There will always be some students who do not conform to the prevalent pattern but the overall trend is clear: the more science students know, the more likely it is that they will also be able to use appropriate disciplinary meaning-making conventions and to display the aspects of critical thinking needed to complete each question.

Figure 10 shows that the overall pattern of correlations is somewhat stronger again at Year 8. This makes sense because knowing about the 'science' way of meaning-making, as opposed to the 'everyday' way, is an aspect of learning that should be part and parcel of appropriate conceptual learning per se.

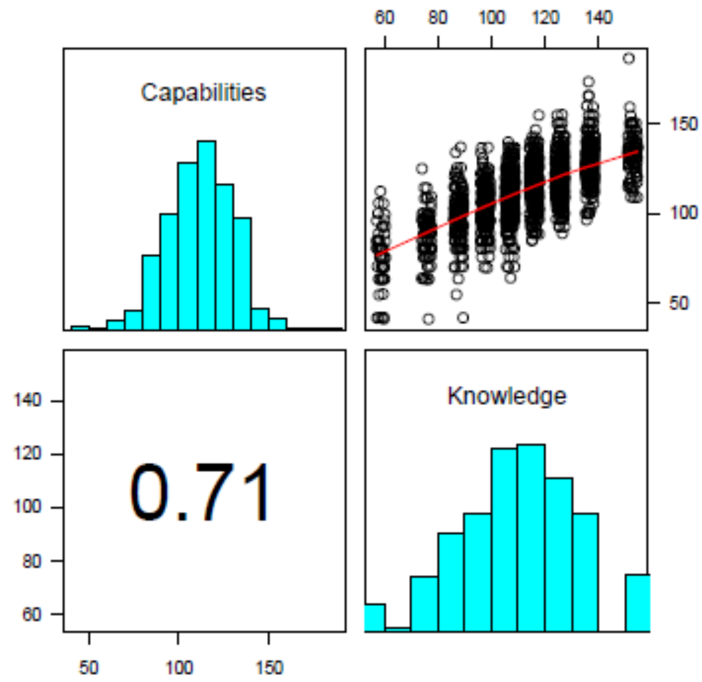

Figure 10. Correlation patterns between knowledge and capabilities at Year 8

The relationship between capabilities and knowledge

Earlier sections of this report have laid out clear evidence that many Year 8 students are held back from making expected progress in science because they do not know (or do not use) relevant meaning-making conventions and practices. In this section we have also shown that students' science meaning-making capabilities are strongly correlated with their overall levels of science knowledge. Those who know more science are more likely to also use the conventions and practices of meaning-making in science.

These findings make sense. As students learn about the ideas of science (at an age-appropriate level), they also learn about how those ideas are communicated within the science community and to the public more generally. But there seems to be a gap between this logic and what actually happens in classrooms. The forms of meaning-making being assessed should not have been especially demanding if students had been given opportunities to learn about them. The possible reasons that many students did not seem to have had such opportunities are beyond the scope of this report.

12. How important are capabilities in the science learning area?

This report has outlined a retrospective analysis of how students demonstrated their meaning-making capabilities when completing the NMSSA *Knowledge and Communication of Science Ideas* assessment which was conducted in 2012.

We have reported on seven distinct aspects of disciplinary meaning-making in science. The clear message from the patterns that emerged is that many Year 8 students are held back from making expected progress in science because they do not know (or simply do not use) relevant meaning-making conventions and practices. We have also shown that students' science meaning-making capabilities are clearly correlated with their overall levels of science knowledge. Those who know more science are more likely to also use the conventions and practices of meaning-making in science. While this should not be especially surprising, it is a useful reminder that a curriculum focus on capabilities (and the key competencies that sit behind them) does not replace knowledge development. The two types of curriculum goals go hand in hand.

To conclude the report we zoom out to the bigger picture with which we began. Why should these capabilities be an explicit focus for science learning?

Science capabilities for citizenship

Like the vision statement, the science learning area of NZC indicates that students should gain capabilities for *citizenship* from their science learning experiences:

In science, students explore how both the natural physical world and science itself work so that they can participate as critical, informed citizens in a society in which science plays a significant role. (NZC, p.17)

The phrase "and science itself" cues the Nature of Science (NOS), of which meaning-making is one aspect. A recent curriculum support project identified five types of capabilities that could help weave key competencies, NOS and science content learning together in ways that bring this purpose into sharper focus as an intentional outcome of learning.[6] These capabilities are:

- Gather and interpret data
- Use evidence to support ideas
- Critique evidence
- Interpret representations
- Engage with science

The meaning-making capability discussed in this report is most obviously aligned with "interpret representations" but goes beyond this to also *constructing* representations. The change of name has come about because the idea of using capabilities as a curriculum weaving strategy, which originated with this pioneering science set, is now being taken up across the whole curriculum. Titles of the capabilities in focus across the whole curriculum need to reflect the many different ways in which disciplines make meaning and represent their insights to the world.

In what ways might interpreting representations/science meaning making make an important contribution to students' growing capabilities for citizenship more generally? This is an important question with which to conclude, especially given that much of the report has been focused on details. Some teachers might ask, for example, how and why it might be that a detail like remembering to add a unit of measurement can make such a big impact on overall assessment results. The next paragraph sums up the argument with

[6] The full resource set can be found at http://scienceonline.tki.org.nz/Science-capabilities-for-citizenship/Introducing-five-science-capabilities

reference to one of these details. Essentially the same case could be made for other detailed aspects of meaning-making discussed in the report.

Precision and clarity are hallmarks of meaning-making in science. A number without a unit of measurement is meaningless. Students need to develop the *disposition* to ask about the unit of measurement and to ensure it is present whenever they work with a data set, however that idea is represented. If they do this often enough over the course of their science learning at school, they could be more likely to also ask this question of any data reported in media accounts of science issues when they are older, or if they need to make a personal decision that involves some aspect of measurement. It seems a small thing but actually can become critical if data are misused, misinterpreted, or misunderstood.

The good news is that the science meaning-making foundations laid during the primary years should not be difficult for either students or teachers – if they know about them and provide lots of practice. The further good news is that this focus does *not* come at the expense of learning interesting and engaging science ideas, or developing curiosity about how science explains the world. Capability and knowledge building go hand-in-hand when students engage with rich learning experiences.