PAT Inquiry and Problem Solving in STEM Contexts

Assessment framework

Australian Council *for* Educational Research

Contents

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Figures and tables

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Introduction

The ACER Progressive Achievement Tests in Inquiry and Problem Solving in Science, Technology, Engineering, and Mathematics (STEM) Contexts, commonly known as *PAT STEM Contexts*, are a set of assessments that allow teachers to accurately and efficiently measure students' abilities to use inquiry-based processes to solve contemporary, real-world problems and issues in STEM contexts, to diagnose gaps, strengths and weaknesses in student learning, and monitor student progress over time during the middle years of schooling. The assessments have been developed especially, but not exclusively, for use in Australian schools. The *PAT STEM Contexts* construct is appropriate for broad international use.

While some tasks predominantly focus on science curriculum aspects, a multi-disciplinary approach is supported with an emphasis on problem solving and inquiry skills. The assessments are designed to be engaging and to encourage students to interact with the content to the best of their ability.

The assessments target STEM skills and are likely to suit the ability of students from Years 4 to 8, with a focus on Year 5 and 6 learning outcomes.

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Rationale for PAT STEM Contexts

STEM education is fundamental for students to gain problem solving and inquiry-based skills needed to solve a range of problems including the complex, global issues that society is facing as the climate changes and finite, non-renewable resources are exhausted. Students who are STEM literate will be able to propose and produce new and improved technologies that can solve these issues and help the economy compete in the global market. Students who are skilled in STEM are predicted to have greater employment outcomes and are considered to be 'future ready' (Timms et al., 2018).

Problem solving and critical thinking skills are essential skills in STEM and are also required across the curriculum and for future employment. The overall purpose of STEM education is to enable individuals to use inquiry processes to draw conclusions and to solve problems in real-world contexts and situations. In today's world, many questions or problems cannot be approached using knowledge or skills from only a single discipline. Instead, individuals often need to draw together and integrate knowledge, skills, and practices from multiple disciplines. When answering questions through inquiry within STEM, the focus is on building understanding of real-world phenomena and scientific investigations. When problem solving, the focus is on finding solutions, which includes suggesting and evaluating actions, and proposing designs. Inquiry questions and problems posed in STEM contexts require individuals to draw on their knowledge, skills, and practices from across the four discipline areas of Science, Technology, Engineering and Mathematics.

In addition to providing a measure of students' ability to answer questions using inquiry processes and to solve problems in STEM contexts, *PAT STEM Contexts* may also support schools in conceptualising how to teach the discipline areas of Science, Technology, Engineering and Mathematics in an integrated way.

Progressive Achievement approach

The Progressive Achievement approach provides a framework for integrating student assessment, resources that support teaching practice, and professional learning. PAT assessments allow teachers to collect evidence of student learning; to identify where students are in their learning at a given point in time; to monitor growth over time; and to reflect on student attainment. They provide reliable measures that enable a variety of interpretations about attainment and progress:

- what students attaining specific levels of progress are likely to know, understand and be able to do;
- how much students have improved over time and what skills, knowledge, and abilities they have been able to develop; and
- how a student's level of achievement compares with other students.

The value of an integrated approach to assessment and student learning has become widely acknowledged. There is now a variety of formative, diagnostic assessment tools used in Australian classrooms. Summative assessments, such as NAPLAN, are often used to inform teaching and learning. As Dylan Wiliam (2011) makes clear, 'any assessment is formative to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers to make decisions about the next steps in instruction'. In his Report, David Gonski (2018, Finding 7) refers to the compelling evidence that 'tailored teaching based on ongoing formative assessment and feedback is the key to enabling students to progress to higher levels of achievement'.

ACER's PAT tests provide indicators of student achievement via scale scores and the accompanying achievement band descriptions. Upon completing their assessments, students are allocated a scale score that represents their achievement in inquiry and problem solving skills in STEM contexts. The scale is divided into achievement bands from which the skills and understanding represented at each level are described. The achievement bands therefore provide valuable evidence-based information about the skills students have achieved, are consolidating, and are working towards. As the Gonski Report recommends, reporting on assessment should have an emphasis on achievement and growth and that the growth should be measured against learning progressions (Gonski 2018, Recommendation 4). Masters (2013) also expresses the idea that learning should be assessed by measuring growth over time and against empirically derived learning progressions.

The PAT reports provide targeted formative feedback, allowing student data to be sorted and analysed in a variety of ways. Using the PAT data and the achievement band descriptions, teachers can structure learning specifically to students' needs rather than where they are expected to be.

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Progressive Achievement in STEM Contexts

In general, the teaching of STEM aims to integrate the core competencies and skills of Science, Technology, Engineering and Maths, and aspects of 21st Century skills (general capabilities) such as creativity, critical thinking and communication (Nadelson & Seifert, 2017; Timms et al., 2018). This integration enables students to creatively explore and investigate new ideas and designs that can solve real world problems and evaluate their ideas and designs. Monitoring of student learning is an integral part of understanding how students are developing these skills and the cognition of knowledge and processes required in STEM (Gao et al., 2020). To assess students, clear learning objectives and progressions need to be established, but there is a lack of consistency and clarity in the strategies and development of STEM learning progressions, curriculum documents and assessments and in the way in which the subjects are integrated (Gao et al., 2020; Timms et al., 2018).

Assessment of STEM as an integrated subject can also be challenging as it needs to assess the connections between the disciplines, rather than focusing on the individual disciplines separately (Fang & Hsu, 2019; Gao et al., 2020). Part of the issue of developing truly integrated STEM assessment is that it has not been as well researched as other areas of STEM education (Donmez, 2020). STEM assessments should allow students to demonstrate their integrated knowledge and problem solving skills and to determine solutions in authentic contexts (Fang & Hsu, 2019). The *PAT STEM Contexts* assessment begins to address these issues by providing a relevant context that enables the integration of the disciplines to assess students' content knowledge, inquiry and problem solving skills.

The Australian Curriculum has aspects of STEM knowledge and skills scattered across the learning disciplines of Science, Technology, Maths, and the general capabilities, but does not treat STEM as a distinct learning area. Therefore, several sources were used to identify the relevant skills and knowledge that are required for students to demonstrate STEM competencies within *PAT STEM Contexts*. This includes the framework for best practices in the sciences, developed by the National Research Council of the National Academies (NRC) in the USA (NRC, 2012). Although it does not specify STEM as a subject, the framework describes the need for the integration of subjects and the skills required to be able to practise STEM. The NRC identified three dimensions that broadly outline the knowledge, skills, and practices required for students to have a foundation in science. These include scientific and engineering practices, crosscutting concepts, core ideas within the disciplinary areas of science, and the relationships among Science, Engineering and Technology (see Appendix 3). Another important source of information was the Trends in International Mathematics and Science Study (TIMSS) framework, which defines the specific cognitive domains that are used when problem solving and during the inquiry process (Mullis & Martin, 2013). These sources were reviewed and used as a checklist to compare against the Australian Curriculum and inform achievement band descriptions. The achievement band descriptions and matching scale scores enable teachers to determine the progress of students, providing data on how students demonstrate their skills and content knowledge along with their connections between concepts. Additionally, the band descriptions describe the complexity and familiarity of the contexts, and the learner's stage of development with respect to the concepts.

Learning progressions, where the stages of learning have been identified for a particular concept and are based on empirical evidence, have not been incorporated within *PAT STEM Contexts* as there had been no large mainstream STEM learning progressions identified at the time of developing the assessment. But there are STEM theoretical assessment frameworks, for example Kelley & Knowles (2016), that can be used to help inform the development of STEM progressions and have assisted in the development of the PAT STEM assessment.

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PAT STEM Contexts and curricula

The Australian national curriculum, and all state curricula, describe expected outcomes in each of the disciplines of STEM at each year level but not for STEM as a specific learning area. Therefore, the contexts of the test items are underpinned by core concepts that cut across the discipline areas of Science, Technology, Engineering, and Mathematics. Due to the multi-disciplinary nature of *PAT STEM Contexts,* progression is conceptualised in terms of the different cognitive domains, or ways of thinking, employed during the inquiry or problem solving processes. The cognitive domain categories (Knowing, Applying, and Reasoning) identified within the large-scale international assessment TIMSS (Mullis et al., 2017) are used for this purpose.

PAT STEM Contexts draws from three learning areas of the Australian Curriculum: Science, Technologies, and Mathematics. Items are developed according to Australian Curriculum, but the PAT assessment is based on a Progressive Achievement approach, rather than year-based expectations. While *PAT STEM Contexts* results may not directly align with curriculum-based year or stage level outcomes, items are mapped to the Australian Curriculum and some state curricula (with content codes and descriptions provided in the online reports and the PAT Teaching Resources Centre). A single assessment is likely to be aligned to curriculum descriptions across the middle year levels, because each test assesses a range of ability.

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Construct

Definition

A construct is a description of an ability that can be measured along a single dimension with a single numeric variable. It often refers to 'what students know and can do'.

A careful definition of a construct enables the transformation of observations (for example, student responses to test items) into measurements of ability/proficiency using a mathematical model. This approach helps ensure that both assessment and reporting are consistent and legitimate.

The *PAT STEM Contexts* construct is problem solving and inquiry capabilities applied to problems that require skills and knowledge in Science, Technology, Engineering and/or Mathematics. *PAT STEM Contexts* measures students' problem solving and inquiry capabilities when applied to problems in STEM. It promotes design and inquiry with a context-driven focus, exploring real life problems. The assessment requires students to utilise these skills across a wide range of subject matter, as reflected by the variety of both written and animated stimulus on an online platform.

The core concepts of *PAT STEM Contexts* relate to pattern; cause and effect; scale, proportion, and quantity; systems and models of systems; energy and matter; structure and function; and stability and change. The core practices relate to defining questions and problems; working with models; planning and conducting empirical investigations; analysing and interpreting data; and evaluating and communicating information. As these skills, concepts, and practices are the focus of the construct, the language used within the assessment is below the targeted year level so that item performance is not affected by poor student comprehension.

Structure

The *PAT STEM Contexts* construct is the organising principle of the assessments; it is used to guide test development and the design of the reports. This structure is also part of the Progressive Achievement approach because the knowledge, skills, and understanding represented in the assessments is designed to support educators in identifying student needs.

Three overarching elements guide assessment development:

- Strands (Australian Curriculum)
- Cognitive domains (TIMSS)
- Contemporary contexts

Strands

PAT STEM Contexts utilises three different learning areas within the Australian Curriculum: Science, Technologies and Mathematics. Although the remaining discipline that makes up STEM – Engineering – is not a learning area within the Australian Curriculum, aspects of engineering are located within the Technologies learning area. Each learning area is divided into strands and sub-strands that describe particular skills or concepts (Table 1, page 6).

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Table 1 *The learning areas, strands and sub-strands of the Australian Curriculum used in PAT STEM Contexts*

Learning area	Strands	Sub-strands
Science	Science understanding	Biological sciences Chemical sciences Earth and space sciences Physical sciences
	Science as a human endeavour	Nature and development of science Use and influence of science
	Science inquiry	Questioning and predicting Planning and conducting Processing, modelling, and analysing Evaluating Communicating
Technologies	Design and Technologies	Design and Technologies Knowledge and Understanding Design and Technologies Processes and Production Skills
	Digital Technologies	Digital Technologies Knowledge and Understanding Digital Technologies Processes and Production Skills
Mathematics	Number and algebra	Whole number operations Fractions and decimals Money and financial maths Patterns and algebra
	Measurement and space	Measurement Space
	Statistics and probability	Statistics Probability

PAT STEM Contexts does not attempt to comprehensively assess all aspects of the strands identified as STEM within the learning areas of the Australian curriculum. Rather it focuses on those strands from any of the three learning areas that are most suited to being understood within a specific context. A fundamental strand central to *PAT STEM Contexts* is Science inquiry. To meet the requirements of this strand, students must demonstrate the critical and creative skills required to identify questions and draw evidence-based conclusions. Concurrently, the Technologies strand is utilised where students apply engineering processes when problem solving, designing solutions, evaluating, and improving designs.

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Cognitive domains

The TIMSS cognitive domains that are used to simplify the integrative nature of the *PAT STEM Contexts* assessments are divided into two dimensions: the content dimension, which specifies the subject matter to be assessed, and the cognitive domain dimension, which specifies the thinking processes to be assessed (Mullis & Martin, 2013). The Science and Maths assessment items allow for students to demonstrate both discipline-specific subject matter, and the cognitive domains.

The TIMSS framework provides separate definitions for three cognitive domain categories within the content dimensions for Science and Mathematics, but these categories can be summarised across the two domains as: Knowing – the ability of students to recall facts, concepts and procedures, Applying – the ability of students to apply knowledge and conceptual understandings to solve problems or answer questions, and Reasoning – the ability of students to go beyond the solution of routine problems to encompass unfamiliar situations, complex contexts, and multistep problems (Table 2).

Table 2 *Trends in International Mathematics and Science Study (TIMSS) cognitive skill descriptions (Mullis et al., 2017)*

Cognitive domain	Description	Skills
Knowing	amount of specific knowledge possessed	Recall/Recognise/Retrieve; Describe; Provide examples; Classify/Order; Compute; Measure.
Applying	the extent to which knowledge is applied	Compare/Contrast; Relate; Represent/Model; Interpret Information; Explain; Determine; Implement.
Reasoning	the extent to which reasoning is employed to answer research questions and to solve problems	Analyse; Integrate/Synthesise; Formulate questions/Hypothesise/Predict; Design investigations; Evaluate; Draw conclusions; Generalise; Justify.

Contemporary contexts

Contemporary contexts were chosen to integrate the different disciplines from the Australian Curriculum, for their relevance to students, and based on how familiar they are likely to be to students. The more difficult items are those that have less-familiar contexts. Contemporary contexts include problems that need to be solved (for example, having effective, sustainable power) or up-to-date research (for example, radio tracking numbats) to everyday issues (for example, insulating materials for the household).

Structure of the observed learning outcome (SOLO) (Biggs & Collis, 1982) was applied to items to ensure that they varied in their complexity. This means that for low-level items students are only required to consider one relevant aspect such as identifying or naming an object. As the items increase in their complexity students are required to combine and describe knowledge and skills, analyse, and apply their understanding, and finally to apply this knowledge to abstract concepts.

PAT STEM Contexts consolidates the three overarching elements Australian Curriculum strands, TIMSS cognitive domains and the contemporary contexts to assess students' ability to use the processes that are involved in problem solving and their use of inquiry skills. Students are expected to show increasing competencies in their ability to observe a problem, to make connections to prior knowledge, to understand the problem, and finally to reason ways in which to solve the problem. Being able to determine the processes by which students solve problems enables the identification of students' gaps and strengths within each of the core competencies, and supports teachers to target specific students' learning needs.

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Assessment design

Measuring the construct

The major criteria considered when developing items and designing test forms for *PAT STEM Contexts* are as follows:

- the distribution of items across strands and context
- the distribution of item difficulty

Distribution by strand and context

It is necessary to assess students using an appropriate variety of different strands and contexts, so that the assessment covers a range of knowledge and skills. This approach ensures that the formative data gained provides insight into possible strengths, gaps, and weaknesses across different learning areas. Items in each test form are aligned to Australian Curriculum descriptions across a range of year levels. As the assessment has a focus on the Middle Years, approximately 50% of items are aligned to Years 5 and 6, while another 25% of items are aligned to Years 3 and 4, with the remaining 25% aligning to Years 7 and 8 learning outcomes within the Australian Curriculum.

Each unit (a cluster of items with a common stimulus) aims to integrate at least two of the Australian Curriculum learning areas, though at times relevant items were drawn from only one area, most commonly Science. Science outcomes were generally assessed more often than Mathematics or Technologies outcomes because the test focuses on inquiry skills that are prominent in the Science inquiry strand (Table 3). Likewise, the cognitive domains assessed were intentionally skewed towards Applying and Reasoning rather than Knowing due to the emphasis on inquiry skills and problem-solving abilities.

***Table 3** Percentages of PAT STEM Context items for each cognitive skill, Australian Curriculum strand, and Australian Curriculum: Science Understanding sub-strand*

	Cognitive skill %			Strand %			Science Understanding sub-strand %			
Test level	**Applying**	**Knowing**	**Reasoning**	**Science**	**Mathematics**	**Technologies**	**Biological sciences**	**Chemical sciences**	**Earth and space sciences**	**Physical sciences**
Middle Years A	41	9	50	35	29	23	23	21	9	47
Middle Years B	47	9	44	70	16	13	23	18	23	35

Distribution of item difficulty

It is important to have a spread of item difficulties that match the abilities of the students.

Table 4 (page 9) shows the mean and standard deviation of the difficulty of the items in each of the *PAT STEM Contexts* tests in scale score units. Standard deviation measures the amount of variation in item difficulty for a set of items.

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Table 4 *Mean difficulty and standard deviation of PAT STEM Contexts tests*

Test level	No. of items	Mean item difficulty (scale score)	Standard deviation (scale score)
Middle Years A	34	115.7	10.9
Middle Years B	34	124.1	10.6

Delivery

Choosing the right test

Planning and consistency in the administration of the tests are important in ensuring *PAT STEM Contexts* is used effectively and that students' results are useful and meaningful. There are two test forms: Middle Years A, aimed at upper primary school, and Middle Years B, aimed at lower secondary.

Table 5 *Summary of test delivery details for PAT STEM Contexts*

Test level	Generally suitable for	No. of items	Time allowed
Middle Years A	Year 4, Year 5, Year 6	34	1 hour
Middle Years B	Year 6, Year 7, Year 8		

Frequency

For the purpose of monitoring student progress, a gap of 9 to 12 months between testing sessions is recommended. Student's learning progress may not be reflected in a change of their scale scores over a shorter period of time. Longitudinal growth should be measured over a minimum of two years of schooling, or three separate testing sessions, in most contexts. This will help account for possible scale score variation, for example where external factors may affect a student's performance on a particular testing occasion.

Test administration

Teachers are required to supervise test administration. Embedded practice items support administration of the tests. The recommended test administration time is 60 minutes. This should be sufficient for all students to complete their practice questions and test questions. Consistency in the time allowed to students will assist teachers in comparing the results of students.

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Item response formats

The majority of items in *PAT STEM Contexts* use a selected response item format (multiple-choice and complex multiple-choice). The rest use an interactive item type (drag-and-drop or hotspot format) to cater for the broad range of contexts. These interactive item types, and animations as stimulus, are used because they assist in determining aspects of a student's practical science inquiry skills (Clarke-Midura et al., 2011; Pedro et al., 2014; Quellmalz & Haertel, 2004) that have previously not been able to be assessed using online assessments.

Item types vary to match the skill being assessed: where the assessment of a skill is better matched to an interactive item type it is used instead of a traditional multiple-choice format. Items are accompanied by various texts or modes (images and animations) that are designed to allow students to visualise contexts.

Drag-and-drop items are particularly appropriate for identifying sequences within designs or steps that need to be taken to solve problems. Hotspots items are useful for items that require pattern recognition. Interactive items are important in *PAT STEM Contexts* as they allow for authentic real-world contexts to be fully conceptualised by students. There are also some items that require students to input a numerical response. Some items feature partial scoring; these are reported either as fully correct (two score points), or partially correct (one score point), providing further diagnostic information.

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Reporting

The information provided by the *PAT STEM Contexts* reports is intended to assist teachers in understanding their students' abilities to use inquiry-based processes to solve contemporary, real-world problems and issues in STEM contexts, diagnosing gaps, strengths, and weaknesses, and measuring learning progress over time during the middle years of schooling.

PAT scale score

A PAT scale score is a numerical value given to a student whose achievement has been measured by completing a PAT assessment. A student's scale score lies at a point somewhere on the specific PAT scale, and it indicates that student's level of achievement in that learning area – the higher the scale score, the more able the student.

Regardless of the test level or items administered to students, they will be placed onto the same scale for the learning area. This makes it possible to directly compare students' achievement and to observe students' progress within a learning area by comparing their scale scores from multiple testing periods over time.

Item difficulty is a measure of the extent of skills and knowledge required to be successful on the item. This makes it possible to allocate each *PAT STEM Contexts* test item a score on the same scale used to measure student achievement. An item with a high scale score is more difficult for students to answer correctly than a question with a low scale score. It could generally be expected that a student is able to successfully respond to more items located below their scale score than above.

By referencing the difficulty of an item, or a group of items, and the proportion of correct responses by a student or within a group, it may be possible to identify particular items, or types of items, that have challenged students.

A score on the *PAT STEM Contexts* scale has no meaning on the PAT Science scale or any other PAT scale. The units of the scale have different meanings for each scale. This is because these units are calculated based on the range of student levels of achievement, which vary widely between learning areas.

Achievement bands

While a scale score indicates a student's achievement level and can be used to quantitatively track a student's growth, it is only in understanding what the number represents that teachers can successfully inform their practice to support student learning. For this reason, the *PAT STEM Contexts* scale has been divided into achievement bands that include written descriptions of what students are typically able to do at that band. A student scoring in a particular band can be expected to have some proficiency in that band and be progressively more proficient with the skills outlined in lower bands.

Two students whose test performance places them into the same achievement band are operating at approximately the same achievement level within a learning area, regardless of their respective school year levels.

Viewing student achievement in terms of achievement bands may assist teachers to group students of similar abilities. By referring to the PAT achievement band descriptions, teachers can understand the types of skills typical of students according to their PAT achievement band. For example, a student who achieved a *PAT STEM Contexts* scale score of 125 could be considered to be at the upper end of achievement band 115–124 or at the lower end of achievement band 125–134. In cases like these, it is important to reference the descriptions of both achievement bands to understand the student's abilities.

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PAT STEM Contexts achievement band descriptions	
135 and above	**Interpret and reason about complex and abstract systems** Students apply understanding and reasoning skills where STEM contexts are unlikely to be familiar. Contexts generally involve several abstract concepts or an abstract representation of a system, where students are required to extract key features and explain interactions of elements within a system. They apply their knowledge and conceptual understanding to interpret many interactions in a system (eg to complete a complex food web or to infer the behaviour of a cart on a roller coaster track by applying both an understanding of acceleration and how multiple forces are acting). They use reasoning to solve a problem by extracting relevant information from an abstract representation of a novel application and accompanying data source (eg find the width of wood used from a diagram of a nest box suited to a bird of a specified size).
125–134	**Recognise interacting cause-and-effect relationships in systems, and predict outcomes of simple changes to a system** Students identify or explain the relationships between the elements of a system by applying understanding of more than one abstract concept, where STEM contexts are likely to be only somewhat familiar. They apply their knowledge and conceptual understanding to explain the sequence of events in a technological system (eg those necessary for electrical charge to flow), recognise the relationship that represents a change over time (eg calculate percentage decrease from the reduction in diameter of chips of stone), and select an appropriate calculation strategy to solve a problem that matches a design brief. They use reasoning to interpret a situation from a third-person rather than a personal perspective (eg interpret a visual pattern from a bird's eye view to create a robot's pathway), predict the effect of changes in a system (eg the behaviour of a cart on a roller coaster track taking into account the forces acting upon it), and they evaluate alternative problem solutions taking into account a number of factors.
115–124	**Develop and use rules for several aspects (or for single cause-and-effect relationships) within a system** Students identify and then apply a rule for a cause-and-effect relationship to make a prediction in less familiar STEM contexts, drawing from everyday experiences, classroom activities and investigations. Students link their observations to more than one abstract concept, but they consider each separately to draw a conclusion. They apply their knowledge and conceptual understanding to make a link from experienced properties of materials to describe how the material suits its purpose, or apply a rule for an abstract concept or element of a system to a new context (eg apply the rule for angle of reflection to the function of a solar cooker box). They use reasoning to integrate two aspects required to solve a problem (eg rank planets by considering both dimensions and comparing each planet to Earth), make predictions based on patterns (eg predict the extent of weathering for sandstone compared to granite), and identify the value in a data set that does not conform to a set of plausible values.
105–114	**Recognise cause-and-effect relationships** Students describe cause-and-effect relationships in familiar STEM contexts, drawing from everyday experiences, classroom activities and investigations. Students link their observations to an abstract concept, generalising from their immediate experience. They apply their knowledge and conceptual understanding to make a link between a natural phenomenon and its effects (eg infer how a lesser-known animal, a numbat, finds food; interpret a diagram or data to identify the number of low tides or the coordinates of a contact point on a technology device). They use reasoning to identify the relationship between factors and features, such as the connection between the presence of light and sensor activity, and the relationship between a product design feature and its use. They also use reasoning to decode a simple visual program, and compare bar graphs to evaluate changes over time.

continued over

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PAT STEM Contexts achievement band descriptions	
104 and below	**Understand single observations with the help of basic STEM knowledge** Students make observations about aspects of their immediate environment they have directly experienced, including those in everyday STEM contexts. They recall individual facts, single concrete concepts they have experienced, and specific procedures. They may be able to identify the key purpose of designed products. They are developing the ability to apply knowledge and conceptual understanding to compare or rank events based on observations. They may use reasoning to identify the key element required to solve a problem (eg interpret a diagram or understand commands in a simple computer program).

The *PAT STEM Contexts* achievement bands were developed through the consideration of:

The complexity of the context

The variation of the number or individual elements to be considered and processed within a context affects the skills required of the learner. For example, when considering a simple system, they might only be required to identify one or two key features or criteria, whereas for a more complex systems, there will be a number of features to identify, as well as the interrelationships between these.

The familiarity of the context

On balance, a judgement was made as to the likelihood that a learner has experienced a context in their daily life including through typical school experiences, or if the context was likely to be unfamiliar because it consists of elements that typically learners would not be expected to have encountered until later in their daily life or school experience. Some contexts will be new and emerging in society, and by their nature are likely to be unfamiliar contexts to most learners. Contexts involving cutting-edge STEM developments are particularly appropriate for assessing a learner's ability to transfer their skills and knowledge to innovative and novel situations.

The learner's stage of development with respect to concepts

Conceptual understanding tends to develop from a learner's perception of how the world works based initially on concrete experiences in their immediate environment. Therefore, responses to questions about concepts are likely to reflect concrete ways of looking at the world in the earlier levels and move to reflect more abstract descriptions of phenomenon and demonstrate relational thinking (integrate several aspects into a whole) at higher levels.

The learner's stage of development with respect to cognitive domain ('Cognitive skills' in the reports)

Cognitive domain dimension ('ways of thinking'), where a students' ability can be measured as the amount of specific knowledge possessed; the extent to which knowledge is applied, and the extent to which reasoning is employed in order to answer research questions and to solve problems.

The following example from the *PAT STEM Contexts* achievement band descriptions (Figure 1, page 14) illustrates how the descriptions can support teachers' understanding of progression in inquiry and problem solving in STEM contexts across the Middle Years and help to inform their teaching practices in a specific and targeted way.

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Observational skills in problem solving

115–124

… Students link their observations to more than one abstract concept, but they consider each separately to draw a conclusion …

↑

105–114

… Students link their observations to an abstract concept, generalising from their immediate experience …

↑

104 and below

… Students make observations about aspects of their immediate environment they have directly experienced …

Figure 1 *Section of PAT STEM Contexts achievement band descriptions, illustrating the development of a students' observational skills*

While the achievement band descriptions are intended to be considered in their entirety and not as discrete components, these extracts help to demonstrate the progression of particular skills within a student's ability to make an interpretation. In 'typical' development of inquiry and problem-solving skills in STEM contexts, students develop their observational, problem solving and reasoning skills within a familiar context. Gradually they are able to apply knowledge to more abstract contexts. This qualitative understanding of students' abilities through band descriptions can help to inform teachers' learning intentions for students performing at these different levels, to provide support to ensure their progression from one level to the next.

Reference groups

The performance data collected by using *PAT STEM Contexts* Middle Years A with a class of students can be compared to the performance of a reference group. *PAT STEM Contexts* Middle Years A reference groups are available as a reference sample against which student achievement can be compared. This reference group is composed of Australian students in Years 5 to 8 who completed *PAT STEM Contexts* assessments between September and December in 2019 or 2020. *PAT STEM Contexts* Middle Years B reference groups will be available once sufficient response data is collected.

The comparison between a student's scale score achievement and the reference group can be expressed as a percentile rank or stanine ranking.

Percentile

The percentile rank of a score is the percentage of students in a given reference group who achieve less than that score. Percentiles ranks are useful when measuring the performance of a student against the reference group for that year level. For example, a student with a percentile rank of 75 (also called being at the 75th percentile) compared to the Year 5 reference group sample has a scale score that is higher than 75% of Australian Year 5 students in that group.

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Stanine

Stanines are ranking scores from 1 to 9 derived from the Australian reference group percentile ranks. Stanines provide a simpler grouping of students with similar skills.

Stanine	Corresponding percentile ranks
9	96th and above
8	90th–95th
7	77th–89th
6	60th–76th
5	40th–59th
4	23rd–39th
3	11th–22nd
2	4th–10th
1	3rd and below

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Appendixes

Appendix 1

Literature review: locating PAT STEM Contexts in the broader research context

The meanings of STEM and STEM education

The Australian government encouraged the uptake of Science Technology Engineering and Maths (STEM) subjects in the late 1990s with a view to improve the viability of the Australian economy. This was quite late compared to other countries, such as the USA, whose government encouraged schools to implement and focus on STEM subjects after 1957, triggered by the Soviet launch of the missile, Sputnik (Blackley & Howell, 2015). The Australian government believed STEM education to be a key strategy to remedy the scientific and technology skills shortage within Australia as a means of remaining globally competitive (Gough, 2015; Murphy et al., 2019; Timms et al., 2018). Despite this, Australia's performance in Science and Mathematics in TIMSS have shown an overall downward trend, even with a slight improvement in the last cycle and Australia's PISA results have declined or plateaued (Echazarra & Schwabe, 2019; Thomson et al., 2020). These results, combined with government policy, have prompted the government to make STEM education a national priority and to promote the subject within schools. However, there are some major issues with STEM education, which include defining exactly it is (Bryan & Guzey, 2020), what subjects are included, and how (and by who) it should be taught.

Defining STEM

Although 'STEM' is now part of the education lexicon, complications have arisen due to inconsistencies in its definition (Siekmann & Korbel, 2016). Early definitions spelt out the acronym as a means of describing the individual disciplines, content, and skills. When schools vary the way in which STEM is taught, they may also change the acronym and definitions. Some schools may not cover the full spectrum of STEM disciplines due to resource issues, resulting in, for example, less emphasis on Engineering and the acronym becoming STeM. Where other schools have included extra subjects, such as art, they have changed the acronym to STEAM, or if they include medicine, schools have changed the acronym to STEAMM (Lyons, 2018). Basing definitions on the acronyms has been found to be problematic as it can limit the integration of subject matter not included in the acronym and creates an appearance that those subjects within the acronym are superior to other subjects (Lyons, 2020). Over time STEM has increasingly been defined in terms of teaching the subject matter as an integrated and interdisciplinary subject that includes purposeful technological design being combined with scientific inquiry as a key component (Sanders, 2008; Siekmann & Korbel, 2016). As STEM is being implemented, various schools are using a spectrum of approaches from subjects being segregated to being fully integrated (Figure 2, page 17) (Nadelson & Seifert, 2017). Fully integrated curricula have been put forward as an effective means of improving student learning outcomes as compared to teaching the subjects individually (Kelley & Knowles, 2016; Thibaut et al., 2018). For this reason, STEM should be defined as a subject that integrates the content and skills of Science, Technology, Engineering, and Maths but not limited to these subject areas and that it promotes design and inquiry with a context driven focus, exploring real life problems.

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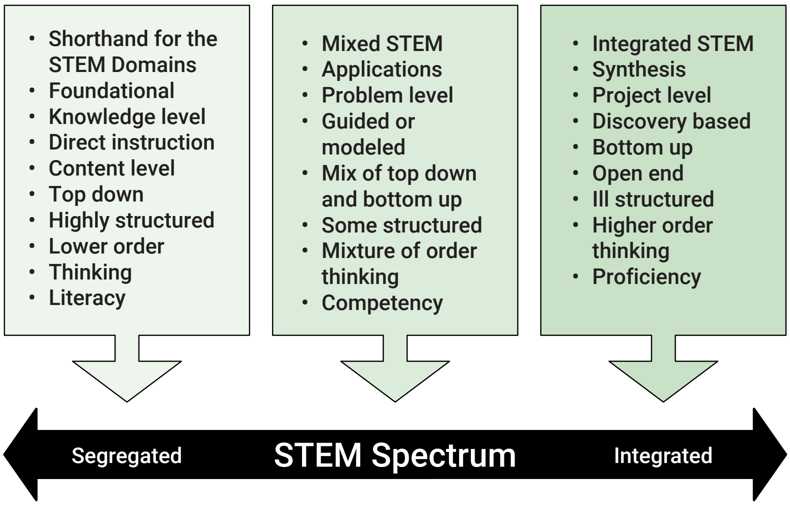

***Figure 2** The STEM spectrum (Nadelson & Seifert, 2017)*

Approaches to STEM Education

Integrated STEM education may be approached by presenting a context or problem that utilises the knowledge of Science combined with Engineering design principles, Technology tools and Mathematics (Kelley & Knowles, 2016; Lyons, 2018). Each subject is dependent on the others, with technology being the 'front face' of STEM, engineering being the method used to design and make the technology, and science and maths being the foundational knowledge (Lyons, 2018). The presented context may require specific content from the individual subjects to be taught so that students can understand the context (Lyons, 2018). Context choice is important so that they are relevant, and connections can be made across the disciplines so that students can further develop skills and knowledge (Timms et al., 2018). Learning STEM in an integrated manner provides students an opportunity to apply their knowledge and skills learnt to relevant and meaningful contexts (Bybee, 2015).

Five instructional practices have been identified as essential for teaching integrated STEM: the integration of STEM content, problem-focused learning (encapsulating problem-based learning, problem-centred learning, and project-based learning), inquiry-based learning, design-based learning, and cooperative learning (Thibaut et al., 2018). These practices link together so that aspects of the disciplines are assimilated while students are presented with authentic problems based on real world contexts and opportunities for students to participate in open-ended challenges. This is provided within a learning environment that allows for students' self-discovery and for students to share and further deepen their knowledge (Thibaut et al., 2018). These five instructional practices have similar outcomes but subtle differences.

Inquiry-based learning is a strategy that emulates real-world methods and practice to improve the cognitive abilities of students (Pedaste et al., 2015; Tawfik et al., 2020). This approach encourages students to be active learners and discover new knowledge for themselves. Inquiry-based learning follows the practice of a lesson or a piece of work being based on an essential question that is formed from real-world problems. Students are then guided to collect evidence and explore the ideas behind the question and formulate explanations. These explanations are evaluated and compared to other research and communicated (Crippen & Archambault, 2012). Problem-focused learning encapsulates three slightly different practices: problem-based learning where students identify a problem and work towards a solution, project-based learning where students are required to make a specific product and teachers act as an expert, and problem-centred learning where students are given a number of problems and the teachers is a guide (Thibaut et al., 2018). These are all slightly different from inquiry-based learning as inquiry learning is where the student defines a hypothesis and conducts experiments or makes observations, which may or may not be centred around a specific problem (Pedaste et al., 2012). Students must then establish their own objectives and determine how they can solve these authentic problems (Hmelo-Silver, 2004). Design-based learning centres on the design process, allowing students to be creative and develop their own designs, thereby finding meaning in their own learning (Doppelt et al., 2008). Cooperative learning involves students working together to create, solve or complete a task (Laal & Laal, 2012), importantly this type of learning would be occurring simultaneously along with the other learning practices. Used within these instructional practices is the engineering design process where students are encouraged to follow an iterative, researched process when designing solutions or objects. This process adds significant benefits to STEM learning, improving higher order thinking and teaching students to define, predict, and critically analyse problems (Fan & Yu, 2017).

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Benefits of STEM

From a governmental perspective, upskilling students in STEM will provide economic benefits as students become future innovators of new technologies and benefit from being meaningfully employed (Gough, 2015; Murphy et al., 2019; Timms et al., 2018). During their schooling, STEM education aims to improve student achievement and interest, and provides rich contexts in STEM and the disciplines of STEM (Becker & Park, 2011). A well-developed, integrated STEM program allows students to experience a stimulating environment where students are active learners that develop higher order critical thinking skills that improves their problem solving skills and their retention of subject matter (English & King, 2019; Kelley & Knowles, 2016; Stohlmann et al., 2012). STEM education also encourages cross-curricula learning that enables students to become independent learners and productively conduct group work. Not only do students improve their results in STEM as an integrated subject, but they have better learning outcomes in the individual discipline areas (English & King, 2019).

Barriers to STEM education

Given that the focus on STEM education came from government recommendation and did not involve educators at the outset, teachers have not fully embraced the integrative concept (Timms et al., 2018). For example, the Australian national curriculum has not included STEM as a separate discipline (Blackley & Howell, 2015). Further challenges with the implementation of STEM education as an integrated subject include: overcoming curriculum structure; allowing time for teachers to have sufficient professional development, particularly in the areas of engineering and technology; and providing adequate preparation time and access to resources and materials (Blackley & Howell, 2015; Bybee, 2015; Thibaut et al., 2018). Although integrated STEM curriculum frameworks have been developed in the USA (NRC, 2012), more research is required to demonstrate how to integrate the disciplines so that it deliberately connects the knowledge, skills and practices of the different subjects (Gao et al., 2020; Moore & Smith, 2014).

Another issue is the lack of consistency and clarity in learning progressions, curriculum documents and assessments (Timms et al., 2018). A STEM learning progression, where the stages of learning have been developed based on empirical evidence, would assist educators in understanding, teaching, and assessing STEM skills and content. Learning progressions in science have been developed for specific topics such as the chemistry subtopics ‘understanding matter’ (Stevens et al., 2010) ‘understanding chemical change’ (Johnson, 2013; Timms et al., 2018) and ‘chemical thinking’ (Sevian & Talanquer, 2014). Although they do often outline STEM skills and cut between disciplines, they are not an integrated STEM learning progression. Even though STEM learning progressions have not yet been developed, assessment frameworks can provide a starting point for their development (Arikan et al., 2020; Kelley & Knowles, 2016; Walker et al., 2018). The NRC in the USA developed a framework for best practices in the sciences and, while it does not specify STEM as an integrated subject, it encourages its STEM practices. The framework identifies three dimensions that provide the foundation for Science:

Scientific and Engineering Practices:

- Asking questions (for science) and defining problems (for engineering)
- Developing and using models
- Planning and carrying out investigations
- Analysing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

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Crosscutting concepts

- Patterns
- Cause and effect: Mechanisms and explanation
- Scale, proportion, and quantity
- Systems and system models
- Energy and matter: Flows, cycles, and conservation
- Structure and function
- Stability and change

Disciplinary core ideas

- Physical sciences
- Life sciences
- Earth and space sciences
- Engineering, Technology, and Applications of Science

These NRC framework dimensions and the TIMSS framework could be considered alongside of the Australian Curriculum to assist in the future development of learning progressions for STEM.

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Appendix 2

Trial design and assessment validity

A test is said to be valid if it measures what it was intended to measure. The *PAT Inquiry and Problem Solving in STEM Contexts* tests are planned and constructed to assess knowledge and skills in contexts that allow for the inclusion of questions that address the Australian Curriculum domains of Science, Mathematics, and Technologies. In constructing the tests, care is taken to include a range of skill areas to ensure that the breadth of students' inquiry and problem-solving skills are captured. All items are subjected to intensive scrutiny, review, and revision by panels of experts and psychometricians.

The items in the assessment are developed by experienced test developers who review and panel the items until they are ready for trial. A rigorous process of quality checking, proofreading, and formatting then takes place. The psychometric team provide a trial design based on the items (number, distribution of strands and item types) to ensure that the most valid and reliable data is available from the trial. *PAT STEM Contexts* items were trialled in standalone trial test forms, with items offered across a range of year levels to determine the appropriate targeting and difficulty for each item.

The trial material was focused on the upper years of primary school (Years 5 and 6), with approximately 50 per cent of items addressing these two year levels. The remaining material targeted either Years 3 and 4, or the first two years of secondary schooling (Years 7 and 8). Some items were trialled at two different year levels to collect empirical evidence about which year level each item was best suited to. By including the same items at two different year levels, test developers and psychometricians can compare item statistics and the performance of students at the different year levels on these items. For this reason, the same set of items was trialled with both Years 5 and 6, and another set of items was trialled with both Years 7 and 8. In total, eight trial test forms were developed for the field trial: one trial test form for Year 3 students, two test forms for students in Year 4, three test forms for Years 5 and 6, and two test forms for Years 7 and 8. Each test form contained a mixture of multiple-choice items, interactive items and/or cloze items. Test form lengths ranged from 22 to 33 items.

Calibration procedures identified items that appeared to be measuring skills different to those measured by the other items at trial. Items 'misfitting' in this way were not retained. The items retained for *PAT STEM Contexts* were shown to fit the Rasch measurement model satisfactorily. All items retained could be regarded as measuring a student's location on a single underlying continuum of inquiry and problem-solving skills in the STEM context. As part of this process, test developers reviewed and evaluated the theoretical strands assessed with these items: applying, reasoning, and knowing and used these item classifications to inform the described achievement bands.

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Appendix 3

Audit on the Australian Curriculum against NRC Framework for K-12 Science Education

The NRC science curriculum framework (NRC, 2012) consists of three dimensions: scientific and engineering practices, crosscutting concepts that bring together science and engineering skills and knowledge, and the content disciplines that are the core ideas of science. These dimensions are further broken down into the practices, concepts, and core knowledge that students are required to learn in Science. The Australian Curriculum does have similar practices, concepts, and core knowledge, but these are dispersed in a range of curriculum areas including General Capabilities. For this reason, an audit (Tables 6 and 7) was conducted across Science, Mathematics, and Technologies within the Australian Curriculum to determine if and where the skills and knowledge identified within the NRC framework are. This was conducted so that *PAT STEM Contexts* could demonstrate true integration of the STEM disciplines and to determine the most relevant practices for STEM that were then included in the achievement bands. The practice of 'Constructing explanations (for science) and designing solutions (for engineering)' was not included in the audit, as these describe the overarching purpose of STEM. Practices and crosscutting concepts that were found to be in both the NRC framework and the Australian Curriculum were included in *PAT STEM Contexts*.

The third NRC framework dimension, disciplinary core ideas, was viewed as equivalent to Knowledge within the TIMSS assessment framework (Mullis et al., 2017). This is the fundamental discipline-specific knowledge that learners need to draw on when applying and reasoning within STEM-based contexts. 'Knowing, Applying, and Reasoning' are the cognitive skill categories described in the TIMSS framework. This framework was used to classify individual items in *PAT STEM Contexts*, and therefore already inform the *PAT STEM Contexts* achievement bands.

Table 6 *Scientific and engineering practices*

Practices, concepts, and core knowledge	Identified in the Australian Curriculum		
	Science	Mathematics	Technologies
Asking questions (for science) and defining problems (for engineering)	Science inquiry: Questioning and predicting	Problem-solving key idea: Investigate problem situations; Formulate problems	Investigating and defining
Developing and using models	Systems: Key idea in Science	Problem-solving key idea: Represent unfamiliar and meaningful situations; Model	Generating and designing
Planning and carrying out investigations	Science inquiry: Planning and conducting	Problem-solving key idea: Interpret	Collecting, managing and analysing data
Using mathematics and computational thinking	Numeracy: general capability required for science	Apply strategies to seek solutions; Formulate and solve problems Fluency: choosing appropriate procedures; Understanding: adaptable and transferable mathematical concepts	Computational thinking: key idea in Technologies
Engaging in argument from evidence	Science inquiry: Evaluating	Problem-solving key idea: Interpret	Evaluating
Obtaining, evaluating, and communicating information	Science inquiry: Evaluating; Communicating	Problem-solving key idea: Interpret	Evaluating; Collaborating and managing

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Table 7 Crosscutting concepts

Practices, concepts, and core knowledge	Identified in the Australian Curriculum		
	Science	Mathematics	Technologies
Patterns	Patterns, order and organisation	Recognise patterns	Interpreting patterns and models
Cause and effect: Mechanisms and explanation	Cause and effect	Understand concepts of variable and function; Calculate derived measures such as area, speed and density.	Breaking down problems into parts
Scale, proportion, and quantity	Scale and measurement	Explore magnitude and properties of numbers; Size, shape, measurements of quantity; Choosing appropriate metric units; Connections between units and calculating derived measures such as area, speed and density.	Computation: quantify data and solve problems; Calculating costs
Systems and system models	Systems	Describe relationships and formulate generalisations.	Systems thinking: key idea Modelling trends; Inputs and predict outputs of a simulation
Energy and matter: Flows, cycles, and conservation	Matter and energy	Describe and model phenomenon.	Testing materials and components
Structure and function	Form and function	Magnitude and scale	Comparing performance
Stability and change	Stability and change	Analyse data and draw inferences, build skills to critically evaluate statistical information	Organising data logically (to monitor performance over time)

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Appendix 4

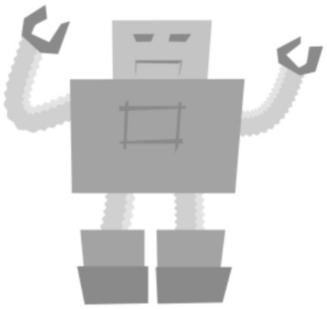
PAT STEM Contexts item response format examples

These examples illustrate commonly used item response formats used in *PAT STEM Contexts* assessments.

Hotspot

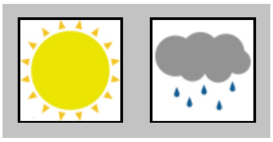
Jane drew this robot.

Select the robot's head.

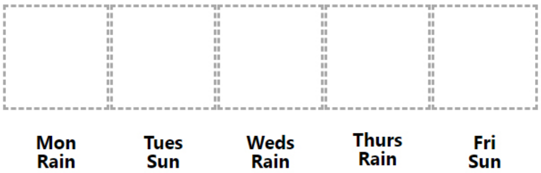


Drag-and-drop

Drag the symbols to show the weather for last week.



Last week's weather at school:



Complex multiple-choice

Does the picture show these things?

Select **one** bubble in each row.

Does the picture show these things?	Yes	No
The frog is brown.	○	○
The frog has red spots.	○	○
The frog is sitting on a leaf.	○	○

Cloze

Jake said the answer to 4 × 17 is 68.

Open the calculator by selecting the calculator button at the top right of the screen.

Move the calculator by selecting it and dragging it to a new position.

Copy your answer from the calculator directly into the answer box by selecting the blue button with the calculator on it.

Close the calculator by selecting the calculator button at the top right of the screen again.

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