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Introduction

Project-based Learning

Australian educators are being required to place more emphasis on science, technology, engineering and maths (STEM) in order to ensure that today's students will be prepared for their future careers. Additionally, it is important that children learn and practise the 21st-century skills of collaboration, critical thinking, problem-solving and digital literacy in their daily curricula. These collaborative skills are imperative for students to learn, but they are not without challenges. *Stepping into STEM: Middle Years* provides students with needed practice in these areas.

Project-based learning, simply put, is learning by doing. Project-based learning, or PBL, tends to be deeper learning that is more relevant to students, and thus remembered longer. We need to educate students to be global competitors, and to do so, we must help them to think creatively, to take risks and to put what they are learning into practice. After all, it doesn't do much good to know a formula if you don't know when to use it. Students also need to learn the value of failure as a learning experience. Some of the ideas and efforts they make during an activity will not work. This can turn into a very positive experience since knowing what won't work, and why, may lead to the discovery of what will work!

Reading informational material provides needed background, but *doing* makes the difference. Concepts, ideas and experiences of hands-on activities remain lodged in the brain for retrieval when needed.

In STEM curriculum, project-based learning is a must! Its collaborative style guarantees that 21st-century skills are fully integrated into the curriculum while supporting students' academic and socio-emotional growth. Furthermore, PBL allows teachers to assess what students comprehend immediately and to adapt curriculum accordingly.

Connecting Science, Technology, Engineering and Maths

STEM activities blend four essential and related learning experiences into one activity. Technology – both simple and high-tech – provides the framework for recording information. Phones, tablets and computers are effective in recording and comparing results. The maths element might involve sequencing, patterns or recognising shapes, size and volume. Comparisons are expressed in decimals, fractions, ratios and percentages, as well as measurements, graphs, charts and other visual representations.

The Need for Interaction and Collaboration

Today's scientists and engineers share ideas, experiments and solutions, as well as failures, with colleagues around the globe. Student scientists and engineers, like their professional counterparts, need experience working with partners in a collaborative and supportive environment. They need to exchange ideas, test theories, perform experiments, modify their experiments, try novel approaches – even those that may not appear useful or serious – and cooperate with each other in all aspects of the project as they seek to accomplish their objective. Depending upon the activity, students may use the *Design Process* to accomplish their objective.

A basic requirement of these collaborative efforts is a willingness to seriously consider all suggestions from the members of the team. Ideas should be considered, tried, tested and compared for use in the project. Students should work together to select the most efficient and practical ideas, then methodically test each one for its useful application in the activity.

Growing Critical Thinkers

While all members of a team need to be respected and heard, members of the team also need to critically examine each idea to see if the idea is feasible. This is part of the design process used by engineers and the scientific method employed by scientists.

Students need to apply their learned experiences in these activities, and serious attention should be given to testing each idea for feasibility and practicality. Students can develop this skill by considering each serious suggestion, testing it for workability and then determining its value. Students need to examine the available materials, work with them in an organised way, record their results and compare these results.

Critical thinkers are organised and methodical in their testing and experimentation. They examine the ideas generated in the free flow of comments and discussions. They determine which ideas can be tested and then carefully compared for useful application to the problem they are trying to solve. They keep an open mind. Critical thinkers base their judgements on observations and proven outcomes. Critical thinkers aren't negative, but they are sceptical until they observe the results of an activity.

"Show me."

"Let's check it out."

"How can we test it to see if it works?"

One of the hallmarks of a scientist is to ask questions. Another is the effort to seek answers through effective investigations, tests and experiments. You want to encourage your student scientists to practise critical thinking by asking thoughtful questions using academic vocabulary, and by developing creative ways to test possible solutions.

The 4 *Is*: Inquire • Investigate • Interact • Invent

The four basic elements of an effective science or STEM activity can be categorised as Inquiry, Investigation, Interaction and Invention.

1. Inquiry is the process of determining what you wish to learn about a scientific or natural phenomenon. It can be as simple as watching a student's swing move back and forth, observing a schoolyard game of marbles or sucking on a straw. Some of the same principles of science may apply to a helicopter rescue of a swimmer, a batted ball in a cricket match or the process of getting water out of a ditch. The questions are always the same:

"Why did it happen? Will it happen every time? What happens if … you change the length of the swing, the size of the marble, the diameter of the straw, the weight of the swimmer, the diameter of the ball or the length of the siphon hose in the ditch?"

In the simplest form, **Inquire** is a question: Why … ? What if … ? How … ?

2. Investigation is the action a scientist takes to learn more about the question. It involves the process a student scientist needs to follow. The investigation can involve background research, the process of doing an experiment and the interpretation of the results. Reading a science text about the workings of the pendulum is not the same as actually constructing a working pendulum, adjusting it to different lengths and weights, and carefully observing its features and behaviour in varying circumstances. Measuring these things in mathematical terms provides the opportunity for valid comparisons as well.

3. Interaction requires student scientists to collaborate with one or more classmates. Together they assess the problem or question, determine and carry out the investigation, and analyse the results.

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From a practical point of view, experiments done with students are more effective with teams of two. In larger groups, one or more team members often feel left out, don't get to actually do the hands-on construction and can end up in distracting behaviours. Teams of two require the active involvement of both individuals in all phases of the activity, all the time. An off-task student in a team can be refocused by a partner or the teacher.

It is important to have enough materials and equipment for the basic activity for each team. The materials used in the activities in this book are inexpensive and easily available to facilitate two-person teams.

4. Invention is the final stage of the 4 "*Is*" in which the science activity involves the effort to create or invent a solution, modification or improvement. This can be the most challenging aspect of the activity. At first, suggestions tend to be far out, impractical, silly or impossible to do with the available materials. The most effective teams discuss possible solutions and then start manipulating the materials as a form of "thinking with their hands".

The invention aspect of the activity is nearly always the final step of the activity. For instance, after multiple sessions manipulating and measuring results with a pendulum, students should have enough background and hands-on experience to invent an application for this tool. It may be a toy swing for a doll, a time-keeping mechanism for a class activity (such as a timed maths exercise) or an attempt to make a perpetual-motion machine (or one that just lasts longer than anybody else's).

1 Inquire

2 Investigate

3 Interact

4 Invent

The Need for Journalling

Scientists keep records. They are meticulous in recording the results of their investigations and often refer back to investigations done in previous months and years. They use this information as needed for further investigations, related experiments and in publishing their work.

Ideally, all science students should keep journals recording the investigations they have been working on. With continued practice, students will develop the habit of journalling after each period of investigation. It is easier for students to keep information in one place and to refer back to previous investigations for discussion purposes and records. Consider having students use three-ring folders to keep unit pages together with additional notes, ideas and sketches.

It is suggested that a separate entry be made for each investigation session. Have students enter the date and investigation title for each new entry. Include a key question for each activity. This is the starting point for each investigation. As students proceed, they should record, using adequate details, the process and materials used to investigate the question. Encourage students to use appropriate vocabulary when journalling.

The variations in technique, the engineering adjustments, the technology employed and the results of each modification should be recorded. The mathematical applications should also be noted. If the length of the pendulum fishing line was doubled or cut in half, this is critical information. If the weight was doubled from 8 grams to 16 grams, this should be noted, and the effect on the pendulum's swing distance and duration should be recorded. The results of each trial should be briefly recorded.

The most important information in the journal should be the conclusions of the research team about the answer to the testable questions the team was investigating. Individual researchers may draw separate conclusions about these questions, but the conclusions need to be based on objective facts and recorded information.

The Design Process Review

The journal entries should be the "notes" student scientists use when sharing their information during the class discussion which is called the *Design Process Review*. The teacher can act as the moderator of this discussion and should ensure that each student gets an opportunity to share their experiences, results and scientific observations. This discussion works well as a 10-minute closure activity at the end of each period.

Encourage all students to take turns sharing the results of their activities and the conclusions they drew from their experiments. Data summaries may include photos, videos or other relevant materials. Model and encourage serious reporting. Encourage students to incorporate new vocabulary into their discussions, their journalling and their presentation pieces.

The writing (journalling) and the review are vital elements in the design process. They provide students with the opportunity to share their experiences, and these activities serve as an excellent part of the assessment process. It is suggested that you allow at least 15 to 20 minutes to complete these activities.

You may choose to act as moderator. You can allow students to share as teams or as individuals about each activity and other activities they have done on related subjects. You may also use smaller groups with student moderators.

Keeping Things in Perspective!

A STEM class will rarely be perfectly quiet! In fact, the low buzz of purposeful conversation is an indicator that students are actively engaged. The teacher serves as the facilitator, providing guidance, crucial information and directions at the outset. It is important to regularly check on each group to offer encouragement, advice, correction and support.

Teachers need to evaluate how students are doing as teams proceed with investigations. In addition to guiding the learning process, it is also very important to draw closure on the activity by moderating the final portion of the *Design Process Review* in which you draw conclusions and highlight the core learning concepts embedded in the activity.

Unsuccessful periods happen in any class, no matter how capable the instructor or how gifted the students. Things can go wrong, bells ring forever, announcements break the flow of instruction and construction, and all the other distractions of school life can occur. You may get a true scientific discussion going but have it go off into areas unrelated to the thrust of the investigation.

But there are also those times when you encounter the pleasant experience of no-one paying any attention to the distraction. A visitor or principal enters the room, observes the activity for a moment and either leaves or joins a group. The science discussion reverts to the main idea and goes smoothly or vigorously along, driven by students who are focused and on task. Yes, it happens!

Students can really "get into" science. They enjoy the openness involved in the activity, the collegial nature of working on a project, the materials they get to manipulate and the mental stimulation of solving a problem or creating a better product. A good, productive, stimulating science lesson can make their day – and yours, too.

How to Use This Book

Stepping into STEM is arranged with flexibility in mind. One method is to move from lesson to lesson in each unit and proceed through the units in order. But the number and order of units completed throughout the year is completely dependent on classroom and curriculum needs. You may want to choose the activities with which you are more familiar or those that better fit your school schedule. In total, *Stepping into STEM: Middle Years* contains several practical units. The organisation of each unit moves from teacher-directed activities to more student-driven activities to a final challenge activity that allows students to create their own unique product or invention. Students should be encouraged to follow the Design Process while doing the activities in each unit. The units require students to incorporate a range of science, technology, engineering and mathematics concepts into their learning. Each unit introduces and defines new concepts and terminology in a vocabulary list. Some of these terms may be new to students – spend time working through the lists with students and have the lists close to hand for quick-reference during each activity.

Stepping into STEM: Middle Years explores the following concepts:

- Crystal Gardens: compounds, structures, chemical changes, atoms, molecules, measurement
- Go Fly a Kite: forces, engineering design, measurement, function
- Static Electricity: electricity, static electricity, charge, electromagnetism, electrons, neutrons, protons
- Structures: area, perimeter, volume, software, engineering, architecture
- Kitchen Chemistry: elements, pH, percentages, ratios, fractions, mode, median, diffusion, chemical reactions
- Flying Saucers: properties of flight, geometry, distance, area and diameter, radius and ratio
- Derby Cars: motion, momentum, load placement, motors, speed, resistance, traction

Pacing Units and Lessons

Planning the length of time for completion of each unit can be flexible. You may choose some or all of the units and pace them throughout the year, building each unit into your science curriculum. You may find a unit compliments other aspects of your curriculum effectively and wish to use only that unit's activities to elaborate on students' existing knowledge. You might also consider using the simpler activities in a unit in one term and extending students' learning by using the Challenge activities, which are more difficult, in the following term. Be mindful of unit supplies; many units reuse materials used or student-built inventions in later activities. Later activities in the unit may use something made in an earlier activity. Hold on to any inventions or creations for subsequent use. If a unit topic fits in well with what is currently being taught, embed it into the schedule where possible and use the unit's activities as an extension of your existing curriculum. Since these unit investigations were developed to foster a STEM approach to learning, they do not have to be tied to any specific time frame or subject in the science curriculum.

To get the most out of a unit, it is suggested that a few sessions be allotted to complete the activities. These can be spread out as needed. Usually, an activity can be done in about an hour. For those fortunate enough to have a one-and-a-half-hour lesson period, students will have more time to explore the variations in each project and to extend their creative explorations. The activities are hands-on, practical and engaging and may be well-suited to a Friday afternoon session, when students would find a sit-down lesson more draining. Remember that the unit activities can also be broken into more than one session! Be sure to allow serious time for journalling and recording information in each period.

Vocabulary and Discussions

Share and discuss the STEM Vocabulary List (page 13) and unit vocabulary lists with students. Identify and use the terms frequently throughout the sessions to reinforce essential subject-area vocabulary. Enlarge each unit list to create posters for student reference, or photocopy a list for each student to keep in their journalling notebook.

Encourage discussions within groups and between groups if the discussions are focused on the topic. At the end of each activity, allow time for the teacher-moderated review activities, in which individuals share their experiments, designs, results and conclusions based on their research.

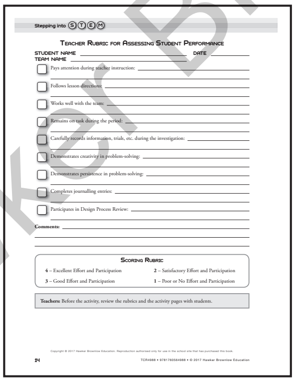
A general activity period could allow 5 to 7 minutes for teacher introduction and review of previous learning, 5 minutes to efficiently distribute supplies and 30 to 40 minutes to complete the activity involving science, technology, engineering and maths. The remaining time should be devoted to science journalling.

Teacher and Student Rubrics

Use the teacher rubric on page 14 to evaluate team progress, time on task and student interaction, and to reinforce STEM objectives. Students who are focused on the objective and are methodically trying different ways to solve a problem are doing science. So are those who are responding a bit randomly to their own ideas and trying them out.

As student groups work through each investigation, they should complete the student rubric on page 15 to reinforce the processes they used and to reflect on the procedures they followed.

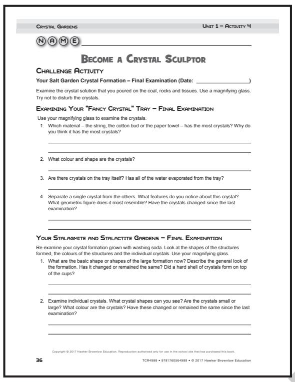
NOTE: Explain both rubrics to students before starting the units. It is important for them to know how their work will be evaluated and what steps they should follow as they work on a unit investigation.

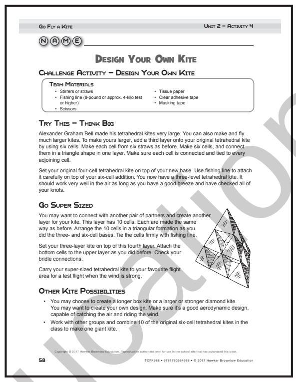


Challenge Activity

Each of the units culminates in a challenge assignment. Students are asked to create a new version of a product or extend experimentation based on the activities in the unit. Students are advised to look over their journals and other documentation collected during the unit and pick an extension to do. There are also some directions and suggestions in each challenge lesson to guide students who need them.

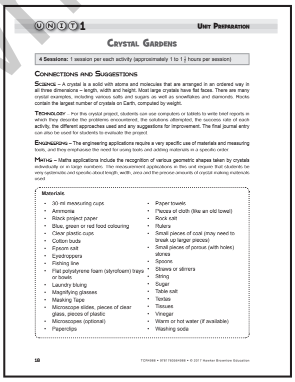
Allow time for imagination, frustration and so forth during the building and testing periods of the challenge assignments. Use the marking rubric for creativity, success, effort and on-task work time.

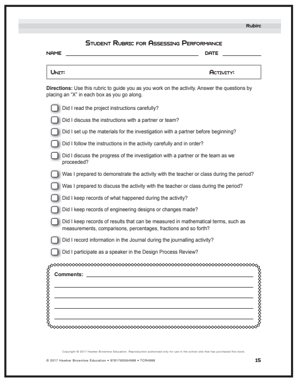




Team Management and Materials

In this explosive era of scientific knowledge and discovery, teamwork matters. All children need the kinesthetic experiences and collaborative interaction with their peers that are essential aspects of science instruction.





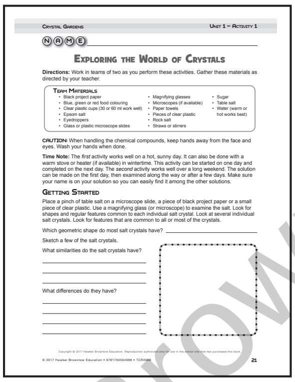
The activities in this series were designed to maximise student participation. Students will work in pairs or small collaborative teams. The collaborative process is essential to construct the apparatus and create the models. Four hands and two minds working together are more efficient and effective than individuals proceeding alone.

Materials used for the STEM activities in this book are not from expensive science kits. Those kits tend to not provide enough materials to engage all students simultaneously. Virtually all of the materials used in this series are available at relatively inexpensive cost at local chain stores and discount shops. Other materials are available in local hardware or craft shops.

Lesson Notes for the Teacher

Lesson 1 – Guided Activity

The first lesson is designed so that the teacher can guide and control the pace of the activity and ensure that students know how to function in this type of science activity and with these materials. It is more teacher-directed in terms of time and following specific directions than later lessons in the unit. In Unit 1 – Crystal Gardens, teachers will guide students through the process of using microscopes to examine the physical features of different crystals. Students are then shown how to dissolve the crystals in a warm-water solution and re-evaluate the crystals' structure after the water has evaporated.

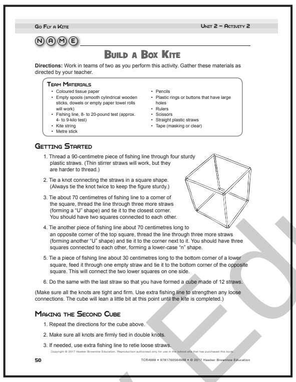


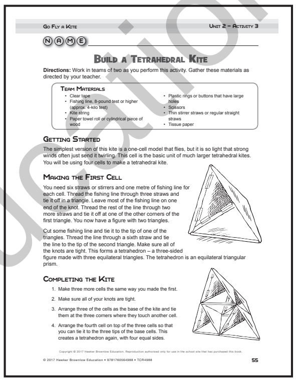
Providing guidance through the beginning phases of each unit will set the stage for student groups to continue with their investigations and discussions throughout the units. This is also an opportunity for the teacher to note which teams or students might be struggling and to provide more assistance to them.

Lessons – Your Turn

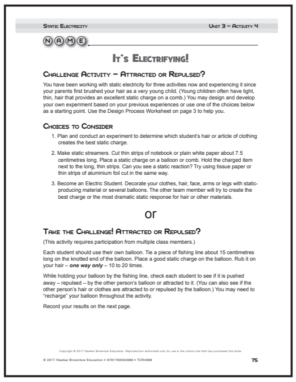
Review students' findings and ideas related to their investigations in Activity 1. Discuss how students will be exploring how a project works under various conditions. This can be an independent or collaborative group activity. Students work in pairs. Unit 2 – Go Fly a Kite has students using engineering principles and technological functions to design and build kite structures of varying degrees of complexity. The second activity in this unit has students not only designing and building a box kite, but suggesting modifications and variations to improve certain aspects of the structure. Just like adult scientists, students are encouraged to keep exploring, experimenting and inventing.

The next two or three lessons allow students to work at their own pace as they do the activities. The teacher circulates through the room giving advice, encouragement and correction as needed. Students work in pairs.





Final Lesson – The Challenge



The final lesson in each unit involves a Challenge Activity in which students apply what they have learned in earlier lessons to solve a specific problem or make the fastest, best or most unique application of the concepts learned. Students should work in pairs. Students may also be called upon to design and develop their own scientific experiments, such as in Unit 3 – Static Electricity. In this challenge, students are encouraged to build off the suggested prompts or develop their own investigations, using technological software to chart their results and write evaluative reports.

About Teams

Although there are always students who prefer to work alone – and have difficulty working with others – most students quickly find that these projects need three or four hands working in unison to work well. Most students also realise that the opportunity to share ideas and experiences helps their own performance and is reflected in their success in a project.

Crystal Gardens

4 Sessions: 1 session per each activity (approximately 1 to 1 $\frac{1}{2}$ hours per session)

Connections and Suggestions

Science – A crystal is a solid with atoms and molecules that are arranged in an ordered way in all three dimensions – length, width and height. Most large crystals have flat faces. There are many crystal examples, including various salts and sugars as well as snowflakes and diamonds. Rocks contain the largest number of crystals on Earth, computed by weight.

Technology – For this crystal project, students can use computers or tablets to write brief reports in which they describe the problems encountered, the solutions attempted, the success rate of each activity, the different approaches used and any suggestions for improvement. The final journal entry can also be used for students to evaluate the project.

Engineering – The engineering applications require a very specific use of materials and measuring tools, and they emphasise the need for using tools and adding materials in a specific order.

Maths – Maths applications include the recognition of various geometric shapes taken by crystals individually or in large numbers. The measurement applications in this unit require that students be very systematic and specific about length, width, area and the precise amounts of crystal-making materials used.

Materials

- 30-ml measuring cups
- Ammonia
- Black project paper
- Blue, green or red food colouring
- Clear plastic cups
- Cotton buds
- Epsom salt
- Eyedroppers
- Fishing line
- Flat polystyrene foam (styrofoam) trays or bowls
- Laundry bluing
- Magnifying glasses
- Masking Tape
- Microscope slides, pieces of clear glass, pieces of plastic
- Microscopes (optional)
- Paperclips
- Paper towels
- Pieces of cloth (like an old towel)
- Rock salt
- Rulers
- Small pieces of coal (may need to break up larger pieces)
- Small pieces of porous (with holes) stones
- Spoons
- Straws or stirrers
- String
- Sugar
- Table salt
- Textas
- Tissues
- Vinegar
- Warm or hot water (if available)
- Washing soda

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