United Nations
Educational, Scientific and
Cultural Organization

International Bureau
of Education

TEACHING, LEARNING AND ASSESSMENT IN A STEM CURRICULUM

Louise Hayward
University of Glasgow

Margret Hjalmarson
George Mason University

Harri Ketamo
Pori Ltd, Finland; BrainQuake Inc, USA

Yanghee Kim
Northern Illinois University

F. Joseph Merlino
The 21st Century Partnership for STEM Education

Barry McGaw
IBE UNESCO and University of Melbourne

Jonathan Osborne
Stanford University

Jennifer Childress Self
Education Policy Consultant

Peter Sullivan
Monash University

Russell Tytler
Deakin University

March 2020

FOREWORD

The Institute of Technology, Economics and Diplomacy (INTED) on behalf of the Mektebim schools in Turkey asked the International Bureau of Education (IBE) of the United Nations Educational, Scientific and Cultural Organisation (UNESCO) to facilitate the development of a new, world-class Science, Technology, Engineering and Mathematics (STEM) curriculum.

The IBE is the UNESCO institute specialising in curriculum, educational content, and learning methods and structures. Established in 1925, the IBE was a pioneer in fostering a broad exchange of ideas, research, and best practices in the education field. It established close working and learning relationships with member states, making recommendations that influenced educational legislation and practice. Today, IBE is a global leader in education capacity development, technical assistance, knowledge management, and policy dialogue. Member countries look to IBE to set the standards and guidelines for what must be regarded as quality curricula.

IBE recruited an international team of experts to develop the new curriculum for the Mektebim schools. The team developed a *STEM curriculum framework* to make clear the purposes of the new curriculum and to guide the development work. The framework addresses issues of teaching, learning and assessment as well as curriculum content because the new curriculum requires a new pedagogy. This document supports the *STEM Curriculum framework* by providing a more complete discussion of assessment and teaching strategies.

Dr Mmantsetsa Marope
Director
UNESCO International Bureau of Education
Geneva
Switzerland

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This is a companion document to *Contemporary STEM Curriculum Framework for Mektebim Schools*. It covers in more detail three topics covered in the *Framework* – the implications for pedagogy, assessment and teacher professional development of the adoption of a competence-based curriculum.

To these, it adds descriptions of eight teaching strategies that could be used to help students be constructive and interactive and not passive in their learning.

However, ideas only matter if they make a difference to practice. The ideas contained in these documents offer a starting point for teachers to begin to offer a 21st century STEM experience for the young people with whom they work. To support teachers translating ideas into practices in schools and classrooms, these documents are supported by a program of professional learning. This program advocates three progressive cycles of Professional Learning to support practitioners to create 21st century curriculum, pedagogy and assessment STEM classrooms

- Cycle One: introduces key ideas in curriculum, pedagogy and assessment.
- Cycle Two: explores how they might emerge in practice by reflecting on examples of STEM modules.
- Cycle Three: uses the STEM Learning App to support teachers as they create new modules designed for the young people in the particular context in which they work.

The Professional Learning program for Cycle One can be found in the PowerPoint, *21st century learning, teaching and assessment in STEM: a framework of professional learning cycles.*

We hope that, as teachers, you enjoy working collaboratively through the range of tasks and activities, learning together, contributing ideas and thinking through how you will make ideas real in your school and classroom. We also hope that every STEM teacher will have the opportunity to take part in this process.

Introduction

Shifting to a STEM competence-based curriculum implies a need for teachers to develop new and different strategies and ways of thinking about the curriculum, about teaching and learning, and about assessment. The focus needs to shift to a wider set of student outcomes that include not only discipline knowledge but also practices, and both general and domain-specific competences such as creative and critical problem solving, interpersonal skills, and particular literacies relating to the STEM subjects. Also, critically important is the development of values such as students being encouraged to develop a productive disposition, to remain curious, to be open-minded, and to build an increased sense of personal and collective responsibility. This has implications not only for viewing curriculum outcomes differently, but also for assessment, and for the ways school leadership organises and supports cross-disciplinary planning and collaboration.

Implications of competence-base for teaching and learning

If we are to develop students' generic and domain-specific competences that emphasise curiosity, creative and critical thinking, collaboration, and STEM practices such as design, complex problem solving and modelling, then students must engage with these practices and be supported to develop them in the classroom. Students must be given the opportunity to ask questions, to engage with meaningful challenges, to generate hypotheses, representations, explanations and design solutions, and to interact with each other and the teacher to build knowledge and receive feedback.

In Chi's (2019) terms, students' roles in classroom activities should be more than passive, or even active, but be *constructive and interactive*. For learning to be *constructive*, young people have to be involved in constructing learning. This means, for example, that students produce ideas and representations, build arguments and develop models that are not simple extensions of processes they are taught. It means they engage with challenging questions and ask and explore their own questions. For learning to be *interactive*, young people are involved in discussions in which they question and discuss each other's ideas, present arguments for their case, justify their positions, and debate aspects of their scientific, mathematical, engineering and technological designs.

Constructive and interactive learning implies changes to classroom practice moving from traditional, direct teaching to the creation of a learning environment where students are engaged in constructing and interacting with ideas and procedures. For example, teachers will:

- Plan topics and lessons around authentic contexts that will stimulate students' interest and raise questions for them that can be explored. This could involve themes that are cross-disciplinary in nature.
- Plan and run challenge activities in which students generate and express ideas through individual, group and whole class discussion, rather than model lessons on teacher input then student practice.
- Work on developing a classroom environment where students share and respond to each other's ideas (see the pedagogical strategies below), rather than ideas always passing through the teacher to be judged.
- Challenge students to produce or invent models, designs and representations and use these to compare, evaluate, and refine/revise their ideas and representations.

- Stimulate argumentation and justification in developing explanations and solutions to problems.
- Constantly monitor students' ideas and their productions, and support them through individual, group and whole class discussion to revise and deepen their understandings.
- Allow for individualisation of ideas, and of design tasks and problems, rather than have all students engage only with activities to which there is one right answer.
- Allow room for students to express their own perspectives.

These more interactive approaches to learning are not simply additions to existing classroom practices. More radical change is necessary. To allow room for students to engage more deeply with learning, to recast learning as the development of competences, and to focus on problems that are often interdisciplinary, implies a need to reduce content, strategically sequence content, and to develop strategies to engage students in generating, sharing and critiquing ideas and productions. The Curriculum Framework in the APP will support teachers in this challenge. A 21st Century STEM curriculum, however, also requires significant changes from traditional teaching and learning approaches. This document and the associated Professional Learning Program (Cycle One: PowerPoint) will support teachers in building and deepening their repertoire of approaches to pedagogy and assessment that will engage students in constructive and interactive learning.

The Appendix provides examples of a wide range of possible teaching strategies to support a competence approach to STEM education (Think-Pair-Share, Argument Line, Four Corners, Listening Triads, Using Technology Polls, Concept Cartoons, Sharing Representative Work and Gallery Walk.

Exemplar modules that illustrate possible pedagogical approaches to develop STEM competences form the basis of Cycle Two of the Professional Learning program.

ASSESSMENT FOR CONSTRUCTIVE AND INTERACTIVE LEARNING

Assessment is a powerful driver in any education system, yet assessment internationally remains one of education's biggest challenges. Changing the assessment culture in Turkey may be one of the most significant challenges. It may be important to be clear what changing the assessment culture means. Assessment is no longer:

- something that measures what it is easy to measure rather than what matters.
- something that happens only at the end of a task or topic or term.
- only tests and examinations.
- used only to judge or categorise learners.
- focused only on the past – on what has been learned.
- used only to assign access to limited resources.

To support a 21st century competence approach to STEM Education, Assessment has to be different. Assessment now is:

- focused on what matters - a process to help young people make progress in learning what matters.
- integrated into the learning process – planning, teaching, learning and evaluation.
- concerned with offering opportunities for learners to demonstrate progress in all that is important in the curriculum: the purpose is crucial – the method is only a way to achieve the purpose.

- primarily concerned with enhancing progression in learning.
- focused on building from what has been learned in the past to inform what should be learned in the future.
- only purely summative when used to assign access to limited resources, e.g., to University, College or a new school.

Changing the assessment culture will require attention to be paid to a range of areas. For example, first it will be crucial to take people with you. Students, parents and teachers will all need a clear understanding of what is changing and why.

Second, assessment has to focus on what matters – and on all that matters. In the Introduction to this paper, we indicated that the new curriculum would focus on:

> *a wider set of student outcomes that include not only discipline knowledge but also practices, and both general and domain-specific competences such as creative and critical problem solving, interpersonal skills, and particular literacies relating to the STEM subjects. Also, critically important is the development of values such as students being encouraged to develop a productive disposition, to remain curious, to be open-minded, and to build an increased sense of personal and collective responsibility.*

These are all areas where teachers and students will want to pay attention to progress and assessment is the means by which we use evidence to discern progress to date and to inform future progress.

Third, it will be important to develop approaches to learning and teaching that are likely to lead to the generation of high-quality evidence. Making sure that students have a clear understanding of what they are learning and why it matters, designing tasks that give students good opportunities to show how much and how well they are making progress in relation to what matters, using assessment evidence to promote progression in learning and, centrally, involving learners authentically in the processes of learning and teaching building their capacity to understand and enhance their own learning.

Assess what matters in the curriculum – take people with you.

Both students and parents should be aware of why traditional approaches to assessment are changing and what these changes will look like. It will be important to have the support of students and parents for the changes proposed. However, once supported and enacted, these new more collaborative approaches to assessment as part of learning will create more constructive and more productive learning environments. In these new environments there is a strong sense of community, one where learners are not only responsible for progress in their own learning but for the learning of all learners.

To have the support of teachers, parents and students, they all have to be involved in the change process. The rationale and evidence base for the proposed changes in assessment must be made clear and opportunities sought for all groups to ask questions about them. Parents and students should also have a sound understanding of what will change and why. For example, if the school has traditionally used tests of knowledge alone, then the importance of the new, broader curriculum and assessment focus on competences should be explained. If the school reporting system was based on grades or marks, the rationale for moving to comments should be explained. Or, if parents are accustomed to students' work having every mistake corrected, the rationale for focusing on the two or three most important areas for a student to work on should be explained. Arrangements for assessment and reporting to parents will both reflect and shape the learning experiences of young people and their teachers in schools and classrooms, helping to determine both what is to be learned and how it is learned. Assessment experiences should help students to build the confidence to believe that they can make progress and the practical knowledge and skills to make good progress.

Curriculum, Pedagogy and Assessment should be a seamless robe and all focused towards students' learning. This section of the document looks at learning through the lens of assessment and identifies four areas to which teachers and students should pay attention as they put the new STEM modules into practice: planning, sharing learning aims, creating opportunities for students to demonstrate progress in what matters, using assessment evidence to promote progress in learning and involving learners. In each area examples of strategies teachers might use to put ideas into practice are suggested. **It is crucial that any strategies used have a clear purpose and are linked to the needs of students in schools and classrooms. Strategies alone will not have the desired positive impact on learning.**

Plan to assess what matters

Good assessment begins with good planning. As teachers plan the curriculum for their students, they identify what matters. If what matters includes generic and domain specific competences, e.g., curiosity, creativity, critical thinking, initiative, responsibility and collaboration, and STEM practices such as design, complex problem solving and modelling, then these become the focus for assessment. We must assess what we value.

Many students in traditional classrooms have little idea of why what they are learning is important. They often see classroom experiences as hoops to be jumped through rather than learning that is important to them on their journey to become educated citizens. If students see little clear purpose for their learning, they are unlikely to engage in the learning process in ways that will result in them producing the best evidence of their learning. Sharing learning aims is an important part of getting good assessment evidence.

Teacher Strategies for Sharing Learning Aims

Creating the curriculum together

If students have the opportunity to contribute ideas to decisions about what their group/class might learn, their level of motivation is likely to be significantly enhanced. With higher motivation comes better engagement and with better engagement comes better learning.

For example, two weeks before you begin a new module, put an A3 sheet on the wall with the topic and extracts of the teaching plan you propose inserted in student friendly language. In discussion with the group/class, introduce the new module in broad terms and ask students over the next 10 days to add to the A3 sheet. They might include questions they might have or specific areas of interest they would like to explore. When students have contributed, remove the sheet from the wall asking for any final thoughts from students. Integrate their suggestions with yours and present the co-constructed curriculum on the first day of the new module. Perhaps also use the WALT/WIM/WILT strategies outlined above.

What am I learning and why?

Key questions that students should ask are, “What am I learning today?” (WALT), Why does it matter? (WIM) and What I am looking for? (WILF).

Teachers should put the learning aims for the lesson in student friendly language on the whiteboard or A3 sheet on the wall of the classroom. The lesson should begin by considering the learning aims with opportunities for students to ask questions to clarify the learning intentions. This approach should be followed up by a discussion of why the learning matters (WIM) and what criteria might I use to reflect on my own progress. What am I looking for? What would my work look like/ sound like by the end of this lesson or topic if I made good progress?

The purpose of this activity is to open up the learning process for students and to help them to be clear about the nature of the tasks, their purpose and criteria for success. These strategies are not stand alone. Putting learning aims on a wall without discussion will have little impact on most learners. As a stimulus for discussion with students, WALT, WIM and WILT approaches can be helpful.

Create opportunities for students to demonstrate progress in what matters

Well-designed tasks such as those described in the previous section on implications of competence-based teaching and learning and in the modules accompanying this document are crucial for students to be able to generate good evidence of their learning. Evidence of how students are progressing in relation to what matters can come from a variety of sources: what students’ say, what they write, how they are going about tasks and from the products they produce. During teaching and learning, there are a number of strategies that can be helpful in exploring how students are progressing.

What do I know already? What can I already do? The Five Minute Warm Up

For teachers to discern what learning has taken place during a module, they need to know what students knew or were able to do before the module started. The easiest way to get this information is to ask them.

At the beginning of a module once students are clear about the work that lies ahead, ask them to jot down in five minutes what they already know and are able to do. This brief task does two things. First, it gets students thinking about the module topic and the tasks they are about to undertake and second, it gives teacher an overview of where students are including, perhaps, insights into misunderstandings.

Involving everyone- No Hands up

In many classrooms the traditional way for teachers to engage with learners is by asking students to raise their hands to answer questions put by the teacher. This approach has the disadvantage that although some students are actively engaged (those who raise their hands), others may not be. Getting good evidence of students’ progression means that ways have to be found to promote the engagement of all learners. Having a classroom with a No Hands Up strategy is one approach. If no student raises her/his hand, then all students have to listen as no-one knows to whom the teacher will direct the next question. An adaptation of this is to have all of the students’ names on Lollypop Sticks and the teacher asks a question and picks out a lollypop stick with a student’s name.

Developing ideas - Basketball not Table Tennis

If as a teacher you want to develop and to deepen ideas or to create a context where students recognize that there can be multiple perspectives on a topic, playing classroom basketball rather than table tennis can be useful. Traditional classroom question and answer sessions between teacher and pupils can be a little like table tennis. The teacher asks a question and the pupil responds. Using a basketball approach, the teacher might ask a question and a student would respond. That student would then ask a second student to comment on and to develop the answer given. The second student would then repeat the process with a third student and so on until students have no more to add to the topic.

Who in the class understands? Traffic Lights.

When working with a number of students it can be difficult to gauge the extent to which students are comfortable with the topic. Traffic lights can offer a quick insight into student perceptions of their understanding. Each student is given red, amber and green cards. When the teacher asks if they understand, each student turns over a card on their table. Red means no – this is tricky. Amber means – not sure – think I understand it in part. Green means, yes, I understand. Teachers can then focus attention on those with amber or green cards.

However, it is important to use this approach with caution. First, the cards represent student perception. A student may think s/he understands rather than really understand. Second, students may quickly work out that if you display a green card, the teacher leaves you alone and for some students, that may seem attractive.

Use assessment evidence to promote progress in learning

Assessment evidence can be used to serve a range of purposes, formative, summative, diagnostic, evaluative or accountability but essentially assessment serves two functions; learning or judgement. If assessment is to enhance students' progress then the focus has to be on learning, the collection and use of evidence to provide useful feedback, i.e., feedback to identify what the student has achieved and what action might next be taken to promote students' progress. Students' progress will depend on their understanding of what matters most if they are to continue to make progress and how best to make progress. It will also depend on how they feel about themselves as learners. Students who believe progress is possible are more likely to be able to make better progress.

Any assessment method used in classrooms, e.g., dialogue, task, teacher designed test or standardized test should be a source of evidence to inform students' future learning. Teachers and students should have a clear idea of what progression in generic and domain specific competences looks like. Being able to describe progression through the learning journey and to identify how a student's current work relates to the broader learning journey is an essential part of the identification of next steps in learning that are crucial for future progression. Only final examinations should have a purely summative purpose, for at this point the purpose of assessment is no longer learning but selection. Assessment evidence is being used to decide which opportunities beyond school should be available to which students.

Feedback is a crucial part of using assessment to enhance learning. But feedback has to be focused, clear and embedded in what matters to make progress in the curriculum for it to be helpful. The most helpful feedback for all pupils is descriptive feedback. Comments that identify where progress has been made and point towards the most important next steps for future learning are most likely to improve performance. Grades or marks alone are judgements. They offer little insight into what has to be done to improve learning. Comments used alongside grades or marks are likely to have far less impact on learning than comments alone, as the number or the letter is a far more powerful communication symbol than words and will detract from the main focus which is what should be done to improve learning.

Focused feedback - Two Stars and a Wish

Too much feedback is as unhelpful as too little. If given too much feedback, students are unsure of where to prioritise their effort. A reasonable balance might be two stars and a wish. The teacher identifies two areas where a student has made progress and adds one wish – the most important next focus for the student to make further progress. The wish should include the area that should be the next focus for progression, why that area matters and how progress might best be made. Feedback that refers only to the what and not the why or the how is less likely to be effective.

Involve learners

One central focus for assessment is to help students become confident in assessing their own progress. This might include:

- Involving students in thinking about what teachers have identified as important learning within a topic and why in addition to considering what they, as students, might like to learn are important ways of engaging students and thus encouraging them to provide good evidence of learning.
- Encouraging students to reflect on what a good performance would look like and from that to develop assessment criteria.
- Involving students in using criteria to reflect on their own work and/or the work of others in their group.

All of the strategies outlined above can be used with students leading the activity.

Student led assessment questions/tasks.

An effective way of having students focus on what matters in learning and assessment in a given topic is to ask the students in groups to write the assessment questions and the success criteria. Groups work in pairs. One group gives their assessment task/questions to another group and receives the assessment task/questions designed by the second group. Each group uses the assessment criteria from the original group to assess their own work and finally the two groups come together to give feedback to the assessment questions/tasks and the criteria.

Managing the process of change for STEM teaching and learning

The challenges involved in shifting to a contemporary, cutting edge STEM curriculum occur at a number of levels in schools, from school leadership, to teachers and subject leaders.

Challenges for school and for STEM leadership

The shift to a STEM vision involves school level challenges associated with interdisciplinary content organisation, with timetables, teacher knowledge and commitments, and finding time for cross-disciplinary planning. Thus, instituting such a curriculum requires commitment by schools, leadership at the curriculum and STEM teaching team levels, and also shifts in perspective by subject teachers. Such changes must happen by degrees, and supported by both professional learning for STEM leaders, and resources.

There are important steps that can be taken within disciplinary subjects to shift towards a competence-based vision, which can be pursued alongside cross-disciplinary work. For instance, groups of mathematics teachers may plan to run curriculum units that are based in design or science-related challenges. Examples of these might be data modelling based around class measurements of body features; height, foot length, arm span. One activity that has engaged students was built around a challenge to work out when parents would have to buy new uniforms, based on an investigation of growth in student height over time. Students put a large poster against a wall in a common area and students voluntarily marked their height on this, with their age, so that a record of height vs age was generated. Another example is the design of a wheelchair ramp at the school, sparking investigations of slope and force, and geometry, trigonometry and scaling. For a number of science units in the Turkish curriculum there are many opportunities for design, so that a significant commitment to building design competence could be built into these units of work. Similarly, there are many opportunities for computer science to be built into the science or mathematics curricula.

For cross-disciplinary units of work however the complexity of collaboration increases. However, this opens up opportunities for the pooling of expertise, for teacher learning, and for richer student learning. A key requirement, as described above, is the commitment of school leadership in opening up planning time, and for encouraging timetable reorganisation and curriculum flexibility. The software tool developed by Joe Merlino as part of this renewal project will allow identification of topics in the STEM subjects that can be productively aligned to form the basis of cross disciplinary project work. In this case, teachers of mathematics and of science and technology can work together, either in a coordinated time slot where they are side by side with students or dealing with aspects of a problem task in their own lesson time. The learning of disciplinary content around projects that students see as meaningful has been shown to significantly engage students, where they see the relevance of their learning (Tytler, et al, 2019). The challenge is to ensure that disciplinary depth in each of the subject is maintained, and enhanced. That is a planning matter, and the exemplar modules provide some leads on this.

Challenges for teachers

For teachers, one significant challenge is to shift focus to a different, more active view of knowledge and competence in their domains of expertise. Rigor and depth should come to be seen as not simply defined by student capacity to remember definitions of concepts and processes in science or straightforward instrumental processes in mathematics but associated with competences in enacting practices that combine a range of types of knowledge, skills and value commitments. This involves a shift in what is valued. Teachers also need to learn to work together, across domains, and this involves learning and negotiation of new knowledge and practices. Teachers need to learn to value students' investigative skills, to work with students' interests to encourage an interest in deeper levels of learning, and to focus attention on students generating and justifying ideas and developing and critically examining design solutions.

Allied with this, there are challenges at the classroom level in enacting a pedagogy where students are more active in generating and negotiating ideas and the teacher's expertise and knowledge is understood as not so much expressed in 'telling' and providing 'explanations', as in providing appropriate challenges, appropriate support, and making judgments about student work and ideas and about how to move these forward. This can require more depth in subject knowledge and also new knowledge of how to support student learning of competences that combine practices (e.g., argumentation, modelling) with disciplinary knowledge. In 'telling' students what to do, teachers can often short-circuit possibilities of problem posing and problem recognition, and of students creating individualised solutions. In learning to ask students for their ideas, and setting tasks where groups generate solutions, teachers are often surprised by the level of knowledge students show. Learning to wait for responses, learning to phrase open questions and to ask for justifications of answers, is a skill that needs to be developed in supporting student competence development. Once learned, however, it becomes a habit, and a pleasure in seeing students engage with ideas and express genuine interest.

Supporting teacher growth

The provision of resources is important, including new curriculum sequencing, new framings of outcomes around competences, and exemplar modules. However, these alone do not bring change, and a program of teacher development is important to clarify what is at stake, what new teaching and learning practices really look like, and what enhanced student learning looks like. Such teacher development involves a combination of change in beliefs, trying out new practices, learning to value these new competence outcomes, driven by external stimuli (Clarke, D. & Hollingsworth, H., 2002). We know that effective support should include the stimulus of external expertise and workshops, collaboration across schools, and mentoring and innovation at the local level. A structured program of support over time is needed for significant change. This needs coordination at both a school network, and a school level. The Appendix provides a range of practical approaches to teaching strategies that will support a competence approach to STEM Education and the Program of Professional Learning in the PowerPoint offer a constructive and interactive starting point for that process.

For change in any system to have integrity, i.e., to be deeply embedded and sustainable over time, it is crucial that those with responsibility for the design of the change process pay attention to three areas.

The proposed change must have *Educational Integrity*: the argument for change has to have a clear focus on improving learning and be based on evidence that the planned approach will improve young people's learning experiences.

It should have *Personal and Professional integrity*: it should be aligned to include what matters to the individual teacher/student as well as what matters to the school; and in ways that mirror the recommendations for new ways that teachers will work with their students, participant teachers should have a significant role in the construction of the program, rather than being passive recipients of policy directives.

The change design should also have *Systemic integrity*. For example, there should be clear support from school leadership and coherence in development at all levels of the education system – all policies should be driving in the same direction; all communities should share the vision. (Hayward & Spencer, 2010), Hayward, 2015).

In Conclusion

This new model of STEM Education offers the potential to create exciting, constructive, interactive experiences for young people. These are experiences that will both encourage more positive attitudes to STEM learning in school and provide a springboard for taking forward STEM learning into the kinds of STEM careers that are so valued in society. Bringing together STEM curriculum, assessment and pedagogy and supporting innovation through high quality Professional Learning is a powerful combination that can contribute to a bright future for STEM Education in schools.

APPENDIX: TEACHING STRATEGIES SUPPORTING A COMPETENCE APPROACH

This section provides an introduction to the many teaching strategies referred to in the exemplar modules and which are advocated as approaches that engage students in creating and sharing ideas. If they are unfamiliar, then it is best to read them carefully and try them out one at a time. First time, through try and be very clear with the students what they are expected to do and how much time they have for the activity.

In addition, try to be very clear about what they are expected to do by the end of the activity and anything they are expected to produce.

Think pair share

This is probably the most familiar structure to most teachers. The idea is that a question is posed to the class such as 'What is the difference between photosynthesis and respiration?' or 'What is the evidence that the Earth is a sphere and not flat?' and students are then asked to write down what their thoughts and possible answers. Then they come together to discuss it in pairs. The time for this varies on the nature of the question but rarely should be longer than 5 min. After their paired discussion, the teacher can then call on the pairs (note not the individual) for their thoughts and arguments. After any contribution, you as the teacher can ask if others wish to 'add on', 'elaborate' or if they have an alternative or better point to make. In each case, your role is to press students for the evidence and reasoning that supports their position.

One way to improve this activity is to make it a written activity using the sheet on the next page.

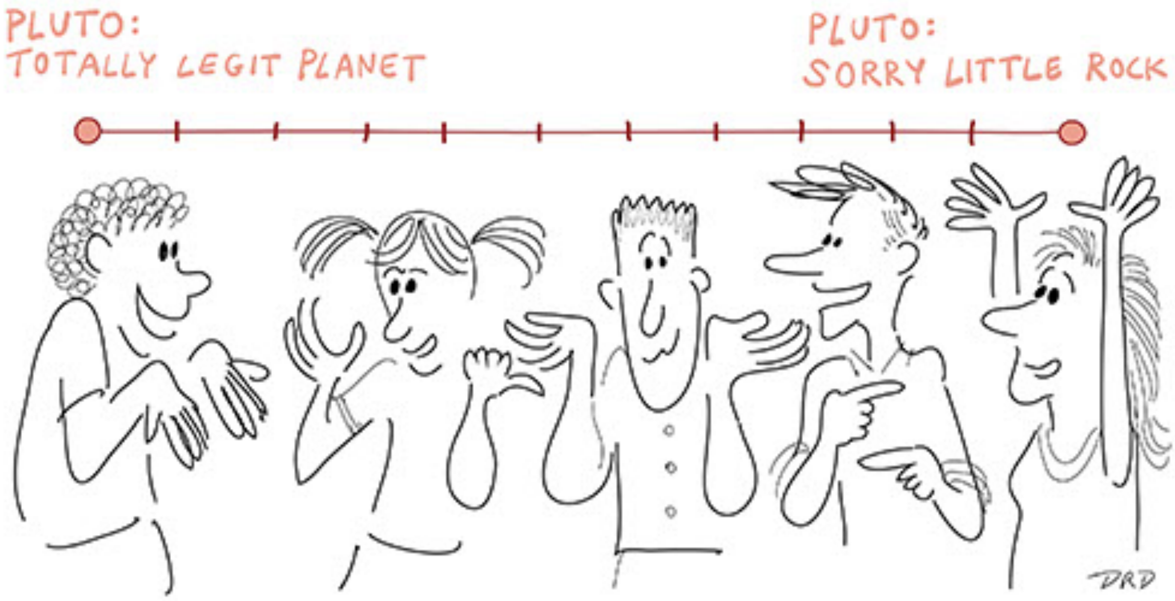
THINK-PAIR-SHARE

My Name____

Partner's Name____

THINK – my thoughts or understanding at this time	**PAIR** – what I understand my partner is telling me
SHARE – our common understanding after talking, what we can share with other and what was most important from our discussion.	

Argument Line



Another strategy to promote discussion is to use an argument line. The question for debate is put up on the board with two opposing alternatives posted. Students are then given up to 2 minutes to think about which position they believe to be true, and the evidence for why they believe it to be true. Once again, this strategy separates the idea under discussion from the individual.

After this time, students are asked to go to the side of the room that represents the view that they hold. Students who think there are reasons for both being right can go to the middle.

Once with others who hold the same view, they should be asked to discuss two things:

a) What are the arguments that justify where they have chosen to go?
b) What are the arguments for why the others are flawed?

Typically, students can be given up to 5 min to discuss their views and work out their arguments.

After this, you as the teacher can call on students on one side to explain why they are there. Then, likewise, you can call on students from the other side to explain why they have chosen that side.

Then, you can ask each side to explain why they think the other is wrong. If you have students in the middle, you may wish to call on them. Productive talk moves (see Chapter 3) may again be very helpful here in helping to advance the discussion.

Ultimately, your job is to steer the discussion so that the evidence for the scientific case is seen to be stronger. If students are not able to do this on their own, you may have to play Devil's advocate for the scientific case.

Four Corners

This is a variant on an argument line. Instead of there being two sides of the room, you use all four corners of the room as shown beneath

This strategy is useful for issues where there might be a range of opinions. For instance, imagine you were studying ecosystems or food chains and wanted students to apply these concepts to a topical question such as:

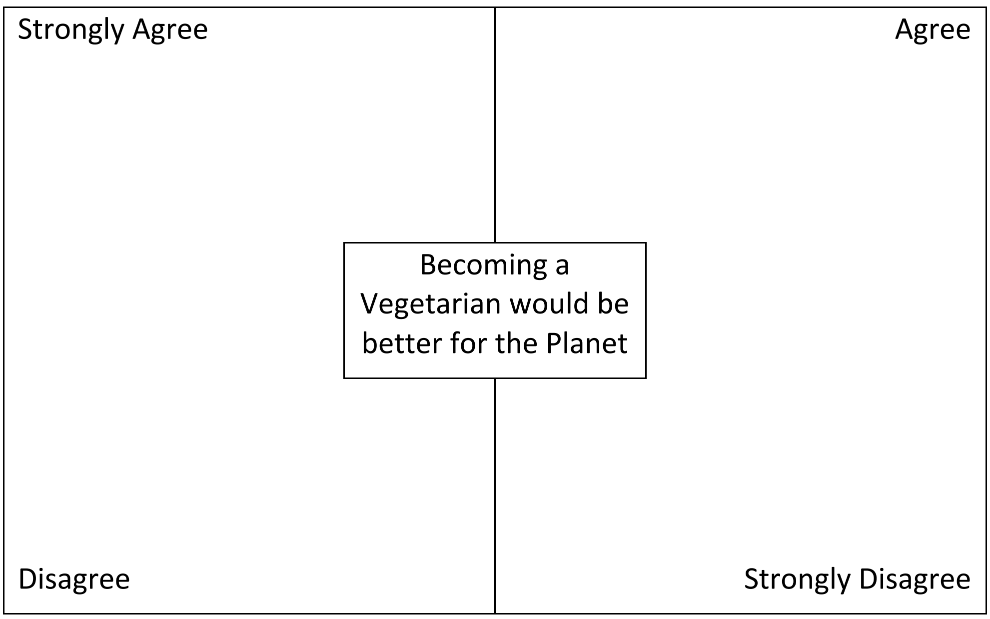
Should wolves be reintroduced into California?

Would becoming a vegetarian would be better for the Planet?

Will genetically modified plants help to feed the world's ever growing population?

Is there is no such thing as an invasive species of plant?

All that is needed is to provide a claim which answers the question and draw a diagram of this nature on the board or a PowerPoint slide.



Once with others who hold the same view, they should be asked to discuss two things:

a) What are the arguments that justify where they have chosen to go?
b) What are the arguments for why the students in other corners are flawed?

Typically, students can be given up to 5 min to discuss their views and work out their arguments.

After this, you as the teacher can call on one corner to explain why they are there. Then, likewise, you can call on the other corners to explain why they have chosen that side.

Then, you can ask each corner to explain why they think the other is wrong. Productive talk moves may again be very helpful here in helping to advance the discussion.

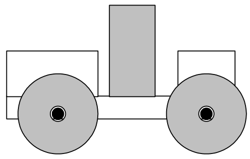
Ultimately, your job is to steer the discussion so that the evidence for the scientific case is seen to be stronger if the issue has a clearly agreed answer. In many cases, such as the example above, there is no agreed answer and the focus of the discussion should be on identifying what the science is and the competing arguments. Students can then be asked to write a summary of the arguments afterwards and include points about why they think the counter arguments are flawed.

Listening Triads

The Listening Triad, as its name suggests, is an alternative discussion structure that is designed to encourage students to listen to the point being made by another student. In this structure, one student takes on the role of the talker, one student takes on the role of the questioner who questions what the talker is saying, and another student takes on the role of the notetaker noting the major points of the discussion. Every 3 min the roles can be rotated so that students all get a chance to take on the different roles. Notably to ask a question or take notes students have to listen!

This structure is useful when discussing the points made in a text, a concept cartoon or the answers to a question such as the one beneath.

Student experiments on battery powered buggy



Alice is investigating the speed of a battery powered buggy.

- She can make a buggy with **small wheels** or **large wheels.**
- She can make a **light** buggy or a **heavy** buggy (with a 500g load).
- She can use **ordinary batteries** or **long-life batteries.**

She wants to find out if these make any difference to the speed of the buggy. She makes many measurements and these are her means.

	Wheel size	**Load**	**Type of batteries**	**Time (in sec) for 5 m**
Experiment 1	Small	Heavy	Ordinary	8.6
Experiment 2	Large	Light	Ordinary	7.5
Experiment 3	Large	Heavy	Long-life	8.3
Experiment 4	Small	Light	Ordinary	7.5

a) What do these results tell you about the effect of wheel size on the time for 5m?
(Choose one)

A. Large wheels make the buggy use less time for 5m

B. Large wheels make the buggy use more time for 5m

C. Wheel size makes no difference to the time for 5m

b) Which two experiments are needed to work this out?

Experiments____________________________

c) What do these results tell you about the effect of weight on the time for 5m?
(Choose one)

A. A heavy load makes the buggy use less time for 5m

B. A heavy load makes the buggy use more time for 5m

C. A load makes no difference to the time for 5m

d) Which two experiments are needed to work this out?

Experiments____________________________

The prompts beneath can be given to students to help scaffold each of their roles.

Questioner

- What do you think?
- Why do you think that?
- Let’s think again..

- Can you say a bit more?
- What else do we know?
- I can tell you about..
- Can you explain?
- I hadn’t thought of that until you said it

- I disagree because…
- But…
- I agree but…
- I believe that…
- I think…
- A different point of view
- I can’t see how your point fits in with….

Talker

- My reason for saying that is..
- Because..
- I have noticed that..
- I have found out that..
- I see if differently…

- If..
- What if…
- Why?
- Maybe we could..?
- I have a suggestion..

Listener

Record only what you think are the MAIN or GOOD points that are made.

RECORDING IN NOTE FORM IS ACCEPTABLE AT PRESENT

Giving students 3 min in each role will provide a total of 9 min for discussion.

After this, you as the teacher can run a whole group discussion calling on each group for the main points that came up in the discussion. You can ask groups if they agree or if they have a different view. Where there is difference try to get them to justify what their arguments and evidence are.

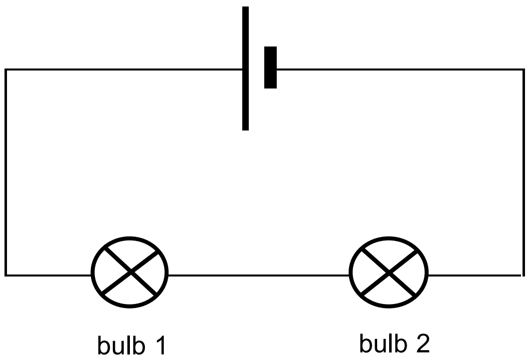
Ultimately, your job is to steer the discussion so that the evidence for the scientific case is seen to be stronger. If students are not able to do this on their own, you may have to play Devil’s advocate for the scientific case and raise points that they have not considered.

Using Technology Tools: Poll Everywhere; Socrative; Kahoot; Brain Candy

Another way to involve students in argument and discussion is to use one of the many websites that make some form of electronic polling or quizzing available. These are all free. As the teacher you have to join them and you can place the question that can then be seen by all the students when they log on. Students then have to submit a response which you can display using your computer. The great thing is that all the responses can be anonymous so it separates the individual from their contribution. From a teaching point of view, what it means is that you are being provided with instant feedback from the students so you can see what concepts and ideas the students are struggling with.

Quizzes can be either true/false quizzes or multiple-choice items of this nature:

The two bulbs in this circuit are identical.



1. How bright will the bulbs be?

   A. Bulb 1 is lit, Bulb 2 is off

   B Bulb 2 is lit, Bulb 1 is off

   C. Both bulbs are lit, bulb 1 is brighter than bulb 2

   D. Both bulbs are lit, bulb 2 is brighter than bulb 1

   E. Both bulbs are lit with the same brightness

Which can then be followed by the question that asks for the justification.

2. How would you explain this?

   A. The first bulb uses up **all** of the electric current, so there is none left for the other one.

   B. The first bulb uses up **some** of the electric current, so there is less left for the other one.

   C. The electric current is shared equally between the two bulbs.

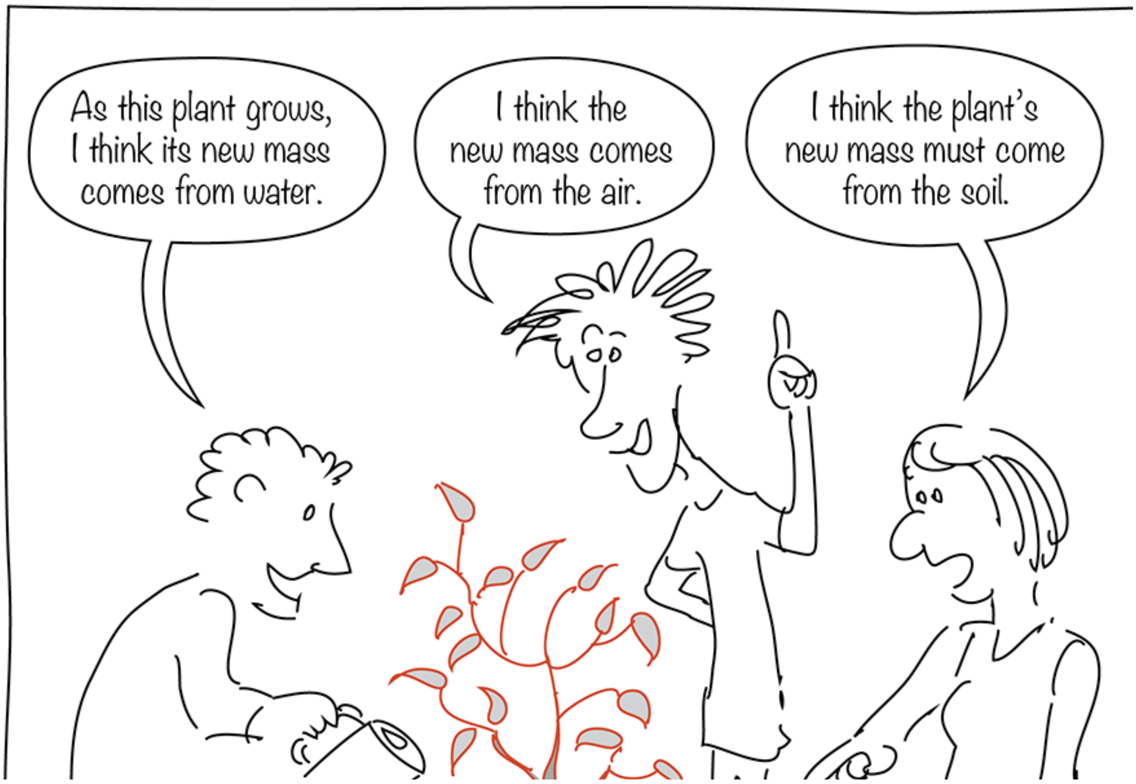
   D. The electric current is the same all round the circuit

When you get the responses, you can ask students who have chosen one to explain why they think students who have chosen another response are wrong. This can either be done by posing the question electronically and asking students to type in the responses to Q3, or by asking students to give their reasoning in class.

3. Explain why you think one of the other choices is wrong and justify your idea?

The second approach though exposes which students have got it wrong. Nevertheless, such methods are a very good way of engaging students in scientific reasoning and argumentation.

Concept Cartoons/Formative Assessment probes



Page 6 of 7

Concept cartoons were an idea developed and promoted by Brenda Keogh and Stuart Naylor from the UK. They all present a phenomenon with different explanations for why it happens or what is going to happen. Students are then asked to discuss the suggestions made by the cartoon characters and argue for which one they think is correct and which ones are flawed. The American version of these are Page Keeley's Formative Assessment Probes published by NSTA and Corwin, which can be used in a similar way.

The important thing about concept cartoons is that they separate the idea from the individual again as students are not talking about their ideas but about the ideas on the cartoon characters.

Concept cartoons can be discussed using think-pair-share, listening triads or 3 (if there are three ideas) or 4 (if there are 4 ideas) corners. Such cartoons can be used formatively to elicit what students understanding is prior to teaching a topic, or after teaching a topic as a way of applying what students have learnt and to see how well the concept has been understood.

Sharing representational work

It is now well established that learning in the STEM subjects involves induction into a set of multi-modal literacy practices that include visual representations (e.g. drawings, animations, microscope images), visuo-spatial representations (3D modelling), written and spoken text (explanations, reports etc), symbols (mathematical equations, chemical symbols), graphs and tables, and embodied representations. In science these representations are constructed to interpret material exploration while in mathematics the exploration involves patterns in shapes, numbers, symbolic expressions etc.

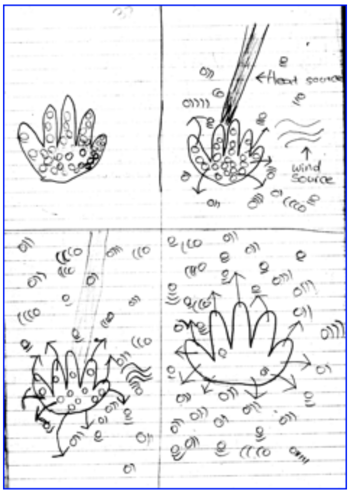
Problem solving and explaining in science involves the construction, translation across and coordination of different representations, such as when explaining seasons could involve 3D models of the earth in orbit, drawings of sunlight on the earth at different seasons, and words. A quick flick through any modern scientific text will demonstrate the importance of a variety of representations. In learning science (or mathematics) from a competence perspective, students need to engage with inventing, evaluating, translating across, and coordinating representations across different modes (Tytler, et al, 2013). Student drawing can provide good insight into the way they are thinking, and monitoring these visualisations, with written text or verbal explanations, can provide opportunities for feedback.

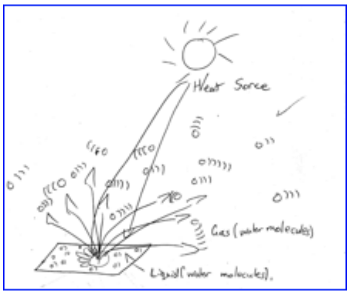
In class, a productive activity is to

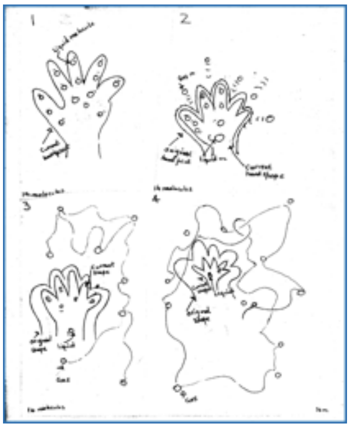
1. prepare students with a question that requires them to use visual or 3D representations to speculate about or explain what is happening;
2. have each student construct a representation;
3. select a number of students to show and explain their representations and guide the class to comment on each - does it answer the question? Is it a plausible representation of what is happening?
4. arrive at class agreement about the features of a good representation, and have students revise/refine their explanations.

In mathematics, this student invention, evaluation and refinement is the basis of inquiry approaches (Sullivan, 2011) that engage all students in thinking mathematically.

An example of such a task in Grade 5/6 science involves students being introduced to the idea of water vapour in the air as particles and discussing how this explains puddles evaporating. Then, students engage with an activity where they place a wet hand on paper and trace around the print. They watch as the wet patch shrinks and are challenged to draw what is happening to the water. Examples of student drawings are shown on the next page (Ainsworth, Prain & Tytler, 2011).







Questions the teacher could ask, as each students shows their representation:

- What does the representation show?
- How does it show that?
- What does it not show?
- Does it answer the question?
- How might it be improved?

In this activity the teacher needs to be clear about what aspects of the representations they want to promote and establish.

Other examples of sharing representational work:

- Challenging students to invent a role play to show the difference between a planet orbiting versus rotating;
- Providing students with a variety of rock cycle images and challenging them to construct their own version; and
- Challenging students to construct a story-board of the forces acting on a parachutists at different stages of a dive.

Gallery walk

Another version of sharing of representations is to have students construct their representations and leave them open on their desk. The teacher then invites students to walk around, looking carefully at other students' work.

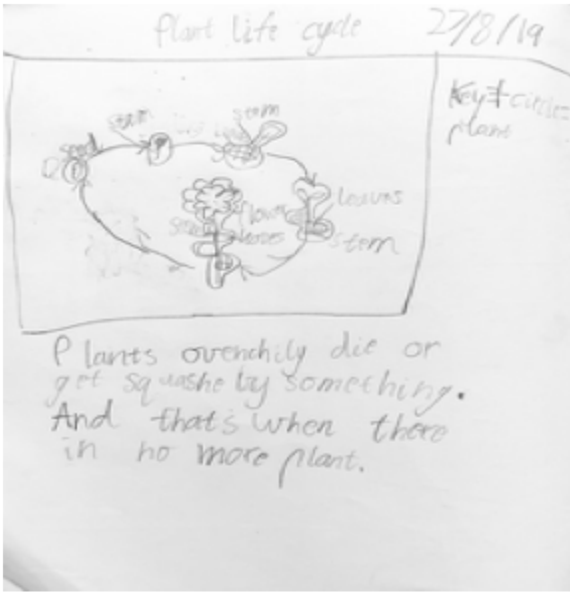
"I want you to look carefully at other students' representations and find ideas that you think would improve your own. Note these carefully since we will be having a discussion about which representations provide a good model."

The teacher then discusses with the class: "What did you notice that was helpful?" "What was it about xx's work that you thought was so good?" (The teacher has xx show everyone their work and explain its features). Out of this discussion, some principles are agreed upon.

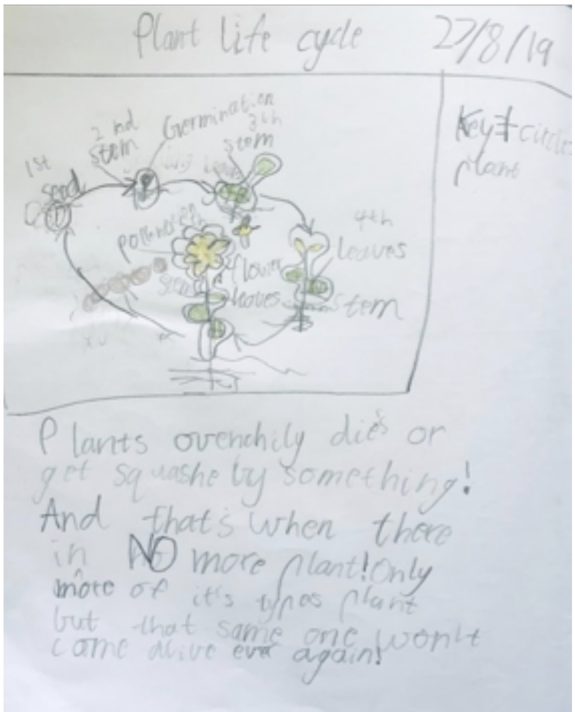
After this, either students go back to their own representations to incorporate features they had discovered, or their ideas are incorporated in a further, related activity.

Below is an example of a Grade 2 student's drawing of a plant life cycle before and after a gallery walk. This was part of a study of plants where students followed the plants from seed through to flower and fruit, measuring and representing growth. Note the addition of a pollination stage, further annotations, and more explanatory text.

Before the gallery walk



After the gallery walk



References

Ainsworth, S., Prain, V., & Tytler, R. (2011). Drawing to learn in science. *Science*, *333* (26 August), 1096-1097.

Chi, M. T. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in cognitive science*, *1*(1), 73–105.

Clarke, D. & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and teacher education*, *18*(8), 947–967.

Hayward, L & Spencer, E (2010) 'The complexities of change: formative assessment in Scotland', *Curriculum Journal*, 21: 2, 161 — 177

Hayward, L. (2015) 'Assessment is Learning: the preposition vanishes in *Assessment in Education: Principles, Policy and Practice*, 22(1), pp. 27-43. (doi:10.1080/0969594X.2014.984656)

Sullivan, P. (2011). Teaching mathematics: Using research-informed strategies. Melbourne: ACER.

Tytler, R., Prain, V., Hubber, P., & Waldrip, B. (Eds.). (2013). *Constructing representations to learn in science*. Rotterdam, The Netherlands: Sense Publishers.

Tytler, R., Williams, G., Hobbs, L., & Anderson, J. (2019). Challenges and opportunities for a STEM interdisciplinary agenda. In B. Doig, J. Williams, D. Swanson, R. Borromeo Ferri, P. Drake (Eds) *Interdisciplinary mathematics education: the state of the art and beyond* (pp. 51-81). Springer ICME series. https://link.springer.com/book/10.1007/978-3-030-11066-6.