MAKE ROOM FOR D-STEM:

A way to inform the teaching of STEM in schools

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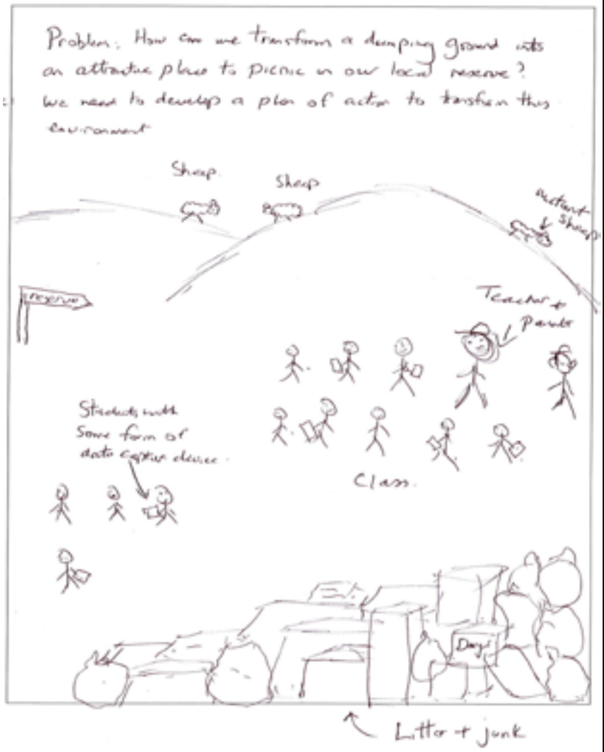
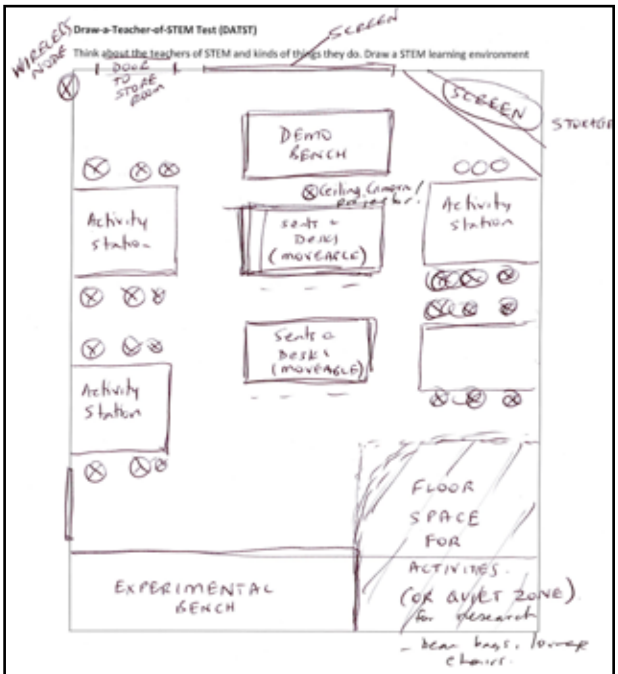
How well do you know your teachers of STEM? Do you know the perceptions they have of STEM learning environments? How might these perceptions inform the school environment, and how teachers are supported to adapt effective STEM teaching practices? Finding out more about the perceptions that teachers of STEM hold about STEM learning environments can help school principals and discipline heads to understand the ways in which STEM teaching is approached in their school. To discover teachers' perceptions, you can ask them. One way to do so is to ask them to create a drawing of a STEM learning environment. You may be surprised at the results.

Across several research studies, we gave groups of STEM researchers (Hatisaru, Beswick & Fraser, 2019), school principals (Hatisaru, Fraser & Beswick, 2020), and university lecturers (Hatisaru, Fraser & Seen, 2020) the task of drawing their perceptions of a STEM learning environment. Their drawings (see Figures 1 and 2), indicated a variety of perceptions about STEM learning environments with regard to the context of teaching and learning, teacher knowledge and practices, the content focus for student learning, and the outcomes of STEM for students. This diversity made us question the importance of having a common conceptualisation of STEM teaching within a school.



This scenario is problem-based. The students need to develop a plan of action to present to a local council to transform a section of their local reserve, that is presently being used as a dumping area, into an attractive place for people to use for picnics, recreation and so on. They need to develop specific plans based on an environmental scan of the location, quantify the work needed, complete cost estimations, and also develop a proposal to submit to council. (Researcher 9)

Figure 1: An example of a D-STEM response emphasising 'Realistic problems'.



The idea is to create a semi-flexible, semi-permanent workspace where collaboration, experimentation and individual work can occur as needed. The design allows teachers to instruct as necessary and allow supervision but also provides opportunities for students to work at their own rate. Students use notebooks/iPads and access online resources. They can use various equipment resources available to complete experiments. They have data loggers, robotics equipment etc. There is also a ceiling mounted camera to record the activities and teleconference. (Principal 9)

Figure 2: An example of a D-STEM response emphasising 'Student-centred instruction'.

Research concern about STEM education

Much of the research in STEM education in the last decade has focused on defining what the acronym encompasses in educational settings, the teaching and learning practices required, and the learning outcomes that are possible through implementing STEM in the classroom. STEM has been described as "working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines" (Honey, Pearson & Schweingruber, 2014, p. 52) or an "approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning" (Kelley & Knowles, 2016, p. 3). STEM has also been viewed as "an effort to combine the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections among these disciplines and real-world problems" (Moore & Smith, 2014, p. 5). Sometimes, STEM is conceptualised as the teaching and learning practices that coordinate the learning objectives of science, technology, engineering, and mathematics through open-ended, realistic, and interdisciplinary problems (Vasquez, 2014/2015). No matter how varied the definition, increasingly, this approach is believed to have a positive impact on the learning outcomes of students (see Margot & Kettler, 2019). There are, nevertheless, several practical challenges in terms of its successful implementation, and there remains a widespread confusion about what STEM looks like in schools and in the classroom (Bybee, 2010; Hobbs, Clark & Plant, 2018).

In this paper, we introduce a research instrument (Draw a STEM Learning Environment: D-STEM) and its accompanying rubric (the D-STEM Rubric), both of which we developed based upon relevant research studies. We describe their usefulness to school principals in commencing conversations with their school's STEM leadership team and teaching staff, after their completion of the D-STEM instrument. We also suggest that, by using the D-STEM instrument, principals can unearth understandings of STEM teaching and learning in their school and importantly, together with the D-STEM Rubric, help reveal the characteristics of effective STEM teaching.

Two research studies

The idea of having educators of STEM draw a STEM learning environment arose after the first author of this paper saw student drawings that powerfully depicted and described a mathematics classroom (see Hatisaru, 2020a; 2020b) and began to research adults' images of mathematics. We were also aware of a series of studies in which preservice and practising teachers of individual STEM subjects (e.g., science and mathematics) completed the Draw a Science Teacher Test (DASTT) (Thomas, Pedersen & Finson, 2001) or its variations (e.g., Ambusaidi & Al-Balushi, 2012). These DASTT studies prompted us to change the directions for our research as we believed that asking educators of STEM to draw a STEM learning environment would give us insight into how much STEM educators knew of the characteristics of effective STEM learning environments.

In our exploration of STEM teaching and learning, we have conducted two research studies with twelve researchers in STEM education (Hatisaru et al., 2019) and twenty-one primary and secondary school principals (Hatisaru, Fraser & Beswick, 2020) across Australia, and fifteen university academics at a university (Hatisaru, Fraser & Seen, 2020).

This article is based on the findings of the first study in relation to school principals who implemented the D-STEM instrument.

The D-STEM instrument informed by DASTT comprises both drawing and verbal descriptions and is constructed as a double-sided sheet (see Appendix A), within which participants are asked to draw a picture of a STEM learning environment on the front side. As we acknowledge that not all researchers and principals teach, we provided our participants with a prompt to help explore their thinking about STEM learning environments: "Think about the teachers of STEM and the kinds of things they do. Draw a STEM learning environment". On the reverse side, participants are asked to describe their picture, responding to the given open-ended items regarding STEM education. The term 'learning environment' is used to describe the diverse physical location, context, and culture in which teaching, and learning takes place. While the literature describes three complementary components of a learning environment: academic (the pedagogical and curricular elements); management (the discipline styles for maintaining order); and emotional (the affective interactions within the classroom) (Evans, Harvey, Buckley & Yan, 2009), the D-STEM instrument has been designed to focus on the pedagogical and curricular elements of STEM learning environments. Participants complete the instrument individually and can then share their drawings and accompanying text with whomever they are working, and compare, discuss, and analyse.

To frame the analysis of participants' responses, we used the literature on effective STEM teaching and created the D-STEM Rubric (Appendix B). The D-STEM Rubric includes elements of effective STEM learning environments that have been identified in research (e.g., Glancy & Moore, 2014; Hobbs et al., 2018; Vasquez, Sneider & Comer, 2013). Specifically, it focuses on evidence of STEM integration, Realistic problems, the Collaborative nature of STEM, Personal experience, Multiple representations (e.g., written symbols, diagrams, and concrete models), Community–industry engagement, and the Teaching and learning of STEM (see Table 1) in either the participants' drawings or accompanying texts. In our research studies, we used the Rubric to code the first six of these elements in a Likert fashion and explored the extent to which each element seemed to be represented in drawings or texts: 'Strong indication', 'Some indication' or 'No indication'. Due to our inability to discriminate further, the final element was coded in a dichotomous fashion, indicating whether each sub-element seemed to be represented or not: 'There is indication' or 'No indication'.

Table 1: Elements of the D-STEM Rubric and their descriptions.

Element	**Description**
	Drawing or text includes:
STEM integration	reference to a context that might require students to use knowledge and skills from multiple STEM disciplines;
Realistic problems	reference to interdisciplinary problems grounded in the real world;
Collaborative nature of STEM	reference to collaboration among students in which members have roles and responsibilities (i.e. teamwork);
Personal experience	reference to a context that problems or tasks are linked to students' lives and tap into/ elicit their interests;
Multiple representations	reference to a problem or context that could support multiple representation, and at least two representational models (e.g., symbols, visual diagrams, verbal statements) are explicit;
Community–industry engagement	reference to linking content with industry, the community, or families in a variety of ways (expert talks, joint works, using business/community contexts).
The teaching and learning of STEM	
	Drawing or text includes:
Teaching and learning practices	reference to open-ended, student-centred instruction (e.g., inquiry, problem-based learning);
Tools	reference to using a range of teaching and learning tools;
Roles of the teacher	reference to the teacher roles other than giving knowledge (e.g., facilitator, guide);
Roles of the students	reference to the student roles other than receiving knowledge (e.g., planner, experimenter).

Perceptions of STEM learning environments

The D-STEM instrument elicited a wide variety of responses, which reflected the diversity of interpretations of STEM learning environments. Table 2 shows the frequency of visual and/or written descriptions at each level for each of the elements of the D-STEM instrument completed by participating principals (for a comprehensive analysis, see Hatisaru, Fraser & Beswick, 2020).

In our analysis of the D-STEM responses, it was clear that most participant principals used the phrase 'STEM learning environment' to equate to the use of student-centred pedagogies in classrooms, where students work collaboratively, and the teacher's main role is to motivate and facilitate their learning. As well as the inclusion of 'collaboration' in their responses, the other most commonly included element was 'open-ended, student-centred teaching and learning practices'. Most of the principals' responses indicated that students should be engaging in experiential learning such as with science inquiry, engineering design, or problem-based learning, where students investigate solutions to tasks or problems through designing, testing, and revising their ideas. Very few responses depicted and/or described these practices as being anchored in 'realistic problems' within which individual STEM disciplines might be integrated or calling upon students to translate concepts across 'multiple representations'. STEM learning environments that incorporated opportunities that 'link content with industry and the community' were almost absent in participants' responses.

Table 2: The frequency of D-STEM responses at each level for each element (N=21).

Element	Drawing/text includes strong reference	Drawing/text includes reference	Drawing/text includes no reference
STEM integration	3	11	8
Realistic problems	2	6	13
Collaborative nature of STEM	3	18	0
Personal experience	4	5	12
Multiple representations	3	9	9
Community–industry engagement	0	1	20
The teaching and learning of STEM			
Teaching and learning practices	NA	18	3
Tools	NA	20	1
Roles of the teacher	NA	16	5
Roles of the students	NA	18	3

NA: Not Applicable

The active role of the teacher and students in STEM learning environments was evident. The teacher and students were described as interacting in an environment in which the teacher is no longer the expert, solely responsible for giving knowledge, with the expectation that their students' role is to receive it. Rather, the teacher is perceived as guiding or facilitating the learning, and students are active learners who collaborate and build and experiment in order to solve problems or find solutions. Nevertheless, as we analysed the D-STEM responses we became concerned that a few participant principals assumed that adapting student-centred pedagogies reduces the teacher's responsibility for designing and overseeing student learning and potentially undervalued the importance of specific pedagogical and content expertise during the teaching of STEM (Keiler, 2018). In our experience, teachers are required to be more than what one of the participant principals described: the teacher being a "co-learner" within a STEM learning environment. In fact, the teacher does need to be an "expert" of sorts (Allen, Webb & Matthews, 2016).

What expertise is actually required — particularly in regards the extent to which an individual teacher needs to be knowledgeable about all science, technology, engineering, and mathematics practices in integrated STEM learning environments (Vasquez et al., 2013) — is as yet unexplored.

Finally, our analysis of principals' (and also researchers') drawings and texts revealed that only a small number of participants included different modes of representations in their learning environments or referenced tasks and activities that could draw from different representational modes. In most of their diagrams and texts, the use of representational tools remained implicit, or were absent altogether. This is an area that is deserving of further research, as the research literature emphasises the importance of incorporating opportunities for students to work with different modes of representations while they learn STEM concepts (e.g., Glancy & Moore, 2013). We recommend that, in order to determine the real extent to which multiple representations are incorporated into STEM teaching or activities in which students engage, further research would benefit from observation in classroom settings.

Implications for schools

Make room for D-STEM

In both of our D-STEM studies, participants treated the drawing-based technique — designed to elicit their perceptions of STEM learning environments — as a serious task, taking some considerable amount of time to capture their responses. In addition, it was our observation that their drawings contained rich information relating to the understanding of professionals in STEM education with regard to STEM learning environments. These outcomes suggest to us that there is value in *making room for D-STEM* in schools. In particular, for principals to have their STEM leadership team complete the D-STEM instrument, and to complete it themselves, with the aim of comparing perceptions and stimulating conversations about STEM in their school. Making their thinking visible in this way enables a discussion of the presence and absence of elements in learning environments shown as being essential for effective STEM learning (e.g., connecting scientific concepts across STEM subjects through using multiple representations). Participating in such an activity provides the opportunity to both challenge conceptions and to stimulate thinking about how such learning environments could be constructed. It can also unearth the dispositions and skills that both teachers and students need to possess, or develop, in order to engage in rich STEM experiences.

How to use D-STEM

In this section, we describe in more detail our interpretation of two responses from principals (P1 and P8) (Figures 3 and 4) in their completion of the D-STEM instrument. We chose these two examples because the richness of the thinking evident in their responses serves to illustrate how the instrument can stimulate conversations amongst staff about STEM teaching and learning.

In Figure 3, you will note that there is an emphasis on learning tasks or activities that could require 'combining knowledge and skills from two or more disciplines' (e.g., mathematics and technology) such as robotics, coding, programming with reference to designing and making, as well as science. 'Real life issues' are also referenced but no further details are provided. The picture depicts a range of areas in which students 'work collaboratively' on problems. The mentioned real-life issues might be 'linked to students' lives' and could elicit their interest. The picture captures a context that could support 'multiple representations' and includes a symbolic representation: "+*xy*˜". There is no evidence of 'linking the content with the community'.

Both the visual and written descriptions include indicators of an 'open-ended student-centred instruction', and teaching and learning practices such as planning, designing, creating, problem-solving, exploring, developing creative and innovative solutions, and computational thinking are mentioned. Technologies such as a TV/ projector, 3D printer, computer, augmented reality, and a Google mask are also included. The teacher is described in terms of their 'role' in both creating a provocation that engages students and encouraging them to explore, and explicitly teaching foundational skills in science, mathematics, literacy, technology, and engineering. The students learn while solving authentic problems and generating creative and innovative solutions.

Student work: Collaborative environment for planning, designing, creating, problem solving and coming up with creative and innovative solutions.

Teachers: Create provocation for students to engage & explore. Explicitly teach foundation skills in science, maths, literacy, technology, engineering (computational thinking). Provide the conditions for collaboration. Scaffold student thinking to be a creative problem solver.

Tools: Range of tools/devices to do the above.

Figure 3: P1's drawing and description of a STEM learning environment.

My picture is about opening up students' minds beyond our school gate and looking at the impact that we are having on our environment. Questioning our current practices and challenging them with new thinking. Teacher: provides a space/environment where they can question, learn new technologies/ information, provide challenges/issues to explore. Students: working together in groups/ (collaboratively) (communicatively) working through issues, going and finding their own data perhaps working with experts in a special field. Tools-- whatever they need. They can be very resourceful.

Figure 4: P8's drawing and description of a STEM learning environment.

In Figure 4, the principal emphasises the context beyond the classroom. An open-ended, 'realistic problem'—the (negative) impact that human beings have on the environment—is provided, which could 'link to students' lives' and interests and require students to draw upon 'knowledge and skills from two or more disciplines'. The picture captures a context that could support 'multiple representations' but includes no specific representation. The response highlights students 'working collaboratively' to collect data, which will enable them to question current practices in relation to environmental issues and possibly 'collaborate with experts' in that field, though the nature of the collaboration with experts is not explicated.

As is evident in Figure 4, the principal provides indicators of 'open-ended student-centred instruction'. Perceived teaching and learning practices involve generating questions, learning new technologies, gaining information, collecting data, and analysing. Students use technology, and as the principal describes, they can be 'very resourceful'. The teacher's role is described as providing the environment and the challenges or issues that students explore. Also, reference is made to expanding students' thinking, encouraging a critical orientation to current practice, and their self-reliance in terms of sourcing data.

The responses provided by all participants depicted in Figures 1 to 4 indicate the depth of thinking of the participants about a STEM learning environment. In our experience, participants enjoy the D-STEM activity once they move beyond a worry about being able to draw; individuals often draw in pencil and spend a considerable amount of time rubbing out bits of their drawings that they want to finesse. Throughout the activity, they can be seen to be thinking very deeply as they complete both their drawing and text responses. The subsequent sharing of their D-STEM creation with others and evaluating their creations using the D-STEM Rubric is a very rich reflection experience for them. Participants are heard explaining their diagrams in more detail and justifying their inclusion of particular elements. Others, who may not have included some aspects (e.g., the role and use of multiple representations), are excited to see them in the drawings of others or in the Rubric. And, while the D-STEM artefact indicates the way each participant was thinking about STEM prior to completing the activity, the subsequent sharing activity and the level of discussions that are sparked, illustrate both a critique of their own thinking and an expansion of possibilities for STEM learning that they may not have thought of previously.

The conversation around D-STEM also elicits a 'what if' way of thinking: "What if all science teachers (or mathematics teachers) were to complete it?", "What if the whole primary school teaching staff had a go?", "What if I were to give it to all my students?'. D-STEM participants in leadership positions experience first-hand the powerful thinking that is initiated through completing the activity. They are able to picture the D-STEM instrument's usefulness in how knowledge of teachers' perceptions can inform the school environment, and how teachers might be supported to adapt effective STEM teaching practices. As the D-STEM instrument and its Rubric have been informed by instructional practices commonly used in both mathematics and science disciplines, they may also be useful for leaders of schools where integrated STEM teaching is not presently a school goal. Unearthing the perceptions of teachers who have particular expertise in one discipline area (e.g., science), and the ways in which they position their discipline within a STEM classroom, provides a map of the variety of understandings within the teaching community and therefore presents a useful starting point for planning STEM. Similarly, within a primary and early childhood educational context, the D-STEM activity will help highlight the extent to which content-related pedagogies (e.g., using realistic problems) might dominate the achievement of content understandings and point to particular professional learning that would be useful in enhancing practice.

At this stage, the D-STEM instrument has been designed for, and implemented with, principals and university teachers, and we are interested in developing and implementing the instrument with teachers and also tweaking it for students. The responses that students provide through their completion of the instrument could challenge our assumptions that, as teachers, we provide them with sufficiently rich and engaging learning experiences. Student responses could also unearth their views about teaching and learning of STEM, and even their perceptions about individual STEM subjects.

We recommend that you try it yourselves with your teachers and/or your students—you have our contact details, and we would be pleased if you could keep in touch with us as you do so. We would love to know how you found using the instrument and rubric as a tool for unearthing perceptions and stimulating discussion and ideas. Was the D-STEM Rubric useful in identifying the elements we have identified as important in STEM learning environments? Which elements of D-STEM were evident in your colleagues' or students' responses? What kinds of understandings did you gain about how STEM is implemented in classrooms in your school, particularly from your students' perspectives? The D-STEM research is still in its early days. Please participate in its evolution as a reliable and useful instrument for enhancing STEM teaching and learning practices in schools.

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Appendix A: Draw a STEM Learning Environment (D-STEM)

Think about the teachers of STEM and the kinds of things they do. Draw a STEM learning environment.

Front page

1. Look back at the drawing and explain it so that anyone looking at it could understand what your drawing means. For example, what does the teacher do? What do the students do? What tools do they use?
2. Please complete the sentences below. To me,

   STEM is:

   STEM involves:

   A teacher of STEM knows:

   A STEM capable person can:

   A person develops STEM capability by:

   The role of the STEM leader is:

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Appendix B: The D-STEM Rubric

Coding category	Definition	Level of inclusion
STEM Integration	• students work on tasks in the context of complex phenomena or situations that require them to use knowledge and skills from multiple STEM disciplines	*Drawing or text includes:* **2:** reference to a context that might require students to use knowledge and skills from multiple STEM disciplines. **1:** reference to a context that might require students to use knowledge and skills from multiple STEM disciplines, but the nature of the problems or tasks is not explicit. **0:** no reference of such contexts or situations.
Realistic problems	• problems are realistic • problems are grounded in the real world • the context is not a problem of a particular STEM discipline but a problem for the community • students use STEM disciplines but the problem itself is interdisciplinary	*Drawing or text includes:* **2:** reference to interdisciplinary problems grounded in the real world. **1:** reference to problems that could involve realistic situations, but the nature of the problems is not explicit. **0:** no reference of realistic problems.
Collaborative nature of STEM	• students work collaboratively • teamwork does happen • members have roles and responsibilities	*Drawing or text includes:* **2:** reference to collaboration and teamwork among students in which members have roles and responsibilities. **1:** reference to collaboration/ group work among students, but the type of collaboration is not explicit. **0:** no reference of collaboration.
Personal experience	• problems are meaningful, i.e. students can relate and engage with them • problems are realistic, i.e. students might make sense of them based on their own experiences • students might encounter the problems in their lives outside of school	*Drawing or text includes*: **2:** reference to a context that problems or tasks are linked to students' lives and tap into/elicit their interests. **1:** reference to a context that problems or tasks may be linked to students' lives and tap into/ elicit their interests, but the nature of the problems is not explicit. **0:** no reference of personal relevance.

Coding category	Definition	Level of inclusion
Multiple representations	• learning tasks or activities can lead to conceptual understanding of big ideas • concepts are presented in different modes of representations (e.g., spoken language, written symbols, diagrams, concrete models, metaphors) • learning tasks or activities are structured to require translations between these modes of representations	*Drawing or text includes:* **2:** reference to tasks or activities that could support multiple representations, and the translation between the representations are explicit. **1**: reference to tasks or activities that could support multiple representations, but translation between the representations are not explicit. **0:** no reference of multiple representations.
Community–industry engagement[1]	• linking STEM disciplines with industry, the community and/or families • such links can involve one-off industry talks or through in-depth exploration of contextualised issues or problems • Engagements: an engineer talks to students about their job during the immersion phase of a bridge-building unit. • Elaborations: Rip Curl provides materials for a materials technology programme where students do tests with neoprene to design a wetsuit. • Contexts: a unit on bees that explores the scientific, mathematical, economic, and social implications of bee parasitism. [1]*Note:* For more details see Hobbs et al. (2018)	*Drawing or text includes:* **2:** reference to linking content with industry, the community, or families in a variety of ways (engagement, elaborations, contexts). **1:** reference to linking content with industry, the community, or families, but the ways of linking are not explicit. **0:** no reference of community engagement.
The teaching and learning of STEM	*Teaching and learning practices* • experiential and open-ended methods such as science inquiry, engineering design, problem-based learning, and similar are implemented	*Drawing or text includes:* **1:** reference to such open-ended student-centred instruction. **0:** no reference of student-centred instruction.
	Tools • a range of learning technologies are used	*Drawing or text includes:* **1:** reference to using such teaching and learning technologies. **0:** no reference of using such learning technologies.
	Roles of the teacher • the teacher takes on roles other than knowledge giver (e.g., guide, collaborator)	*Drawing or text includes:* **1:** reference to the teacher roles other than giving knowledge. **0:** no reference of such teacher roles.
	Roles of the students • students take on roles other than listener or knowledge receiver (e.g., collaborator, planner, experimenter)	*Drawing or text includes:* **1:** reference to the student roles other than receiving knowledge. **0:** no reference of such student roles.