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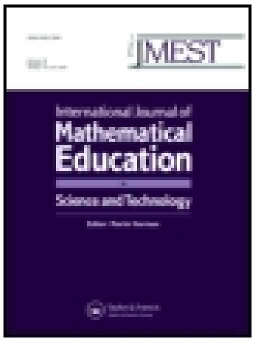

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Educational leaders' perceptions of STEM education revealed by their drawings and texts

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ABSTRACT

This study explored school principals' and teacher educators' perceptions of STEM education based on how they described STEM as a discipline, their understanding of the nature of teaching and learning of STEM, and the capabilities of a STEM-educated person. Data were generated through the Draw a STEM Learning Environment (D-STEM) instrument comprising drawn and written descriptions where participants drew a picture of a STEM learning environment and completed five prompt statements about what STEM is and how an individual develops personal STEM capability. The Legitimation Code Theory (LCT) specialization codes were used for data analysis (198 individual response items in total) to understand how the participants perceive STEM education. Almost half the participant responses indicated knowledge-code perceptions with a smaller but significant number (approximately a third of responses) indicating knower-code perceptions. The remaining responses showed élite-code perceptions, indicating a small proportion of participants valued the development of both disciplinary knowledge/practices and generic skills/attributes in STEM education. We posit that curriculum structure and reporting requirements influence these perceptions. Further research in relation to the influence of such understandings on enacted curriculum is warranted.

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KEYWORDS
Teacher educators; LCT; principals; STEM education; STEM perceptions

1. Introduction

STEM education is generally defined as teaching and learning practices that coordinate learning objectives of science (S), technology (T), engineering (E), and mathematics (M) subjects through open-ended, realistic, and interdisciplinary problem situations (e.g. Asghar et al., 2012). Research indicates this approach contributes to a positive impact on learning outcomes of students in both schools and universities (e.g. Becker & Park, 2011). However, the emphases and value educators place on learning in STEM, for example,

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priority given to learning disciplinary knowledge versus more generic practices and skills (i.e. so called '21st century capabilities') – is less known (e.g. Holmlund et al., 2018; Morrison, 2006). Popular misconceptions about interdisciplinary STEM education reported years ago, such as it 'dumbing down' the learning of science concepts, or simply equating it to 'hands-on' activities, remain current (Morrison, 2006). Some educators believe that teachers of STEM do not necessarily need to have a thorough understanding of the disciplinary knowledge but that they can be 'co-learners' with students, while some others consider STEM to be more about communication and teamwork (Hatisaru et al., 2020). Importantly, there are concerns about whether STEM discipline-specific content knowledge and practices have been 'diluted' in STEM teaching and professional learning activities (e.g. Winberg et al., 2017).

In this study, we investigate how STEM education is perceived by school principals and teacher educators, to gain a deeper understanding of the kinds of *epistemic relations* (STEM knowledge and practices) and *social relations* (generic skills and personal attributes) that are emphasized in STEM education. The study is guided by two research questions:

1. What are school principals and teacher educators' perceptions of STEM education as revealed by their STEM depictions and descriptions?
2. What are possible implications from these views for the design of STEM education curricula?

To answer the research questions, we frame our ideas within the context of Australia because of its familiarity to us. Nevertheless, we believe that readers from other countries will be able to see in this context example a set of global points on how research methods like the ones used in this study can be transferred into useful and usable triggers for STEM education work in their own contexts. We begin with significance of the study and then move to conceptual considerations underpinning the research before presenting its methods.

2. Significance of the study

The study makes several contributions to the current research literature in this field. First, drawing is independent of language-based methods and is non-textual, hence as a research method, it can provide researchers with an alternative and versatile way of knowing (Alerby, 2015). As a genre of visual research methods, drawing is 'a new and novel approach to qualitative research derived from traditional ethnography methods used in anthropology and sociology' (Glaw et al., 2017, p. 1). Researchers use drawing and/or multimodal data methods (i.e. blends of drawing, text and verbal responses) to explore participants' understandings of different phenomena. As elaborated by Glaw et al. (2017), those methods of data 'add to traditional methods [e.g. interviews, open-ended questionnaires] by capturing more detail and a more different kind of data than verbal and written methods' (p. 2). In our research we were interested in exploring how educationalists perceive STEM learning environments, to provide insights into how this might affect the emphasis and value they place on particular aspects of their STEM curriculum. We drew on our previous work (Hatisaru et al., 2020) and that of other researchers in mathematics and science education (e.g. Hatisaru, 2020; Thomas et al., 2001) to develop a multimodal research instrument: *Draw a STEM Learning Environment (D-STEM)* and have used the instrument to gather data responding to the research questions.

Second, we extend the findings on teachers' perceptions about STEM education (e.g. Margot & Kettler, 2019) to explore school principals and teacher educators' understandings, and we contribute to the debate about the priority being given to learning discipline content knowledge in interdisciplinary STEM curricula (see Winberg et al., 2017). By drawing on data from a sample of school principals and teacher educators, we present both groups' perspectives on the way STEM knowledge is viewed, understood, and spoken about in schools and universities. In interpreting data, we assume the participants' ways of describing STEM and STEM-related issues are related to the perceptions they hold regarding the underlying bases of knowledge and attributes in STEM. Our belief is that, as also suggested by Breiner et al. (2012), understanding individuals' perceptions can help initiate more integrative discussions about STEM education within educational institutions that might lead to a clearer understanding about how to address issues in STEM education to achieve desired learning outcomes in students.

Furthermore, understanding how school principals and teacher educators prioritize and value specific outcomes from STEM education and validate types of knowledge, skills and attributes as evidence of achievement, is important for improving STEM curriculum design, pedagogy, and assessment. It also provides useful information for evaluating the extent of alignment between enacted STEM curricula and broader visions and purposes for STEM education, as reflected in official documents such as school curricula and education authority and government policy statements.

Finally, and most significantly, by utilizing a social realist framework – namely *Legitimation Code Theory (LCT)* (Maton, 2014), we develop and present a conceptualization that can be used to critically analyse perceptions of education professionals – in this case, those involved in teaching or leading STEM education in schools and universities. The *LCT specialization codes* (below) provide a means of analysing data to reveal dominant emphasizes or what perceptions of STEM are most reflected in a particular response. The *codes* help us build deeper understanding of the priorities that participants placed on specific outcomes from their STEM curricula, and make the underlying reasons for this more apparent.

3. Conceptual considerations

3.1. Perceptions and beliefs

Perceptions is one of a range of terms often used without clear definition to encompass what individuals think, feel, or believe about a given construct. In STEM education and related fields, it has been used essentially to mean attitudes (e.g. Christensen et al., 2014) and synonymously with beliefs defined as any proposition that an individual regards as true (e.g. Beswick & Jones, 2011). When used to describe attitudes, perceptions can be said to be positive or negative whereas when used to reflect beliefs there is no inherent evaluative component. In this study, we were concerned with participants' underlying beliefs about STEM education, that is, what they perceived it to be, and how it might best be taught and learned. We were less interested in whether principals and teacher educators felt positively or negatively inclined towards STEM or some aspect of it, but rather in the content of their thinking, and we did not make any judgment about whether a particular belief was indicative of a positive or negative attitude. Nevertheless, we were aware that participants could express beliefs with attitudinal components, by saying, for example, 'STEM is the most important part of the school curriculum': a belief statement indicative of a positive attitude to STEM education. For this reason, the term 'perceptions' is used here to incorporate both beliefs and attitudes.

Research on educators' perceptions, (or beliefs or attitudes) is premised in the assumption that what an individual believes influences their practice (e.g. Beswick, 2005) and the extent to which they perceive something to be important, enjoyable, interesting, or useful (all dimensions of attitude) influences the likelihood that they will pursue a particular course of action (Ajzen & Fishbein, 1980). It is well established that school principals are positioned to enhance student outcomes by attending to the quality of teaching in their school (Robinson, 2007), and can influence teachers' motivation and capacity for innovation by adopting more transformational leadership styles (Pietsch & Tulowitzki, 2017). It is reasonable to argue that teacher educators can be similarly influential through their direct interactions with practicing and prospective teachers, and their contributions to educational debates concerning such things as curriculum design and content, and appropriate pedagogies.

3.2. A conceptual tool for exploring perceptions of STEM

Legitimation Code Theory (LCT) was selected as the conceptual referent for this study, as it supports analysis of knowledge practices in many academic disciplines. It has been applied to, for instance, online education (Maton & Chen, 2020), beliefs and pedagogy in teaching (Richardson, 2019), STEM education (Winberg et al., 2017), university students' perceptions of mathematics, natural science, psychology (Maton, 2007) and the practices and beliefs of teachers and students about technology use (Howard, 2009). One of the dimensions of LCT is *specialization* – that is, what makes someone or something distinct, special, or different (Carvalho et al., 2009). The premise of *specialization* is that all knowledge, beliefs, or practice claims are about or oriented towards something, and are practiced by someone, and it sets up *epistemic relations* to an object (e.g. STEM disciplinary knowledge) and *social relations* to a subject (e.g. attitudes towards STEM). These relations consider what can be objectively described as knowledge and who can claim to be an ideal knower (e.g. a student or teacher). The relative strength (+/−) of these relations gives rise to four principal codes which can be positioned at different locations within four key modalities on a *specialization plane* (Maton, 2014) (see Figure 1). There are:

a knowledge code (ER+, SR-), where possession of specialised knowledge, skills or procedures are emphasised as the basis of achievement, and the dispositions of authors or actors are deemphasised;

a knower code (ER-, SR+), where specialist knowledge or skills are less significant and instead the dispositions of the subject as a knower are emphasised as the measure of achievement;

an élite code (ER+, SR+), where legitimacy is based on both possessing specialist knowledge and being the right kind of knower. ('Elite' does not necessarily mean 'socially exclusive' but rather highlights the necessity of possessing both legitimate knowledge and legitimate dispositions.); and,

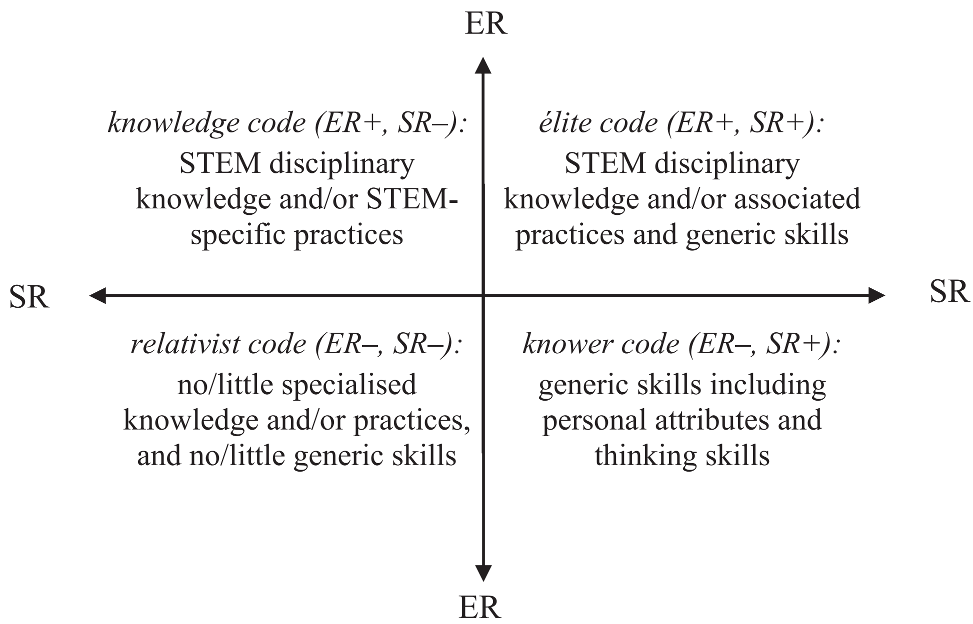

Figure 1. The conceptual tool used in this study.

> *a relativist code (ER-, SR-)*, where legitimate insight is ostensibly determined by neither specialist knowledge nor specific dispositions (Carvalho et al., 2009, pp. 487–488).

In STEM education, the knowledge code incorporates discipline content knowledge (i.e. science, technology, engineering, mathematics) and also extends to the discipline-specific practices that are associated with them, such as scientific inquiry, investigations, analysing and interpreting data, and designing solutions (Ellery, 2019). However, as Maton (2007) indicates, 'for every educational knowledge structure there is also an educational knower structure' (p. 96). This means, in addition to STEM knowledge and practices, specialization in the relevant generic skills must be considered. This is because there are many contexts within which disciplinary knowledge and practices are needed, and many others within which generic skills or both knowledge and related practices and skills are needed.

Broadly defined, generic skills are the skills that apply across a variety of employment or professional and life contexts (Australian National Centre for Vocational Education Research [NCVER], 2003). They are sometimes referred to as '21st century skills', capabilities, key competencies, soft skills, or employability skills. NCVER (2003) lists six common elements of generic skills, based on a comprehensive review:

> Basic/fundamental skills—such as literacy, using numbers, using technology.
>
> People-related skills—such as communication, interpersonal, teamwork, customer-service skills.
>
> Conceptual/thinking skills—such as collecting and organising information, problem-solving, planning and organising, learning-to-learn skills, thinking innovatively and creatively, systems thinking.

> Personal skills and attributes—such as being responsible, resourceful, flexible, able to manage own time, having self-esteem.
>
> Skills related to the business world—such as innovation skills, enterprise skills.
>
> Skills related to the community—such as civic or citizenship knowledge and skills (p. 8).

According to the NCVER (2003), every sector of education should play a role in fostering the development of generic skills amongst their students. These skills are developed in multiple settings throughout a student's personal life and in employment and educational contexts.

In the use of the LCT *codes*, a conceptual tool is necessary to operationalize the analysis of the data (Maton, 2014). Building on Carvalho et al.'s (2009) model, the authors developed a conceptual tool to code the data in this study (Figure 1). In Figure 1, *epistemic relations* in participants' responses describe stronger or weaker relations to STEM disciplinary knowledge or practices. These exist along a continuum, from responses strongly emphasizing STEM knowledge and/or practices, to little or no emphasis. *Social relations* in the responses reveal stronger or weaker relations to generic skills, ranging along a continuum from skills that are independent of any discipline (e.g. communication, teamwork, thinking innovatively and creatively, being flexible, self-efficacy) to an emphasis on STEM discipline specific knowledge and/or practices, or neither. The *knowledge quadrant* (ER+, SR–) has stronger *epistemic relations* to STEM knowledge and/or practices and has weaker *social relations* to generic skills, whereas the *knower quadrant* (ER–, SR+) has weaker *epistemic relations* to STEM knowledge and/or practices but stronger relations to generic skills. The *élite quadrant* (ER+, SR+) has stronger relations to both STEM knowledge and/or practices, and generic skills. Descriptions in the *relativist quadrant* would have no/little focus on STEM knowledge and practices, and no/little focus on generic skills.

4. Methods

4.1. Study context

The present study builds on previous research undertaken by some of the authors (Hatisaru et al., 2019; Hatisaru et al., 2020). The D-STEM instrument (Hatisaru & Fraser, 2021) used in this research was developed from literature (e.g. Glancy & Moore, 2013; Thomas et al., 2001) and implemented as part of an Australian national research project: *Principals as STEM Leaders – Building the Evidence Base for Improved STEM Learning (PASL)* which aimed to enhance principals' leadership of STEM education through engagement with professional learning modules designed and delivered by teacher educators (the research team) with expertise in STEM education. A two-day face-to-face workshop was held for the research team (teacher educators) and invited school principals at the start of the project. A flyer about the PASL event was distributed to education systems and through principals' professional associations, and principals were invited to submit an *Expression of Interest* through the PASL website. All principals who applied and were available to attend on the designated days, were invited to participate. Principals attended from ten primary and eleven secondary government schools across Australia (New South Wales, Queensland, Western Australia, Tasmania and both the Northern and Australian Capital Territory), drawing largely from more rural locations (60%). Twelve teacher educators from seven

Table 1. D-STEM instrument items mapped to STEM education aspects.

Aspect of STEM education	D-STEM item
STEM as a discipline	STEM is …
	STEM involves …
Teaching and learning of STEM	STEM learning environment drawing and text
	A teacher of STEM knows …
Capabilities of STEM-educated persons	A STEM capable person can …
	A person develops STEM capability by …

different universities across the country, active in teaching or leading STEM education in their institutions, were invited to complete the D-STEM instrument as an opportunity to initiate discussions on STEM education.

4.2. The D-STEM (Draw a STEM learning environment) instrument

The D-STEM instrument (Hatisaru & Fraser, 2021) comprised visual and written components where participants were asked to draw a picture of a STEM learning environment and provide a brief explanation of their drawing. They were prompted with these cues:

1. Think about the teachers of STEM and kinds of things they do. Draw a STEM learning environment.
2. Look back at the drawing and explain your drawing 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?

Participants were also presented with five prompt statements that aimed to determine the way they perceive STEM education in terms of what constitutes STEM as a discipline, teaching and learning of STEM, and capabilities of STEM-educated individuals (see Table 1):

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 …

In this paper, we analyse and report on responses to the D-STEM instrument provided by the sampled principals and teacher educators. We examine participants' responses by applying *LCT specialization codes* as an analytical framework, building on our earlier work in this area (Hatisaru, 2021; Hatisaru et al., 2022).

4.3. Data analysis

The analysis was intended to capture the general gist of the views in the participants' D-STEM responses. In the LCT framework, this approach is defined as *soft focus* (Maton, 2014). Coding comprised content analysis (Stemler, 2000) of statements the participants made responding to the five prompts above, and the depictions and descriptions in their STEM drawings. Analysis followed conventional deductive procedures that identified patterns within participants' accounts that provided insights into the way they understood and perceived STEM as a discipline, the teaching and learning of STEM, and the capabilities of STEM-educated individuals (see Table 1). The conceptual tool detailed in Figure 1 was used to align the *LCT specialization codes* with participants' responses. To ensure anonymity participants were assigned abbreviations, for example, principals are PR1, PR2, PR3, etc. and teacher educators are TE1, TE2, TE3, etc. Data were manually analysed by three of the authors using a combination of the NVivo 12 qualitative data analysis application and Excel spreadsheets. To ensure consistency in data coding and the trustworthiness of the analysis (O'Connor & Joffe, 2020), they coded the data independently and met to compare their coding and discuss differences. Initial coding by two authors (Hatisaru and Powling) was followed by independent analysis of data by a third author (Seen) who also extended data analysis of the *knowledge* coding to differentiate Knowledge, Theory, Concepts (KTC) and Skills and Practices (SP) (see below). Re-coding of data was then undertaken by Powling, taking into account the extended coding to include KTC and SP labels, followed by a final confirmation of coding by Hatisaru. Frequencies and percentages of each *code* were computed once data coding was completed. A summary of these results is presented in Tables 2 and 3, and examples of *specialization code* alignment with responses are included below.

Participants' responses to the five prompts were analysed against the *specialization codes*. However, noting that many discipline-specific practices are also generically applicable (e.g. defining problems, identifying and acquiring relevant information and knowledge from a range of sources, designing solutions), the context of a participant's response(s) (including their disciplinary focus, if present) was considered in differentiating skills and practices as generic or discipline-specific. Where a particular response foregrounded STEM discipline or discipline-specific practices such as scientific inquiry or designing solutions and there was no emphasis on generic skills, this aspect was interpreted as displaying a predominantly *knowledge code*. For example (italics added for emphasis):

> [STEM is ...] Interdisciplinary – *the knowledge bases of science, technology, engineering, and mathematics*, to solve 'real world' problems and meet needs or opportunities *through project-based learning approaches*. (TE9)

> [STEM involves ...] Solving problems, people working together to find solutions often using digital technology. *Hardening subject knowledge* technology. Creating Solutions. *Inquiry based approach*. (PR2)

> [A STEM capable person can ...] *Use scientific knowledge and processes*. (PR5)

> [A person develops STEM capability by ...] Continually questioning, *improving their skills and knowledge*. (PR8)

In contrast, where a response *only* demonstrated aspects relating to general employment or life skills, personal attributes, or thinking skills of knowers, it was interpreted as greater emphasis on generic skills and was aligned with the *knower code* category. For example:

> [A STEM capable person ...] Is *curious* about their world, *keen to collaborate with others* and had strategies they can use to help them when they are stuck! *Growth mindset*. (PR3)

Table 2. Participants' responses grounded on the specialization codes.

		Knowledge code (ER+, SR–)			Élite code (ER+, SR+)			Knower code (ER–, SR+)		
	D-STEM item	Principals ($f = 125$)	Academics ($f = 71$)	Total ($f = 196$)	Principals ($f = 125$)	Academics ($f = 71$)	Total ($f = 196$)	Principals ($f = 125$)	Academics ($f = 71$)	Total ($f = 196$)
STEM as a discipline	STEM is …	18	11	29	1	1	2	2	–	2
	STEM involves …	9	7	16	5	-	5	7	4	11
	Total	*27 (64.3%)*	*18 (78.3%)*	*45 (69.2%)*	*6 (14.3%)*	*1 (4.3%)*	*7 (10.8%)*	*9 (21.4%)*	*4 (17.4%)*	*13 (20%)*
Teaching and learning of STEM	Drawing and text	8	6	14	9	5	14	4	1	5
	A teacher of STEM knows …	6	4	10	4	3	7	11	5	16
	Total	*14 (33.3%)*	*10 (41.7%)*	*24 (36.4%)*	*13 (31%)*	*8 (33.3%)*	*21 (31.8%)*	*15 (35.7%)*	*6 (25%)*	*21 (31.8%)*
Capabilities of STEM-educated persons	A STEM capable person can …	5	6	11	5	1	6	11	5	16
	A person develops STEM capability by …	9	6	15	5	1	6	6	5	11
	Total	*14 (34.1%)*	*12 (50%)*	*26 (40%)*	*10 (24.4%)*	*2 (8.3%)*	*12 (18.5%)*	*17 (41.5%)*	*10 (41.7%)*	*27 (41.5%)*
	TOTAL	*55 (44%)*	*40 (56.3%)*	*95 (48.5%)*	*29 (23.2%)*	*11 (15.5%)*	*40 (20.4%)*	*41 (32.8%)*	*20 (28.2%)*	*61 (31.1%)*

Note: *f* represents frequency.

Table 3. Stronger epistemic relations (ER+) assignments differentiated as subject knowledge or subject-related skills [KTC (+/–), SP (+/–)].

		(KTC+, SP–)			(KTC+, SP+)			(KTC–, SP+)		
		Principals (f = 85)	Academics (f = 51)	Total (f = 136)	Principals (f = 85)	Academics (f = 51)	Total (f = 136)	Principals (f = 85)	Academics (f = 51)	Total (f = 136)
STEM as a discipline	STEM is …	13	5	18	5	7	12	1	–	1
	STEM involves …	1	1	2	9	6	15	5	–	5
	Total	*14 (41.2%)*	*6 (31.6%)*	*20 (37.7%)*	*14 (41.2%)*	*13 (68.4%)*	*27 (50.9%)*	*6 (17.6%)*	–	*6 (11.3%)*
Teaching and learning of STEM	Drawing and text	–	–	–	6	5	11	11	6	17
	A teacher of STEM knows …	1	1	2	8	6	14	1	–	1
	Total	*1 (3.7%)*	*1 (5.6%)*	*2 (4.4%)*	*14 (51.9%)*	*11 (61.1%)*	*25 (55.6%)*	*12 (44.4%)*	*6 (33.3%)*	*18 (40%)*
Capabilities of STEM-educated persons	A STEM capable person can …	–	–	–	3	5	8	7	2	9
	A person develops STEM capability by …	1	1	2	8	4	12	5	2	7
	Total	*1 (4.2%)*	*1 (7.1%)*	*2 (5.3%)*	*11 (45.8%)*	*9 (64.3%)*	*20 (52.6%)*	*12 (50%)*	*4 (28.6%)*	*16 (42.1%)*
	TOTAL	*16 (18.8%)*	*8 (15.7%)*	*24 (17.6%)*	*39 (45.9%)*	*33 (64.7%)*	*72 (52.9%)*	*30 (35.3%)*	*10 (19.6%)*	*40 (29.4%)*

Note: *f* represents frequency.

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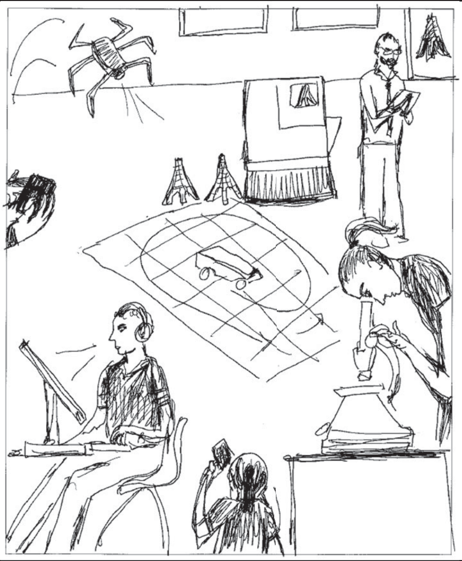
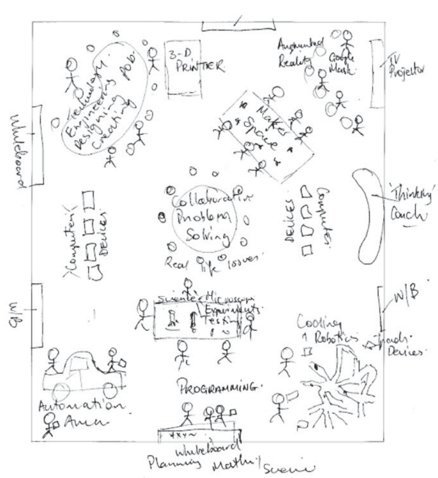
<td></td>
<td>
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<td>The teacher demonstrates how to do a 3D print of the Eiffel Tower. One student uses a drone to film this and project on a screen. Students are working independently/remotely or different resources of STEM - research, communication, investigation. A girl has programmed a new robot. In another scenario they are all working separately on aspects of one topic/project (e.g., sustainability) to add the body of knowledge & learning. (PR5)</td>
<td>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 condition for collaboration. Scaffold student thinking to be creative problem solver. Tools: Range of tools/devices to do the above. (PR1)</td>
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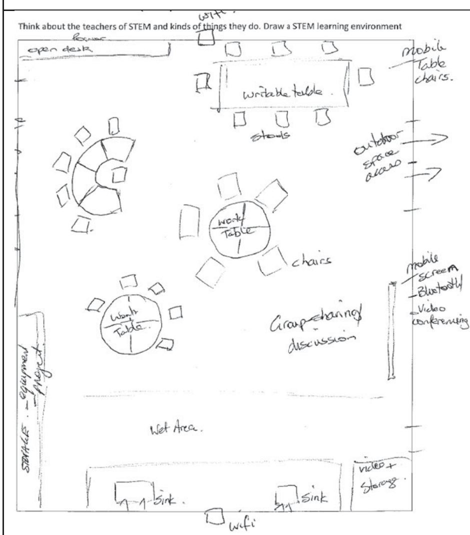
<td>
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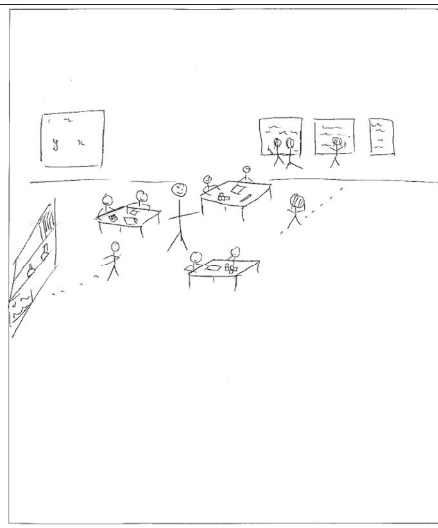
<td></td>
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<td>The focus is on mobile & adjustable furniture. The teacher & students are flexible to work across the different settings depending on the learning activity.

Storage space – projects/experiments + resources for innovations projects.

Tools – Wi-Fi & Bluetooth enabled devices, opportunity for video conferencing & online collaboration.
- Display and sharing area
- All stages of the learning process (TE11)</td>
<td>The students are working on a challenging mathematics problem. They have a range of tools available to use as they see fit- e.g., computer with internet, calculators, blocks, rulers... They are working in groups or alone, at tables and on vertical surfaces to share them working. They are free to move around the room. Teacher has introduced the problem as briefly as possible. The problem could be contextualised, perhaps modelling some science phenomenon. Students discuss, argue, critique own and others thinking. Teacher orchestrated rich discussion. (TE13)</td>
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Figure 2. Examples of responses by participants representing the *knowledge* (PR5), *élite* (PR1, TE13), and *knower* (TE11) *code* drawings.

> [STEM involves . . .] Teachers and students working in various curriculum areas *to develop creative minds . . . problem solvers* as opposed to consumers of knowledge *via all those so called 21st century skills*: collaboration, reflection, curiosity, questioning, resilience . . . (PR3)

> [A teacher of STEM knows . . .] How to bring students together, *spark interest*, *aspire students* to contribute to their world. (PR8)

> [Person develops STEM capability by . . .] Engaging in active learning, exploring alternative perspectives, *critique and reflection*. (TE10)

> [Person develops STEM capability by . . .] *Being valued* as part of a team, *taking responsibility* as a team or community to transform the conditions of their life. (TE4)

Where the focus was both on STEM discipline or discipline-related practices and the generic skills or attributes of the knowers, data was interpreted as aligning with the *élite code* category. For example:

> [STEM is . . .] An interdisciplinary approach to teaching and learning that *not only develops discipline specific skills and knowledge but also transliterate skills such as collaboration, communication, problem-solving* etc. (TE14)

> [A teacher of STEM knows . . .] How to lead and inspire young minds to have a thirst *for knowledge* and develop *skills to create new knowledge and technology*. (PR9)

> [A STEM capable person . . .] Can problem solve, *using knowledge and skills from these [STEM] disciplines*. They draw on the expertise of others and *utilize collaborations, critical thinking, innovation and problem-solving skills*. (TE11)

The same *specialization codes* were used to analyse participants' STEM drawings and associated descriptions. Consistent with Maton and Chen's (2020) application of the LCT framework, where a STEM drawing or description included more indicators of specialist knowledge or practices, and less or no indication of personal beliefs, personal dimensions of learning, collaborative learning or of personal skills, data were considered to align with the *knowledge code* category. Where specialized knowledge or associated practices were less apparent and generic skills of knowers were emphasized instead – or *only* generic aspects of teaching were depicted (e.g. classroom setting, resources used – see TE11's drawing in Figure 2), data were considered to align more with the *knower code* category. Where the drawing or associated description clearly included both, it was considered to align with the *élite code* category. In Figure 2, examples of responses are presented representing all three *code* categories. In their drawings while PR5 includes a relatively considerable amount of knowledge and knowledge practices such as research, investigation and programming, TE11 only depicts some physical aspects of a STEM learning environment. Implicit in TE11's descriptions are some generic pedagogical issues that might be applicable to the teaching of most subjects such as flexibility in learning arrangements and opportunities for online collaboration. PR1 and TE13 both include knowledge and knowledge practices (e.g. solving a mathematics problem, modelling a science phenomenon, computational thinking) and general skills and social aspects of learning (e.g. collaboration, working in groups, critiquing own or others' thinking).

In STEM education, the *knowledge code* incorporates the content knowledge of the STEM disciplines, but it also extends to associated practices or skills such as scientific inquiry or designing solutions (Ellery, 2019). Maton and Howard (2015) note that 'the (specialisation) model distinguishes epistemic relations into ontic relations that specialize the known, and discursive relations that specialize the discursive practices whereby it is known' (p. 64), but that these two relations are collapsed into a single knowledge and practices or skills scale within the LCT framework. They later propose 'to create two scales that addressed knowledge and skills separately' (p. 64), and after further consideration, expand the knowledge label to include (content) Knowledge, Theory, Concepts (KTC) and the practices or skills label to include Skills and Practices (SP) to improve understanding of these categories.

With this in mind, we undertook a more thorough analysis of the stronger *epistemic relations* assignments – i.e. (ER+, SR–) and (ER+, SR+) to provide more detailed information about participants' perceptions of STEM education. To do this, we interpreted and coded the presence of KTC as the disciplinary content knowledge or theory underpinning the relevant discipline(s). Similarly, we interpreted and coded SP as part of the training within each STEM discipline, such as those used in scientific inquiry. Assignment of each of the relevant measures as KTC+/– and SP+/– acknowledged the context of the response and the participant's disciplinary focus (or otherwise), as illustrated in these examples:

(KCT+, SP+):

[STEM involves ...] *Solving problems*, incorporating *knowledge and skills from* science, technology, engineering and mathematics. (PR4)

[A teacher of STEM knows ...] How to connect these subjects in an integrated learning unit, *focusing on the skills, knowledge, and understandings*. (TE11)

(KTC+, SP–):

[STEM is ...] *Science, technology, engineering and mathematics* (PR8)

[STEM involves ...] *The disciplines*: Science, Technology, Engineering and Mathematics. (TE2)

(KTC–, SP+):

[A person develops STEM capability by ...] Researching and developing *scientific enquiry* techniques (PR5)

[A STEM capable person can ...] *Work* relationally, *formulate* mathematics, *use* evidence in decision making, *modify* practice/create solutions. (TE4)

5. Results: school principals and teacher educators' *epistemic* and *social relations* to STEM education

Twenty-one principals and twelve teacher educators responded to the six measures (five prompts and the drawing and associated description), totalling 198 individual response items. We coded each of the items according to where we considered they best aligned with one of the *quadrants* on the *specialization plane*. These decisions considered whether responses emphasized *epistemic relations* (e.g. subject knowledge, discipline interrelationships, scientific method, and inquiry-based science) or *social relations* (e.g. collaboration, teamwork, communication, cognitive skills, and personal attributes), or combinations of both. A summary of the results is presented in Table 2.

5.1. *Knowledge-code relations to STEM education*

Responses coded in the *knowledge quadrant* emphasize STEM disciplinary knowledge or practices. Approximately 48.5% of responses about priorities in STEM education emphasized *epistemic relations* without a social dimension. Data coded as emphasizing knowledge building became more prominent when participants described STEM as a discipline (69.2%), with teacher educators emphasizing the knowledge aspects (56.3%) more frequently than principals (44%). STEM was, first and foremost, understood to be about different domains of knowledge and the relationships between them. Responses indicated one of the defining characteristics of interdisciplinary STEM was the permission it granted, and the encouragement it gave, for building connections between the individual disciplines (37 occurrences). The relationships between science, technology, engineering, and mathematics were viewed by participants as being more constructive and beneficial than when they were taught in isolation. For example, TE12 stated:

> [STEM is…] An approach to finding solutions to real world problems. It can be interdisciplinary and/or transdisciplinary and draw from the strengths of its component disciplines.

Participants considered the benefits of interdisciplinary STEM came from being able to grapple with real-world problems or projects (e.g. sustainability, future-focus) which they commented could not be addressed effectively from within any one discipline (41 occurrences). Furthermore, STEM-related practices were highly valued. Practices such as research, systematic inquiry, problem – and project-based learning, engaging scientific methods and gathering and interpreting data, were frequently mentioned (167 occurrences).

Physical manifestations relating to STEM education were also indicated in participants' drawings and descriptions. They considered teaching and learning in STEM requires flexible learning spaces that could be configured to suit different requirements of projects (22 occurrences). These spaces might be indoors, outdoors, or a mix of both, and include facilities such as laboratories, technology hubs, and maker or breaker spaces. Responses indicated the need for flexibility in these rooms that ideally should have moveable partitions to create open learning spaces or break out areas, and storage and durable surfaces for experimentation or making. In describing their drawing, PR11 wrote:

> The STEM space overleaf is a large and flexible space. There are some dedicated zones (e.g. science lab), however most areas are configurable. There is a large space for group learning, and areas for small group and individual work. There is ample storage throughout to ensure materials are accessible and organised. There are spaces for dry activities (robotics, printing, etc.), and areas where paint, dirt and liquids can be used. These areas spill outdoors. A testing zone has a platform, racing track and other equipment as necessary. There are multiple charging and wireless access points to ensure seamless access to technology. Students design projects and tasks with the environment in mind and the teacher is the learning activator.

Responses also indicated that teaching and learning in STEM was strongly associated with the use of contemporary digital technology. Drawings included tools such as computers, robots, 3D printers, and programmable drones (45 occurrences). More traditional ICT was also evident, such as smart boards, printers, calculators, blocks, and rulers. Most prominent of non-digital tools were those associated with science and engineering (conventional microscopes, telescopes, etc.) and basic materials for experimentation and prototyping (e.g. see PR5 and TE13 in Figure 2).

5.2. Élite-code relations to STEM education

Coded responses in the *élite quadrant* displayed both STEM disciplinary knowledge or practices and generic skills or pedagogies. Data coded in the *élite quadrant* (20.4% of responses) were more prevalent in responses requiring participants to illustrate and describe the teaching and learning of STEM. More responses from principals (23.2%) than teacher educators (15.5%) were coded in the *élite quadrant* (see Table 2). Data in this category were associated with discipline knowledge learning or integration (*knowledge code*), while *knower* coded data were most frequently associated with generic or twenty-first century or transferable skills. In this respect, many D-STEM visual and text responses reflected the relationships existing between *epistemic* and *social relations*. Several of these illustrated and described collaborative work involving individuals and groups of students using inquiry methods to design, create and problem solve solutions to authentic needs and opportunities. For example:

> Teacher provides learning environment where students (learners) can challenge thinking, own and others. Teacher can provide explicit teaching of concepts, knowledge, or direct students to where they might access this- provides checks, accountability for authentic, owned learning. Students- identify problem to create solution/understanding individually/collaboratively, real world, future focus. Learning based building on own and generally accepted prior knowledge. (PR10)

> The teacher and students are collaborating on an inquiry. Input is valued. The environment is a safe place for students to put forward ideas. The teacher helps the students to identify resources needed to move forward with the collaboration project. Each member feels that their knowledge is valued and that they are learning. Together they are identifying possibilities and constraints – a plan of action. (TE4)

Such responses emphasized the importance of 'authentic' STEM learning, where disciplinary knowledge and/or practices are combined with generic skills, particularly; working and communicating with others, defining problems, completing research engaging a range of different information sources, and designing solutions. These generic skills, working in combination with disciplinary knowledge, reflect data coded in the *élite* categorization.

Data coded that emphasized a *social relation* generally related to pedagogy and relationships that supported learning (e.g. teacher-student relationships). Responses particularly emphasized the teacher's role in being able to lead, inspire, challenge, and motivate students. Students' social dimensions included personal qualities such as agency, confidence, curiosity, and passion. Additionally, responses indicated an important attribute of STEM education was a tolerance and acceptance of mistakes – and more importantly, learning from them. The teacher's role in the social dimension emphasized the facilitation of engaging learning experiences and establishing productive and supportive relationships. As PR12 commented, (a teacher) 'facilitates learning using a design thinking process… engages and inspires students to inquire', while PR10 noted that a 'teacher provides a learning environment where students can challenge thinking… their own, and others'. The importance of STEM learning environments supportive of risk taking is also reflected by PR7, who commented that (an effective STEM learning environment) 'allows risk-taking and acknowledges failure as a component of teaching'.

5.3. Knower-code relations to STEM education

Data coded in the third *quadrant* represents an emphasis less on disciplinary knowledge or practices and more on students acquiring and developing generic skills. Approximately 31% of responses were aligned with the *knower* category, and these data were more frequently associated with participants' descriptions of the capabilities of STEM-educated persons (41.5%). Interestingly, data from teacher educators emphasized *knower* priorities marginally less than the principals (28.2% vs 32.8%). In this *quadrant*, data emphasized the role of STEM in developing '21st century skills' (41 occurrences) including creativity, imagination, innovation (40 occurrences); collaboration and teamwork (57 occurrences); cognitive or thinking skills such as critical thinking, problem-solving, and reasoning (18 occurrences); communication (13 occurrences), along with personal attributes such as curiosity, resilience, self-motivation, and risk-taking (19 occurrences). These responses emphasized the work processes associated with interdisciplinary STEM projects and took into consideration group dynamics and important qualities needed by individuals and the team. Much data suggested the processes involved in interdisciplinary STEM work were highly compatible with equipping students for employment in a variety of sectors, within and beyond STEM careers.

Although some data suggested teachers did not need to be a disciplinary expert to teach STEM effectively (e.g. TE14, PR15, PR16), it was generally accepted that teachers needed sound foundational knowledge in one or more STEM disciplines, and an understanding of the interrelationships between disciplines. However, responses indicated that fundamental to this was a requirement that teachers understood the practices and skills by which new knowledge is developed. In the case of STEM, these include the 'methods of science', e.g. what is known and not known, designing investigations, and generating and analysing data to build new understandings. These were seen as foundational skills students needed to support any STEM inquiries.

5.4. Further elaborations of the strong epistemic relations categories

In STEM, knowledge not only incorporates content knowledge of the STEM disciplines but also extends to the practices associated with implementing this knowledge in activities within the disciplines (Ellery, 2019). We therefore undertook further analysis of the strong *epistemic relations* categorisations (ER+, SR– and ER+, SR+) to investigate these relationships in greater depth through using the KTC (knowledge, theory, and concepts) and SP (skills and practices) *codes*.

Table 3 indicates responses coded as (KTC+, SP+) were rated higher (52.9%) than those in the (KTC–, SP+) (29.4%) or (KTC+, SP–) (17.6%) categorisations. The greater emphasis in responses on (KTC+, SP+) was consistent across the three measures (i.e. STEM as a discipline, teaching and learning of STEM, and capabilities of STEM-educated persons – 50.9%, 55.6% and 52.6%, respectively). Of note is that teacher educators placed greater emphasis on combined knowledge and skills (KTC+, SP+) than did principals (64.7% vs 45.9%). Data coded as (KTC+, SP–) was chiefly present in responses describing STEM as a discipline (37.7%), whilst (KTC–, SP+) rated lowest for this measure (11.3%) compared with the other two measures – 40.0% and 42.1%, respectively. While a minority of participants considered that 'STEM is … ' and 'STEM involves … ' knowledge only (37.7%), the majority considered both knowledge and practices were most relevant to teaching and learning of STEM (55.6%) and the capabilities of individuals educated in STEM (52.6%). These results indicate participants viewed the practices and skills developed through interdisciplinary STEM education beneficial and applicable to a range of general tasks and employment opportunities. For example (STEM is):

> … a way of solving real world problems using *subject discipline and problem-based inquiry approach*. To prepare young people for the skills they need in the future. (PR2)

> … the art of *integrating the subject areas*: Science, Mathematics and Technology *with the 21st century skills* (general capabilities). And applies these to real life- open-ended experiences. It's a pedagogical approach. (PR21)

> … an interdisciplinary practice of *collaborative inquiry drawing upon disciplinary knowledge* and creating new knowledge for a particular context or problem. (TE4)

6. Discussion

The results of this study suggest both principals and teacher educators held strong views about the primacy and priority that should be given to discipline knowledge mastery (ER+, SR–: 48.5%) in any approach to STEM education, whether this be subject-based or interdisciplinary. In many respects this is unsurprising, given other studies related to this project (e.g. Falloon et al., 2022) and internationally (e.g. Honey et al., 2014), determined the powerful influence of subject-based, 'high stakes' assessment and reporting principally focused on content mastery, on the design of schools' STEM curricula. This perception was even more strongly held by the teacher educators, and again is likely related to the staffing, structuring and assessment of STEM teacher education programmes, and the content heavy nature of school curricula and syllabi with which graduating students are expected to be familiar. Interestingly, both groups of participants viewed learning in STEM to be more effective and beneficial when relationships could be identified between the disciplines, and combined knowledges operationalized through interdisciplinary projects based on addressing authentic needs or opportunities. While adopting such approaches does not imply diminished emphasis on discipline knowledge construction, research suggests coordinating, teaching and assessing this in interdisciplinary project-based STEM curricula is more complex, given the requirement to report student achievement against separate discipline learning outcomes (e.g. Honey et al., 2014).

Much literature discussing the benefits of interdisciplinary STEM curricula point to advantages of learning of STEM through interdisciplinary STEM tasks for developing generic learning skills and personal dispositions, such as communication, teamwork, critical thinking, creative problem solving and resilience and self-efficacy (e.g. Holmlund et al., 2018; Marginson et al., 2013). Participants emphasizing these as important outcomes from STEM curricula (SR+, ER–: 31%) generally associated them with the attributes of 'STEM-educated' individuals, particularly recognizing that interdisciplinary approaches provide students with valuable opportunities to learn and practice these through collaborative projects. This perspective was reasonably consistent across both groups, suggesting solid knowledge of broader outcomes from STEM education, beyond academic knowledge alone. Of note, however, when this result is evaluated relative to data coded as KTC+, SP + (emphasis on combining knowledge *and* skills/practices), a substantial difference exists between principals (45.9%) and teacher educators' (64.7%) prioritization. While both groups displayed strong commitment to discipline knowledge construction as a priority outcome of STEM education, this result suggests principals may have been less concerned than teacher educators about the skills and practices underpinning that process. Again, this conclusion is consistent with other research that revealed the strong influence of mandatory curriculum and assessment and reporting requirements on what is prioritized in school STEM programmes (e.g. Honey et al., 2014).

Current general discourse and much research argue broad benefits from interdisciplinary STEM education (e.g. Kelley & Knowles, 2016; Vasquez, 2014/2015). However, English (2016) suggests that one of the challenges associated with interdisciplinary approaches is to ensure that 'learning across the disciplines be evenly distributed so that student achievement in one area does not overshadow or reduce gains in others' (p. 3). Furthermore, she identifies the 'need to focus on both core content knowledge and processes … [and] nurture generic skills, in depth conceptual understandings, and their interdisciplinary connections' (p. 3). As results from the current study indicate, while some participants understood the importance of both *epistemic* and *social* relations (ER+, SR+: 20.4%) in STEM education to varying degrees, as English points out, effective 'balances' between these are yet to be defined, and likely will vary considerably between schools and teachers. For example, increased emphasis on knowledge outcomes could be defensibly inferred at secondary school or even university level, where the measure of learning success generally prioritizes mastery of specific content and concepts through examination or other summative assessment. In primary schools, however, curriculum and assessment usually focus less on content mastery and more on generic skill development, with learning progress often being assessed more formatively using a wider array of methods. It is likely that data in this study reflected these different emphases at different school levels.

7. Concluding words

We identified a diversity of perceptions amongst participants. Across the six measures, almost half the participant responses indicated *knowledge-code perceptions* with a smaller but significant number (approximately a third of responses) indicating *knower-code perceptions*. The remaining responses showed *élite-code perceptions*, indicating a small proportion of participants valued the development of *both* disciplinary knowledge/practices and generic skills/attributes in STEM education. Teacher educators' perceptions dominated the *knowledge-code*, while principals' perceptions were more highly represented in the other two *codes*. The further elaboration of the knowledge dimension highlighted that principals placed less emphasis on combined knowledge and process skills than did teacher educators. Further research in regards how these perceptions contribute to the ways in which participants educate and/or lead the education of STEM in their contexts is warranted.

We have gained better insights into the priorities that participants place on different aspects of STEM curricula and pedagogy. The preponderance of *knowledge-code perceptions* may mirror the importance placed upon discipline knowledge mastery because of the content-heavy nature of school curricula, and the influence of mandatory school and university assessment and reporting requirement. Both principals and teacher educators, however, indicated that STEM learning is most effective when learners experience the relationships between disciplines through their engagement with interdisciplinary projects.

One of the challenges in such an approach is to ensure that opportunities for authentic learning in each of the component disciplines, inclusive of knowledge and processes, conceptual understandings and generic skills, are provided. While data from a small number of participants aligned them with the *élite-code* classification, further research is needed to determine whether this is reflected in enacted STEM curricula. While we can assume that such curricula represent effective balances of *epistemic* and *social* goals, we yet have an understanding of what this might look in different contexts.

Using LCT as a theoretical lens to understand principals and teacher educators' perceptions of STEM education may help provide insights into priorities they place on different aspects of, and approaches to teaching STEM in their schools and universities. This is important, given the relationship between perceptions, attitudes, and *courses of action* as discussed earlier. Importantly, this research has highlighted the methodological significance of using the LCT framework with data gleaned from the D-STEM instrument to unearth participants' perceptions of STEM education. It has enabled the representation of the kind of knowledge that might be valued, and the kind of knowers that might be desired by principals and teacher educators of STEM.

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