

STEM Learning Environments: Perceptions of STEM Education Researchers

Vesife Hatisaru

University of Tasmania

<vesife.hatisaru@utas.edu.au>

Kim Beswick

University of New South Wales

<k.beswick@unsw.edu.au>

Sharon Fraser

University of Tasmania

<sharon.fraser@utas.edu.au>

In efforts to provide effective support in STEM education in general and to help school teachers and leaders to consider STEM approaches and carry them out effectively, the perceptions of researchers active in STEM education or initiatives regarding STEM are significant. Despite many efforts to disseminate and implement STEM education, little research has focused on the researchers. The present study aimed to explore STEM researcher perceptions of STEM learning environments using the Draw a STEM Learning Environment Test (D-STEM). The drawings portrayed varying levels of STEM integration and in all depictions, there were indications of student-centred instruction. We conclude this paper with a discussion of the implications for practice and research.

For over a decade, global interest in STEM from both educational and workforce perspectives has proliferated. Despite the current global interest, however, no universally agreed definition has been established (English, 2016). 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). Moore and Smith (2014) described STEM 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” (p. 5). A common feature in these and other definitions (e.g., Vasquez, 2013) is the integration of science, technology, engineering, and mathematics. In addition, STEM has been interpreted as enhanced teaching of single STEM disciplines by, for example, the use of challenging problems in mathematics (Hobbs, Clark, & Plant, 2014).

It is widely agreed that STEM education is vital for the future success of individuals (Stohlmann, Moore, & Roehrig, 2012). It can afford students a chance “to make sense of the world rather than learn isolated bits and pieces of phenomena.” (Morrison, 2006, p. 4); develop their competence in STEM disciplines (Stohlmann et al., 2012) and the knowledge and skills needed for the contemporary workforce (Vasquez 2013). Effective STEM teaching can increase students’ interest and motivation in pursuing STEM-related careers (Stohlmann et al., 2012). Over the years, much research has focused on STEM teaching and, in particular, maintaining and increasing STEM teaching capability.

The learning environment has been identified as a main contributor to successful STEM teaching (Maltese & Tai, 2010) and considerable attention has been paid to student and teacher perceptions of learning environments in individual STEM disciplines: mathematics, science, and engineering (e.g., Afari, Aldridge, Fraser, & Khine, 2013). Few studies have, however, focused on ‘whole of STEM’ learning environments (e.g., Vennix, Brok, & Taconis, 2017). Furthermore, despite their prominent role in STEM movements across the country and internationally, little research has focused on the views of researchers active in STEM education or initiatives. The aim of this study was to explore this cohort’s perceptions of STEM learning environments. The research question we addressed in this article was: How do researchers active in STEM education research perceive STEM learning

environments? In particular, how do they perceive discipline integration and student-centred pedagogy as part of STEM learning environments?

STEM Learning Environments

John Dewey, Zoltan Dienes, and Richard Lesh, whose ideas have impacted science, mathematics, and engineering education for years, provide theoretical foundations for effective STEM learning environments (Glancy & Moore, 2013). Glancy and Moore (2013) promoted an integrated approach to STEM learning. In their vision of STEM learning environments, STEM practices (e.g., engineering design) use knowledge from different disciplines (e.g., mathematics), and problems are completed combining practices from two or more STEM disciplines (e.g., scientific experimentation and engineering design). STEM problems are interdisciplinary and grounded in the real world in that they are experienced by the community. In effective STEM learning environments students can relate to and engage with problems and make sense of them based on their own experiences. As is the case when interdisciplinary problems are worked on outside of the classroom they are tackled by teams, whose members have different knowledge and expertise: students work collaboratively with each undertaking particular roles and responsibilities. To facilitate concept development, generalisation, and abstraction, concepts are presented in multiple ways including written symbols, diagrams and concrete models, and problems are structured so as to require translations between these modes of these representation.

Vasquez (2014/2015) argued that STEM teaching activities do not necessarily incorporate all four STEM subjects every time. Furthermore, Vasquez argued that all STEM learning experiences are characterised by application. That is, STEM learning experiences provide students opportunities to apply the knowledge and skills they have already learnt or are currently learning. Accordingly, STEM teachers need to draw upon multiple teaching approaches, and especially experiential and open-ended methods such as science inquiry, engineering design, project-based learning, and problem-based learning (Honey et al., 2014; Vasquez, 2013). Moving from traditional pedagogies to these sorts of teaching and learning practices necessitates changes to the roles of both teachers and students, and hence changed learning environments. According to Vasquez (2013), the teacher sets goals, leads instruction, facilitates student learning in each or across disciplines, and invites students to shape the learning experiences. Students are active, collaborate to complete learning activities, take ownership of their learning, and apply their knowledge and skills to real problems.

Drawings in Learning Environment Research

Inquiring into individuals' conceptions of their educational experiences is acknowledged as vital (Haney, Russell, & Bebell, 2004) and although classroom observations and questionnaires have been used in this research for some time (see Fraser, 2014), "there is considerable scope for the development of new methods and the wider use of established methods for qualitative studies." (Fraser, 2014, p. 116). Drawings offer an alternative technique for documenting individuals' conceptions of their teaching and learning experiences (Haney et al., 2004). For over 40 years, educational researchers have explored students' conceptions of scientists, mathematicians and science/mathematics teachers elicited through their drawings.

The "Draw a Scientist Test (DAST)" (Chambers, 1983) was patterned on Goodenough's (1926) "Draw a Man Test". Finson, Beaver, and Crammond (1995) developed the "Draw a Scientist Test Checklist" to facilitate assessment of drawings. In later years the, "Draw a Science Teacher Test (DASTT)" was adapted, and its accompanying checklist (DASTT-C)

devised (Thomas, Pederson, & Finson, 2001). This test was used in teacher education to document the knowledge and beliefs held by preservice elementary teachers about elementary science teaching methods (see Thomas et al., 2001, for a comprehensive review). These efforts opened the way for researchers in mathematics education such as Picker and Berry (2001) to develop the “Draw a Mathematician Test (DAMT)”. Knight and Cunningham (2004) adapted DAST research to engineering education. For decades, DAST, DAMT, or DASTT studies have been conducted in many countries and on different continents including in Europe, the Middle East, Asia, and the United States. Participants have included students from K-12 and prospective teachers.

The Study

The study reported here was part of the national project, *Principals as STEM Leaders: Building the Evidence Base for Improved STEM Learning*, which aims to develop robust approaches to supporting principals to effectively lead whole-of-school enhancement of STEM teaching and learning. Participants comprised of twelve of the fourteen members of the research team who attended a two-day face-to-face workshop for invited school principals and the research team, held near the start of the project. They came from diverse backgrounds representing all four STEM disciplines and six Australian universities.

Instrument, data collection and analysis

We used an adaptation of Thomas et al.’s (2001) DASTT and Haney et al.’s (2004) work using drawings to document educational phenomena, to create the Draw a STEM Learning Environment Test (D-STEM), to collect data about participants’ perceptions of STEM environments. The D-STEM task required participants to draw a STEM learning environment and then to explain their drawing. The purpose of the descriptive narrative was to clarify and expand upon the information contained in the drawing, and thereby to assist with coding. Data were collected at the start of the workshop.

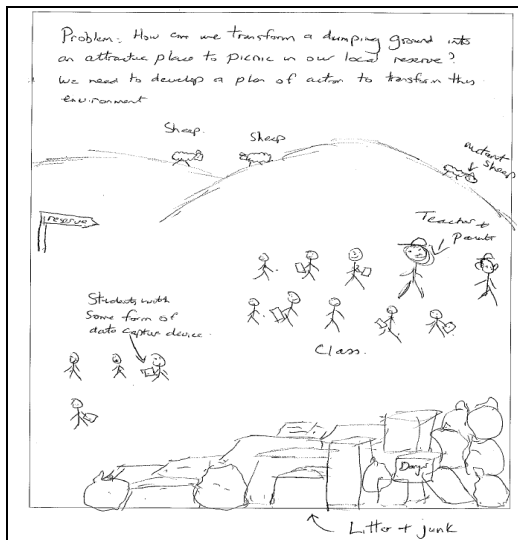
To analyse the drawings and associated written descriptions, the authors developed the D-STEM rubric based on an extensive literature review and initial drawing data from school principals. The rubric included elements of effective STEM learning environments identified in Glancy and Moore (2014), Honey et al. (2014), and Vasquez (2013). Specifically, we looked for evidence of the extent to which: STEM disciplines were integrated; students worked on realistic problems; there was collaboration, connection to students’ personal experience, use of multiple representations, and student-centred instruction, and materials were used. Each element was unpacked in the form of a set of indicators, and the extent to which each seemed to be represented in the drawing and writing considered holistically, was coded in Likert fashion as ‘None’, ‘Some’, or ‘Strong’. The first and third authors independently coded the D-STEM responses achieving 92% agreement. Disagreements were resolved through to discussion to reach consensus. Table 1 shows the indicators for the two elements that we will focus on in the presentation of results, and illustrates what constituted each of None, Some, and Strong in relation to these.

Table 1
Example indicators and rubric

Element	Indicators (from the literature)
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

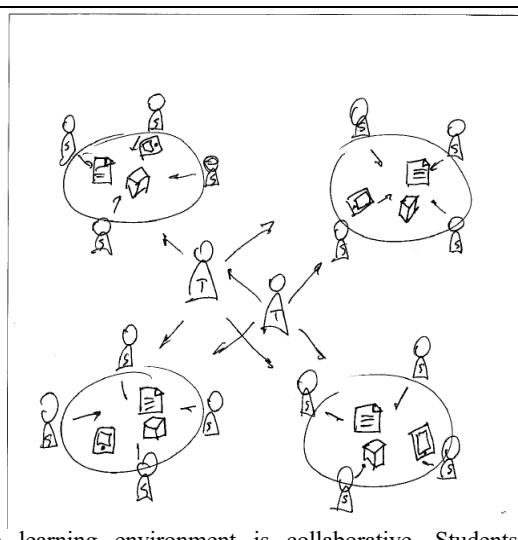
Student-centred instruction group work happens; experiential and open-ended methods such as science inquiry, engineering design, problem-based learning, etc. are implemented to solve realistic problems; the teacher takes on roles other than knowledge giver; students are active; students take on roles other than listener or receivers of information; there is interaction between the teacher and students

Figures 1 and 2 are examples of participants' drawings. Our judgment of the extent to which each of the elements of the rubric is evident, is shown in Table 2. In Figure 1, the emphasis in the picture is on a context beyond the classroom and school. It depicts a meaningful problem grounded in the real world which possibly requires students to use knowledge and skills from a range of STEM areas. There are indications that the environment is one in which students work collaboratively on the problem, along with the teacher and possibly parents. The written description confirms the presence of a realistic problem and mentions transforming and presenting the knowledge and using different representations.



This scenario is problem-based. The students need to develop a plan of action to present to the 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 locations, quantify the work needed, complete cost estimations, and develop a proposal to submit to council. (T9)

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



The learning environment is collaborative. Students are working together to explore and design solutions to an open-ended problem. They are using physical and digital resources to: access information; try out solutions; document their progress; share their work with others. The teachers provide support, ask questions, give feedback, and highlight good work to be shared with the whole group. Depending on the problem, the tools include physical resources such as pens, papers, crafting materials, handheld computers/tablets to access online resources, electronic resources to build prototypes, etc. (T10)

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

In Figure 2 the emphasis in the drawing is on students working in groups. The written description confirms these elements and there is also a mention of open-ended problems. Students work collaboratively to find solutions to problems by using a range of resources and tools. The teacher's role is depicted as guiding the groups.

Table 2
Assessments of D-STEM responses shown in Figures 1 and 2

Elements	Extent present: Fig. 1	Extent present: Fig. 2
Integration	Strong	Some

Realistic problems	Strong	Some
Collaboration	Some	Some
Personal experience	Strong	Some
Multiple representations	Some	None
Student-centred instruction	Strong	Strong

Results

The frequency with which each of elements of STEM learning environments was deemed to be present at each level in the twelve participants' responses is presented in Table 3, and we describe the results for Integration and Student-centred instruction in detail. Participants are designated by codes: T1, T2 and so on.

Table 3

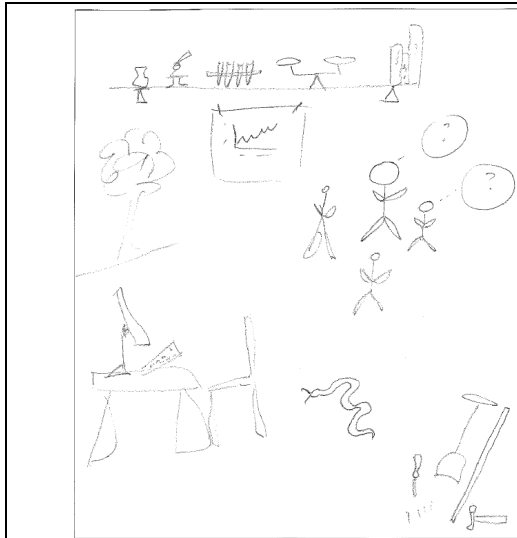
Numbers of D-STEM responses at each level for each element (n=12)

Elements	None	Some	Strong
Integration	2	7	3
Realistic problems	4	5	3
Collaboration	0	11	1
Personal experience	4	4	4
Multiple representations	4	7	1
Student-centred instruction	0	7	5

Integration

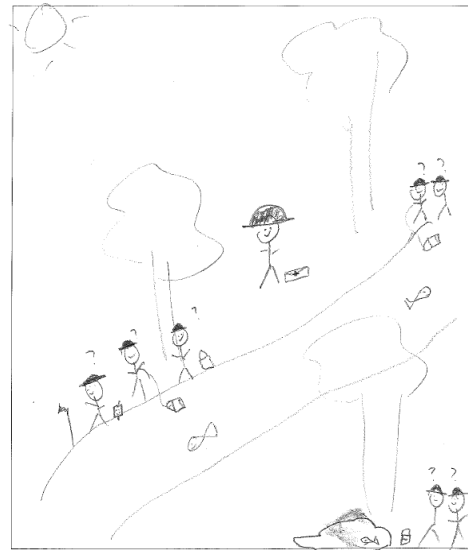
There was no indication of isolated teaching of the four STEM disciplines in either the participants' drawings or writing. Most responses emphasised helping students to develop meaning through the applied STEM experiences. In most (n=10), real-world problems were indicated. In some drawings (n=4) the problem was explicitly stated (e.g., Figure 1), whereas in others (n=6) the nature of the problem was not specified (e.g., Figure 2). In the remaining drawings (n=2) there was no reference to a content area or to a problem.

In four drawings (T2, T4, T10, and T11) reference was made to open-ended, innovative and inquiry-based, or real-world problems, but because these problems were not explicitly stated, it was difficult to interpret the extent to which the STEM disciplines were integrated. In the other eight drawings, the degree of Integration was judged Some or Strong. The degree of integration was deemed to be low in two of those drawings (T5 and T12). In one (T5), a context was depicted in which students learn concepts and skills from two or more disciplines and use them in an investigation: "Students are in small groups conducting a mathematical design investigation. They are looking of different aspects of the same investigation." (T5). In the other (T12, shown in Figure 3), the environment portrayed suggests students apply skills from the various STEM disciplines.



A STEM environment is one in which the students and teacher(s) have a variety of tools at their fingertips which can be drawn upon at need- in the solution to problems/ the investigation of ideas/experimentation for solutions. The questions of interest are generated from the group in relation to real world problems. The issues are important and relevant to the group. Students and teacher(s) work together with the teacher facilitating the students' learning. The curriculum guides their practice. 21st Century skills best is a goal. (T12)

Figure 3. An example of D-STEM response emphasizing a low degree of Integration.



The drawing shows the students engaged in a learning activity perhaps science and maths are being used to answer questions they have about their local environment. In particular, this one could be water sampling in a local creek and other water environment present such as ponds. The teacher has provided the learning/tools environment and in this case a variety of equipment/tools students may need to answer their questions. (T14)

Figure 4. An example of D-STEM response potentially showing extensive Integration.

The level of integration was rated Some in three responses (T1, T6, and T13). In these depictions the learning activity appeared potentially to draw on STEM disciplines in an interconnected and interdependent way. In two of them a problem or project was indicated, in which students create a mathematical model to solve a scientific problem. Written responses included:

Students are investigating to projectile motion of a rocket. An inquiry approach is adopted by the teacher. Students develop a mathematical model for the rocket that allows for the prediction of range against distance.” (T1)

In the remaining three pictures the potential for extensive integration was apparent (T7, T9, and T14). In these drawings, students could possibly apply their knowledge and skills from multiple disciplines to real-world problems or projects. The STEM activity in one of those drawing was developing a plan to present to the local council to transform a section of their local reserve that was being used as a dumping area into an attractive place for people to use for picnics, recreation and so on (Figure 1). In another (T14) students use mathematics and science to solve an environmental problem (Figure 4). In another (T7) students use STEM knowledge build a bridge in the school's garden:

The teacher is drawing upon elements of Science, Technology, Engineering, and Maths in order to create a real-life learning experience for students. The students are having the teacher review their mathematical calculations of physics laws as they use these to build a bridge in the school's garden. The students also using technology (i.e. drone/computer, etc.) to monitor the building progress and cross checking with initial plans. (T7)

Student-centred instruction

In all drawings there were Some (n=7) or Strong (n=5) indications of Student-centred

instruction. In most drawings, a well-equipped context in which students were investigating solutions to real world problems through developing, designing, testing, and revising their ideas was represented. Numerous materials and resources such as construction tools, electronic materials, or materials used in design were available in most of the drawings (Figure 3). The learning environments represented showed students working collaboratively to solve problems (Figure 2) and appeared to portray pedagogies that included engaging students in the learning process and promoting inquiry in an authentic manner (Figure 1). Creativity and student autonomy were encouraged as was enabling students to link the knowledge they learn at school with their lives outside of school (Figure 4). In most drawings, there was interaction between the teacher and students. Students were described as active, taking on roles other than listener or knowledge receiver such as collaborator, planner, experimenter, and the teacher's role did as guide or facilitate the learning. A representative description is:

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. (T13)

Discussion and Conclusion

As shown in Table 3, there was considerable diversity in the extent to which the STEM researchers depicted or described the various aspects of effective STEM learning environments described in the literature. This is in spite of the fact that this team of researchers were working together on a specific project that had already involved them in several meetings and planning workshops. Such diversity can be considered a strength, reflecting the differing backgrounds of the researchers whose diverse knowledge can be brought together to address the issues that are the focus of the PASL project in much the same way as the four STEM disciplines can together contribute to the solution of complex authentic problems. It also underlies the importance of avoiding assumptions in STEM education research. While it is recognised that there is no single definition of STEM, and that there are variations in the extent to which disciplinary integration is regarded as essential to STEM education, this study underscores the importance of STEM education researchers articulating their conceptions of STEM.

Not only is there no agreed definition of STEM (English, 2016) but there is also a lack of conceptual clarity in the ways in which elements of STEM learning environments are defined. It was made apparent to us in our attempt to develop indicators to unpack the meanings of the various elements of STEM learning environments, that there is considerable overlap in the way constructs are used in the literature and suggest that further refinement of our scoring rubric is required: for example, both Collaboration and Student-centredness include reference to students working in groups. Of note, these two elements were the only ones represented in the drawings and/or writing of all respondents. It could be that these researchers, to some extent at least, equated STEM learning with a pedagogical approach that emphasises students working in groups. Less commonly depicted or described were Realistic problems, problems that students could connect to their own Personal experience, and Multiple representations. Because participants both drew STEM learning environments and elucidated their conceptions using text, it is unlikely that the emphasis on students working in groups can be attributed to such things being relatively easy to portray in drawings.

Acknowledgement

Principals as STEM Leaders: Building the Evidence Base for Improved STEM Learning is an initiative of, and funded by, the Australian Government Department of Education and Training. We acknowledge the contributions to PASL of team members: Chris Branson, Julie Clark, Lorraine Day, Garry Falloon, Vince Geiger, Derek Hurrell, Jenny Martin, Jodie Miller, Andrew Pierpoint, Stephen Viller, Helen Watt, and Dennis Yarrington.

References

- Afari, E., Aldridge, J. M., Fraser, B. J., & Khine, M. S. (2013). Students' perceptions of the learning environment and attitudes in game-based mathematics classrooms. *Learning Environments Research, 16*, 131–150.
- English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education, 3*(3), 1-8.
- Fraser, B. (2014). Classroom learning environments: Historical and contemporary perspectives. In Lederman, N. and Abell, S. (Eds). *Handbook of Research on Science Education* (Volume II, pp. 104-119). USA: Routledge.
- Glancy, A. W., & Moore, T. J., (2013). *Theoretical Foundations for Effective STEM Learning Environments*. School of Engineering Education Working Papers. Paper 1.
- Haney, W., Russel, M., & Bebell, D. (2004). Drawing on education: Using drawings to document schooling and support change. *Harvard Educational Review, 74*(3), 241-271.
- Hobbs, L., Clark, J. C., & Plant, B. (2018). Successful students – STEM program: Teacher learning through a multifaceted vision for STEM education. In R. Jorgensen & K. Larkin (Eds.), *STEM education in the junior secondary* (pp. 133-168). Singapore: Springer Nature.
- Honey, M., Pearson, G., & Schweingruber, A. (2014). *STEM integration in K-12 education: status, prospects, and an agenda for research*. Washington: National Academies Press.
- Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(11).
- Knight, M., & Cunningham, C. (2004). Draw an engineer test (DAET): Development of a tool to investigate students' ideas about engineers and engineering. In *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*, Salt Lake City, UT.
- Maltese, A., & Tai, R. S. (2010). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among U.S. students. *Science Education, 95*, 877 – 907.
- Morrison, J. (2006). *STEM education monograph series: Attributes of STEM education*. Teaching Institute for Essential Science, Baltimore, MD.
- Moore, T. J., & Smith, K. A. (2014). Advancing the state of the art of STEM integration. *Journal of STEM Education, 15*(1), 5–10.
- Picker, S., & Berry, J. (2001). Your students' images of mathematicians and mathematics. *Mathematics Teaching in the Middle School, 7*(4), 202-208.
- Stohlmann, M., Moore, T., & Roehrig, G. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research, 2*(1), 28–34.
- Thomas, J. A., Pedersen, J. E., & Finson, K. (2001). Validating the Draw-A-Science-Teacher-Test Checklist: Exploring mental models and teacher beliefs. *Journal of Science Teacher Education, 12*(4), 295-310.
- Vasquez, J. (2014/2015). STEM: beyond the acronym. *Educational Leadership, Dec./Jan.*, 10-16.
- Vasquez, J., Sneider, C., & Comer, M. (2013). *STEM lesson essentials, grades 3–8: Integrating science, technology, engineering, and mathematics*. Portsmouth, NH: Heinemann.
- Vennix, J., Brok, P., & Taconis, R. (2017). Perceptions of STEM-based outreach learning activities in secondary education. *Learning Environments Research, 20*(1), 21-46.