

RESEARCH REPORT

Responding to the Demands of the STEM Education Agenda: The Experiences of Primary and Secondary Teachers from Rural, Regional and Remote Australia

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Abstract: *In recent years STEM education has been the focus of Australian government funding initiatives, policy and curriculum development at the national and state levels and a key driver of school innovation. Principals, teachers and students have been called upon to develop their capability and interest in the individual STEM discipline subjects or to engage in interdisciplinary STEM activities. Much of the focus on STEM has been driven by a national agenda informed by the needs of industry, and research that indicates that the students graduating from schools and universities today with STEM qualifications will not be sufficient for society's needs. While the agenda encompasses more than individual teachers or schools, it is teachers who are at the forefront of its implementation in classrooms. In this paper we report on the perceptions of teachers about issues impacting on the effective teaching of STEM in rural, regional and remote Australia, and strategies they use to overcome issues/barriers and building the confidence and capacity of STEM teachers. Based on these, the paper reports some potential solutions to the issues faced by schools in rural, regional and remote Australia addressing the demands of the STEM Education focus.*

Keywords: *STEM teaching; teacher capacity; STEMCrAFT; rural, regional and remote Australia; school leadership.*

Introduction

Developing an innovative and dynamic knowledge-based economy is recognised as a global pursuit (Kearney, 2011). The Australian Chief Scientist stated that a “workforce with a substantial proportion educated in Mathematics, Engineering and Science (MES) is essential to future prosperity” and a “critical underpinning for the future of innovative economies” (Office of the Chief Scientist [OCS], 2012, p. 6). In both reports by Kearney and the Chief Scientist, teaching was identified as a fundamental priority for achieving such a workforce, with the latter highlighting “inspirational teaching” as a key recommendation.

The term STEM is now ubiquitous (Fraser, Earle, & Fitzallen, 2019) and used in the literature and government reports to encompass both the teaching of the individual curriculum areas (science, digital and design technologies [encompassing engineering principles], mathematics) and the teaching of these subjects in an integrated manner through student engagement with real world and authentic problems (Honey, Pearson, & Schweingruber, 2014). STEM teachers include teachers who teach science, digital and design technologies and mathematics and/or integrated STEM through inquiry and problem-based learning, in either primary or secondary school settings. A significant difficulty facing

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the implementation of STEM education in schools is the chronic shortage of teachers appropriately qualified, with adequate content knowledge and pedagogical content knowledge or expertise to teach science and mathematics throughout Australia (Hobbs, 2013). More than a third of Australian secondary mathematics teachers and a quarter of science teachers are not adequately qualified to teach in those fields (Productivity Commission, 2012). It follows that being taught by teachers without expertise in a teaching area negatively affects student achievement (Whitehurst, 2002). Teachers who are teaching out-of-field, that is, teaching a subject for which they are not qualified (Education and Training Committee, 2006), often have little confidence or self-efficacy to teach science and/or mathematics individually. It would be even more unlikely that such teachers would have the capacity to reframe their teaching and their students' learning or adopt new pedagogies for integrated STEM argued by Hobbs, Cripps Clark and Plant (2018). Importantly, in relation to the arguments we pose in this paper, rural, regional and remote (RRR) schools experience these issues to a greater extent than schools in urban areas.

Teaching in rural, regional and remote schools

The term “regional and remote” is used to encompass all areas in Australia outside its major cities. In relation to the research reported here, undertaken with participants from Tasmania and Western Australia, the Australian Standard Classification System (Australian Bureau of Statistics [ABS], 2016) classifies the majority of Tasmania as regional and its west coast and some areas of the east coast deemed remote, while the majority of Western Australia is categorised as very remote.

The keys issues cited in the literature concerning teaching and learning in RRR areas of Australia are: the difficulty in recruiting, retaining and supporting teachers (Halsey, 2018) and potential impact of out-of-field and inexperienced teachers on the quality of teaching and student learning (Ingvarson et al., 2014; McConney & Price, 2009) and teachers' beliefs about RRR Australia (Kelly & Fogarty; 2015). The need for STEM-literate parents (Timms, Moyle, Weldon, & Mitchell, 2018) as well as community understanding of and engagement with education and STEM (Council of Australian Governments, 2015) have also emerged as key to strong STEM learning environments.

There is much research documenting the issues faced by teachers in RRR schools and the challenges for recruiting teachers to teach in these locations (e.g., Cuervo & Acquaro, 2018; Lamb, Glover, & Walstab, 2014). In recent years the focus of policies has been on providing incentives to teachers to take on rural placements, including financial gain and/or cancellation of debt, and rewards through subsequent desirable placements (Reid et al., 2010). Once teachers take up a position in RRR schools, they may experience issues that undermine their decision to stay (Rural and Regional Affairs and Transport References Committee, 2009). These include professional isolation and the inability to build advice networks naturally (Baker-Doyle & Yoon, 2011), as well as the lack of access to mentoring expertise, release time and collaboration, and poor access to technical and support services (Sullivan, Perry, & McConney, 2013). Furthermore, principals in these schools may be inexperienced but are required to manage a large proportion of beginning teachers and a transient teacher workforce with high rates of teacher turn-over (Handal, Watson, Petocz, & Maher, 2013).

First year out and out-of-field teachers are common in schools in RRR Australia (Hobbs, 2013; Lyons, Cooksey, Panizzon, Parnell, & Pegg, 2006). Such teachers are known to struggle initially to teach effectively, which may result in them feeling inadequate and stressed, influencing “the extent of the success of their development in teaching as a profession” (Steyn & du Plessis, 2007, p. 149). In some states in Australia, mentoring of first year teachers is mandatory (Department of Education and Early Childhood Development, 2012), based on the premise that the exchange of ideas, knowledge and experience between colleagues can contribute positively to teacher professional development, and reduce teacher attrition (Ingersoll & Kralik, 2004; Smith & Ingersoll, 2004).

Kelly and Fogarty (2015) have argued that the barriers to attracting and retaining teachers in schools in RRR Australia are many and complex. They and other researchers highlighted the impact of internal representations of rural life that underpin teachers' consciousness about rural teaching (Reid et al., 2010), the psychology of teachers, their sociological context and their behavioural intentions (Kollmuss & Agyeman, 2002), as key factors contributing to barriers to teachers electing to teach in rural schools. Handal et al. (2013) speak to the internal factors outlined by Kelly and Fogarty (2015), indicating that teachers who take up positions in RRR schools do so due to "a perceived sense of a stronger staff collegiality; because of the attraction of a rural ambiance and the desire to gain exposure/experience in rural education, and to help rural and remote communities" (p. 13). Nevertheless, a recent longitudinal study of pre-service teachers conducted by Cuervo and Acquaro (2018) found that despite having a positive outlook toward teaching in an RRR context, all their participants (n=8) held deficit views about rural schooling. Such views included that schools are poorly resourced and staffed and that they make do with teachers teaching out-of-field. While some caution is needed in making generalisations from such a small study, this research does signify the need for further exploration of the views held by teachers in RRR contexts.

Teachers are an important part of the community and according to Halsey (2018) "have the most direct impact on children's learning in schools" (p. 38). While attracting and retaining teachers remains an issue as discussed, of equal importance is the RRR teachers' academic capabilities and the personal attributes needed for teaching (Teacher Education Ministerial Advisory Group [TEMAG], 2014). TEMAG highlighted the importance of the teachers' commitment to place and people and, as Halsey summarized, their role in "building student achievements and successful post school pathways" (p. 39). The consciousness that teachers bring to their teaching context influences both their approach to teaching and the expectations they have of their students. McCarthy, McCourt, Ikutegbe and Zhou (2018) found that student outcomes and their intrinsic motivation for studying improved when their teachers had high academic expectations of them and presented them with challenging work. Teachers may also hold unconscious biases (Lavy & Sand, 2015) and communicate their expectations to students. This conclusion has been supported by others (e.g., Beyerbach et al., 2009) who found a correlation between student achievement and teacher expectations or beliefs (e.g., girls do not do mathematics [e.g., Agbley, 2015] or physics [e.g., Zohar & Bronshtein, 2005]).

Communities are key to educational attainment in RRR Australia. In describing the importance of community and family, James et al. (1999) summarized the outcomes of earlier work of Williams, Long, Carpenter and Hayden (1993) who argued that "...rural disadvantage is in the main part related to family and community attributes, contending that the principle determining factor is the extent to which education is valued and promoted in the family and local community" (James et al., p. 10). More recently, Watson et al. (2017) reported that members of the RRR communities they surveyed believed that students are either academic or not (p. 65). This supposition, Watson et al. argued, would mediate student aspirations for further study. In their study participants made specific reference to the values held by the parents regarding education and their lack of understanding of the value of education (p. 66). As students are perceived to assimilate the attitudes held by their parents towards education, such a limited understanding of education could influence students' responses to the pathways to further education that are offered to them.

Challenges for teaching STEM and S.T.E.M subjects in RRR

Research has identified that students in schools in rural Australia are less-advantaged than their urban counterparts (Human Rights and Equal Opportunity Commission, 2000); they are less likely to finish secondary school (Lamb et al., 2004) or attend university (ABS, 2013). Such disadvantage has also been identified in the data gathered in relation to science and mathematics education (Sullivan et al., 2013). Data collected in two major international studies (Program for International

Student Assessment [PISA]; Trends in International Mathematics and Science Study [TIMSS], have consistently shown that students in rural and remote schools perform at a lower level in both mathematics and science than their metropolitan counterparts (Aldous, 2008). Sullivan, McConney, & Perry (2018) noted that Australia has one of the largest gaps in urban-rural achievement in PISA.

An analysis of the international data collected through PISA indicated that urban schools are:

usually larger, have a more socio-economically advantaged student body, enjoy greater responsibility for resource allocation, are less likely to experience staff shortages, are more likely to have a higher proportion of qualified teachers, and have higher student-teacher ratios than schools in rural areas and towns (Organisation for Economic Cooperation and Development [OECD], 2013, p. 2).

These findings align with the factors identified in Australian research as contributing to lower student performance in science and mathematics in RRR schools (Sullivan et al., 2018). In particular, the difficulty of recruiting and retaining teachers (Goodpaster, Adedokun, & Weaver, 2012; Handal et al., 2013; Sullivan et al., 2013) and the consequent relative inexperience of rural teachers (Aldous, 2008; Handal et al., 2013; Hobbs, 2013; Lyons et al., 2006) as discussed previously. Schools located in the smallest rural communities have the lowest socioeconomic profiles and “the lowest academic performance and the largest shortages of teaching staff and instructional materials” (Sullivan et al., 2013, p. 354). Such inequitable distribution of resources (including educational resources, instructional materials, qualified and experienced teachers) has been found to be associated with students’ learning and educational outcomes (Chiu & Koo, 2005). While the context of the school may be a source of constraints to student learning outcomes, school leadership and strategic resourcing have been identified as key to overcoming them (Robinson, Hohepa & Lloyd, 2009).

Du Plessis, Carroll and Gillies (2014) stressed the importance of school leadership in embedding support for STEM in their schools; leaders who understand the issues and who are connected with teachers’ experiences in classrooms and can engage in “inside-out” (Darling-Hammond, 2010) school improvement. Berlin and White (2012) recommended that those new to teaching STEM disciplines work collaboratively (inclusive of team-work, team teaching, mentoring and collective engagement in professional learning) to design and implement STEM teaching and learning. Steyn and du Plessis (2007) argued that an important aspect of supporting teachers teaching out-of-field is the involvement of the school community in recognising the impact that this phenomenon has on the learning environment. They recommended that school leaders develop a shared sense of purpose among parents, teachers and learners and the broader community resulting in “cooperation between the home and the school [which] creates a secure environment in which effective learning can occur” (p. 155). Such reciprocal engagement and shared understandings of the importance of STEM education, may go some way to influencing students’ interest and engagement in STEM subjects.

Not only can community engagement support teachers teaching out-of-field in RRR contexts, such engagement may also influence and be influenced by the espoused purpose and goals of the school. In the report, *Inspiring Australia: A National Strategy for Engagement with the Sciences* (2010), the Steering Committee for a National Science Communications Strategy argued that Australia “must engage the wider community in science” (p. xiii). The Chief Scientist later reasoned that at the heart of such community engagement is scientific literacy, for which a higher level “...within the broader community is essential for a modern, well-informed society” (OCS, 2012, p. 10). Scientific literacy will be influenced by the extent to which schools sustain focussed initiatives aligned with purposeful STEM goals, and both communicate with and co-opt their school and local community into achieving them.

According to Roberts (2018), a key issue for STEM education in RRR contexts is lack of understanding on the part of students and teachers as well as parents, of the ways rural industries operate and the capabilities they need in their workforce. He found that the link between school subjects and present and future careers in rural industries was missing (Roberts, 2014). As those working in and leading rural industries were also disconnected from the language of schooling and curriculum, they were not necessarily able to communicate their needs and relate them to subjects that students would benefit from studying in order to enter their industry. Roberts (2014) summarized this as being a significant language (and hence understanding) gap between students, teachers and rural industry and communities.

The issues related to school leadership and resourcing, educational outcomes and community understanding of and engagement in STEM education, indicate that a more systematic approach to solving the problems faced by teachers and more specifically STEM teachers in RRR contexts is required in order to both attract and retain quality teachers of STEM. Australia has the *National STEM School Education Strategy* (Education Council, 2015) for improving STEM teaching and learning, as well as dedicated national, regional and/or local centres to address this purpose. Other countries have implemented similar strategies (e.g., the Netherlands, Belgium, Norway, Ireland, France, Israel, Switzerland, Italy) with centres that aim to improve the quality of STEM teaching and sometimes to increase the popularity of science and technology (Kearney, 2011). A common approach in Australia described by Murphy, MacDonald, Danaia, and Wang (2018) is to establish networks of teachers, teacher trainers and other relevant stakeholders, often at the regional level, with the aim of implementing curricular reform and supporting initiatives favouring inquiry-based learning (e.g., cross-disciplinary, thematic or project work).

The extent to which these national, regional and/or local initiatives have begun to address the issues known to impact upon teacher quality, particularly in relation to teachers of STEM in RRR, is as yet unknown. The purpose of the research reported here was to investigate the following research question: *How do teachers address issues that they believe impact upon their ability to teach STEM (subjects) effectively?* In this paper, we both explore these issues with RRR STEM teachers, and examine how they cope with them by explicating the strategies they have either used or that they believed might help. We also explore the extent to which their proposed strategies align with school, state and national initiatives.

The project

In this paper we report on some outcomes of a project undertaken by the School of Education and the Centre for University Pathways and Programs (CUPP) at the University of Tasmania funded by the Australian Department of Education, through the Australian Maths and Science Partnerships Program initiative. The project was titled *Evaluating and selecting STEM resources: Capacity building for teachers in rural and regional schools* (STEMCrAFT). The aim of STEMCrAFT was to build capacity for RRR STEM teachers using a peer support model. The project arose out of the recognition that staffing challenges in RRR schools can mean that teachers with limited expertise in mathematics, science and technology, teach in these subject areas and this impacts on student achievement and subsequent student ability to engage in STEM pathways to tertiary learning.

STEMCrAFT brought university teacher educators with expertise in mathematics and science teaching and relevant discipline representatives from science and engineering together with rural and regional teachers of science, technology and mathematics – both experienced (> 5 years teaching in the STEM discipline) and novice teachers (< 2 years teaching in the STEM discipline). It aimed to identify the tacit knowledge of experienced science and mathematics teachers through them reflecting critically (Schön, 1983) on their practice and to provide novice and out-of-field teachers access to their expert ways of selecting teaching resources. As a result, a framework for selecting resources

was developed, and field tested iteratively by both experienced and novice teachers. Details about the framework, the process by which it was developed, and its perceived usefulness are presented elsewhere (Beswick, Fraser & Crowley, 2016; Kilpatrick & Fraser, 2018).

In this paper, we report the outcomes of a reflexive thematic analysis (Braun & Clarke, 2006) of responses to questions asked of participant teachers, prior to them engaging in the collaborative development of the framework. This approach was deemed the most appropriate to unearthing participants' perceptions of the issues that they believed impacted upon their ability to effectively teach STEM (in either an integrated manner or as individual disciplines) in their schools. It also unearthed their suggestions for possible strategies that would enable these issues to be addressed.

Method

Participants comprised of 26 experienced and 11 novice or out-of-field teachers of science and mathematics from early primary to senior secondary. Two workshops were held, one in each of two Australian states, Tasmania (18 experienced, two novice) and Western Australia (eight experienced, nine novice). All participants were nominated by senior education systems leaders to attend the workshop, either due to them being recognised as experienced science, mathematics and/or technology teachers or as novice teachers who had expressed interest in these discipline areas. Of the 37 participants, 21 were female and 23 taught in secondary schools. The initial workshop spanned three days and was held in Tasmania. It resulted in the development of a draft framework for selecting resources by the project team, which was field tested and enhanced by the novice teacher participants. The draft framework was taken to the second day-long workshop in Western Australia where participants contributed to further refinements of the framework, after which it was deemed to be at a stage where it could be disseminated and trialled.

Prior to participating in this collaborative exercise in both of the workshops, participants were asked to respond to the following set of four survey questions:

1. What do you perceive as the main issues affecting the effective teaching of STEM in your own context?
2. What strategies have you implemented that serve to overcome these issues/barriers?
3. What do you perceive as the main issues affecting the effective teaching of STEM for teachers teaching out of field and/or teaching in rural, regional and remote contexts?
4. What do you identify as particular strategies that would build the confidence and capacity of STEM teachers teaching out of field and/or teaching in rural, regional and remote contexts?

The aim of getting participants to consider such questions was three-fold. Firstly, the project team was generally interested in unearthing the issues that teachers felt were being experienced in schools interested in teaching STEM (as well as the individual discipline subjects) and the solutions that they felt might mitigate against them. Secondly, the project team wanted to ensure that as much as possible any framework developed contributed to solutions to the issues identified. Finally, the team wanted participants to be able to articulate any negative sentiments they might have held about STEM teaching and set them to one side, prior to engaging positively in the collaborative professional learning the project presented through explicating their practice. Participants' responses to the four questions provided through a hard copy survey were transcribed into qualitative data analysis software, NVivo, and analysed thematically. After an initial reading of participants' responses to the survey, preliminary themes or codes were identified and subsequently grouped together. They were then checked for emerging patterns, variation and consistency through iterative reading and re-reading by the authors and reference to the literature.

Participant responses are reported below using unique alpha-numeric codes (T: Tasmanian participant; W: Western Australian participant; P: Primary; S: Secondary), and any emphasis incorporated by the participant (e.g., use of capital letters) is retained in the quotations.

Results

A reflexive thematic analysis of participant responses within and across all four questions revealed five aspects of the education system that both impacted on STEM teaching and underpinned the strategies identified to mitigate them.

1. The students
2. Teacher capacity
3. The system within which they operate
4. Availability of quality resources and resourcing, and
5. STEM and the wider community

Each of these five themes are discussed in relation to the four questions. Due to the related focus of questions and responses, Questions 1 and 3 are reported together, as are Questions 2 and 4.

All participants in the project had either taught in rural, regional or remote (WA in particular) regions previously or were currently doing so, and could, therefore, speak from experience about the issues particular to STEM teaching (experienced either as STEM subjects taught separately or in an integrated manner without explication) in these contexts. While the issues and strategies identified for teaching STEM in their own contexts (Questions 1 and 3) were evident in their answers to Questions 2 and 4, others that were particular to RRR contexts were added or discussed in more detail.

Questions 1 and 3: What do you perceive as the main issues affecting the effective teaching of STEM in your own context (Q1)...for teachers teaching out of field and/or teaching in rural, regional and remote contexts (Q3)?

The Students: Participants indicated that teachers' ability to teach STEM effectively was affected by their students' attitudes to, and capacity to learn and/or engage in integrated STEM or individual STEM subjects.

The impact of students' low literacy and numeracy levels on their ability to learn in STEM subjects was highlighted. Both students' lack of a deep understanding of mathematics and their limited exposure to science concepts in earlier stages of their education were noted as influencing their learning in later years. This lack of basic knowledge was believed to impact on their ability and/or interest in further study, for example, *Students have limited exposure and understanding of the science concepts. They struggle to do well in pre-tertiary biology and chemistry* (TS1).

Participants referred to students' lack of motivation to study these subjects, citing their perceived lack of relevance: *Student motivation is secondary. Motivation is falling away earlier, even in late primary. High school students don't see the need for future jobs. Don't see the people who are using the math/science* (TS11). Low aspirations and an unwillingness on the students' part to put in the effort to develop their subject understandings, as well as teachers' aspirations for their students, were cited as reasons for students' lack of engagement in STEM subjects: *Because of the low aspirations of students/teachers in relation to maths/science, students do not engage. They get a negative attitude towards the subjects* (TS5). One participant linked the low STEM proficiency and student motivation with it having a low priority in schools: *Student motivation: STEM area often a 3rd or 4th priority area* (TS15).

Student numbers in RRR schools can be small, with one participant highlighting that this

results in the need to address *challenges of special needs students in a mixed ability composite class* (TS11). Participants highlighted a feature of RRR contexts in Western Australia – inconsistent student numbers. They noted that numbers were inconsistent due to either the irregular attendance of particular students or the transient nature of the population. Together, this resulted in the high turnover of students—especially, in mining areas in Western Australia. While details of the impact of this phenomenon were not provided, it could be presumed that teachers who must accommodate the needs of itinerant students in an ongoing way, may perceive that this impacts upon their ability to teach a unit of work effectively.

Teacher capacity: Participants recognised the pivotal role of the teacher in the learning environment and determined that both teacher capacity (personal attributes and/or capabilities) to teach STEM and the limitations imposed upon them due to external factors impacted on their teaching effectiveness.

Participants highlighted a lack of science and/or mathematics content and pedagogical knowledge in STEM teachers, as a result of inexperienced and/or out-of-field teachers teaching STEM subjects. These deficits were perceived to impact on the quality of teaching and learning; for example:

Misunderstandings of effective teaching and learning approaches that build and develop students' understandings. Serious ignorance of what pedagogy actually means, let alone pedagogical content knowledge – don't even go there lately with the blank looks I get. (TS4)

The development of teacher capacity for teaching STEM was perceived to be limited by a lack of time for expert STEM teachers to effectively share their expertise or to mentor less experienced staff. This lack of time in conjunction with the limited number of science and mathematics teachers in schools, also impacted upon their ability to plan, collaborate and to identify relevant resources. As one less experienced teacher commented: *At our school I am the only Maths/Science teacher. There is no-one with whom I can discuss and plan my lessons* (TS6).

When considering issues specific to RRR contexts, participants noted that it is more likely that RRR schools are staffed with inexperienced teachers: *Rural teachers are of the least/less experienced (new) teachers* (TS13) and/or out-of-field teachers. Consequently, RRR teachers often lacked sufficient content knowledge and/or the confidence to teach in STEM subject areas. In particular they have *low confidence to perform experiments (safety issues)* (TS5). Both inexperience and lack of expertise were identified as being linked with a teacher's reluctance *to try new things* (WP13) and/or teachers not being *confident to ask for help* (TS5).

The isolation of teachers in RRR schools was believed to limit professional conversations and make building professional relationships or collaborations more difficult. Participants indicated that they lacked support and did not have access to good role models or mentors, often *working on own so need to prepare every unit topic, assessment task etc. which takes time* (TS8) with little time to organise and plan. Again, a lack of time was identified as having pivotal impact teaching in STEM in RRR contexts, for example:

The students prefer hands on activities and get motivated through these activities, but we teachers lack time to organise these things at our Schools where only one person is responsible for teaching and preparing resources for STEM. (TS6)

Participants mentioned a *lack of time to build resources* (TS13) and not enough time for *building the relevance [of activities/curriculum]* (TS7).

The system within which they operate: The importance school leaders give to STEM staffing

was highlighted as key to effective teaching and learning practice.

In particular, the impact of principals' disinterest in STEM was identified: *Management (school principals) not perceiving STEM (especially Science) as important so resourced last, get 'any old teachers' (TS2)*. Overall, staffing was perceived as problematic, for example:

The lack of forward planning by schools. Often maths/science teachers are the last to be sourced. The school picks up whoever is 'left over'. [These teachers then] get the "worst" loads as the "top" classes need to be covered by trained/experienced teachers. Those teachers then need to spend more time supporting the less experienced COPE. But we all know that. (TS4)

As one participant noted, the high level of teacher turnover affects the quality of teaching STEM subjects:

Some teachers (non-expert) that end up teaching these subjects are on short-term contracts and pretend to be doing a good job because they are afraid of not having their contracts renewed so they do not seek expert help. (TS2)

This participant went on to explain that in his or her view such practices influence students' interest in STEM subjects: *Because of the above, students do not engage, they get a negative attitude towards the subjects. (TS2)*

Reflecting on RRR contexts, participants noted that staff turnover in schools is high and staff numbers are generally low in the smaller schools. Participants identified that not having teachers capable of teaching STEM subjects in these RRR schools makes staffing the required number of teaching areas/levels difficult, and/or if a STEM teacher is available, it creates an overwhelming workload for them. This means that there are few staff to 'cover their teaching' and it is *harder to get release time for PD (need longer) (TS11)*.

The ways in which schools structure classes was also perceived as limiting teacher effectiveness: *Ability levels of children. I have a year 2/3 class - 7+8 year olds that range [in ability] from Foundation level to Year 10 level (WP3)*. It was also recognised that gifted students and students with special needs must also be catered for. Several participants from Western Australia identified school and system requirements for documentation to cover risk as limiting engaging learning activities and opportunities: *'Red tape' that prevents 'fun' + engagement (excursions/ethics policy) (WP5)*.

The impact of the Australian Curriculum was also identified as negative, with one participant citing its crowded nature: *Time in a crowded curriculum as I teach all subjects trying to cover all science concepts in a year (WP7)*. Another referred to its *huge range of content (WP5)* and several others perceived it as constantly changing thereby impacting upon teachers' ability to plan and prepare appropriately. At least one participant recognised the impact of other educational goals and/or demands on teacher practice and student learning in STEM: *The demands of many other things put on by DoE [Department of Education] and society. Sometimes teaching knowledge and skills come second or third (T8)*.

In relation to RRR schools, it was noted that with few staff and little access to professional learning or expertise, the Australian Curriculum was implemented without support or guidance about what aspects on which to focus. One participant suggested that *support for PL from their admin* was lacking, highlighting that *admin have to believe it is worthwhile (TS3)*. As a result of this lack of support, professional learning and isolation, participants felt that RRR teachers lacked confidence in the quality and/or appropriateness of their teaching and student learning outcomes: *moderation of work?? How is this done?? (TS8)* as *moderation [is] harder in small isolated schools (TS11)*.

Availability of quality resources and resourcing: Participants differed in their experience of

STEM teaching resources, discriminating between teaching resources including kits, equipment and support, information technology (IT) infrastructure and access, and available funding.

Tasmanian teachers tended to recognise that while there are a *great MANY OUT THERE* [emphasis provided in participant response] (TS3) and they are *easy and available* (TS7), there is a lack of *funding for resources and equipment* (TS11), which themselves, can be insufficient for purpose. As noted earlier, time was highlighted by participants as a limiting factor, in particular: *A lack of time to organise resources* (TS6); and to identify suitable resources: *What are the best resources for teaching the AC [Australian Curriculum] outcomes? Not time to find out* (TS15). This participant went on to explain that this situation leads to a *reliance on textbooks which generally provide poor explanations of concepts and not used by students (despite paying for them)*.

IT infrastructure was identified as an issue for some participants, particularly those from RRR in Western Australia: *Internet access: We are a satellite school very poor coverage* (WP7). Participants also identified a lack of support staff: *There is no lab assistant, so I have to look after the Science lab. I find it difficult because of limitations of time* (TS6).

In the RRR context in particular, funding was perceived to be inadequate, with their isolation impacting upon *travel costs for excursions* (TS5) and resulting in a *lack of well-equipped science labs, lack of science lab assistants make it more difficult* (TS6). One participant felt that there was a *lack of resources for gifted [students] especially in these [RRR] schools* (TS11). The lack of access to resources and expertise makes it difficult to keep up to date adding to their planning requirements as the *liberty of buying ad hoc [resources] not there, have to plan way ahead, can make it difficult to do things as the students come up with ideas* (WP15).

STEM and the wider community: Participants referred to the potential negative impact that a community (parents, the local community, industry) that lacks understanding of STEM and STEM education can have on the effectiveness of STEM learning.

It was noted by one participant that families are influential in guiding student participation in STEM, while another noted the persistence of a “*girls don’t do science*” (TS13) mindset. Yet another suggested that subject choice is influenced by community perceptions in regards career options: *Any good students are encouraged to go to Health Sciences rather than exposed to ‘pure’ sciences such as chemistry/physics* (TS5).

Participants believed the importance of STEM subjects was not necessarily recognised in the community: *Parents/students don’t see the importance of STEM subjects (exception maths – but only because the grade is ‘counted’ by employers* (TS5). This participant also observed that there are *no/minimal links to Science/Maths to rural/regional setting (e.g., industry)*. In relation to RRR context, it was noted that *community perception of STEM as a united/integrated & important discipline* (WP15) is limited, with another participant identifying that there was *not much enthusiasm for STEM related subjects in the community* (TS1). Finally, the way STEM subjects are taught was noted as having a *lack of interest/relevance of local community/culture* (TS8) and the content and/or the way students engage with it, resulting in a *lack of relevance to students (when will I use this?)* (TP9).

Questions 2 and 4: What strategies have you implemented that serve to overcome these issues/barriers (Q2). What do you identify as particular strategies that would build the confidence and capacity of STEM teachers teaching out of field and/or teaching in rural, regional and remote contexts (Q4)?

Participant responses to Questions 2 and 4 aligned well with their identification of the issues relating to STEM teaching, with responses to these two questions including both personal strategies for teaching and learning in STEM and strategies that they think would “fix” the issues.

The Students: Responsibility for increasing interest, engagement and student outcomes in STEM was perceived to rest firmly with the teachers and school system.

While participants identified a lack of student motivation and aspirations for STEM as issues, the strategies they nominated for ameliorating them focussed upon teacher practice and the provision of learning support (foundation courses, literacy support and targeted tutorials). Participants highlighted the need to provide engaging lessons with content that is relevant to individual interests and their lives outside/future after school to improve student engagement in STEM subjects. Such learning experiences should be both appropriate to ability (high and low achievers) and challenging for students: *Teach more challenging science/maths rather than accept minimal mediocrity* (TS5).

Teacher capacity: The teacher, the teaching team, the school and the broader education system have responsibility for improving teacher skills, expertise and experience.

At the individual level, suggested strategies included: the teacher being strategic and targeting deep learning: *emphasis on one learning concept per semester* (WP1) *in order to cover concepts properly* (WP7), while continuing to innovate: *Increase excursions to local industries, e.g., Savage River Mines* (TS5). One participant suggested it would be useful for teachers to *redesign the way in which maths is taught. Use a problem-solving approach to identify skills needed* (TS15), while another encouraged teachers to be adaptable: *trying to match interest of each student with ability and look for the appropriate individual ways of delivering the topic* (TS7) in order to both improve the learning environment and enhance student learning.

Having an adaptable teaching approach, being able to cater for a diversity of abilities in the one class, using content selectively, contextualising curriculum and making STEM learning “hands-on”, were highlighted as important for teacher practice. Exposing students to the teacher’s *passion and interest is the key* (TS3) as well as his or her *life experience – bring it into the classroom* (TS13) were noted as important for engaging students in and inspiring them about STEM. Curriculum integration and *cross-curricula approach across learning areas and ages* (WS14) was also identified as important for achieving curriculum relevance and effective STEM teaching and learning.

Support for less experienced teachers was viewed as an important responsibility of more experienced teachers and the school (system) with individual teachers *mentoring and “piggy back” teaching to assist teacher confidence and teacher skilling; peer buddy - side kick training - learning another person’s skills, everyone has an understudy* (WS16).

The System within which they operate: Overall the school principal [and discipline leaders] was identified as being responsible for, contributing to and enabling quality STEM teaching and learning.

Principals provide approval and support for teachers implementing the strategies articulated earlier, and they or their delegates are responsible for timetabling teaching sessions and ensuring that *learning area meeting times given priority* (TS8) to enable collaboration. Principals approve and support *school-based PL whereby we go through practicals to give them confidence to teach* (TS2) and the establishment of teaching teams: *new teacher mentoring and sharing of workload – share preparation, assessment, common resources, collaborative planning and timetabling* (TS8) as well as in-class observation and *swapping classes* (TS4) for *expertise in topics* (TS11). They approve class structuring, for example, *streaming for maths for some year levels* (WS3) and authorise the structuring of the timetable to facilitate the achievement of educational goals, and to *build meetings of teams into the school timetable* (TS11).

School leaders are responsible for *developing a whole school business plan outlining targets up to “year xx” in all learning areas* (WS14) and *advancing a whole school program for science in line with the Australian Curriculum, which offers specific resources* (TP14). Principals can also lead the development of a whole of school *communication strategy [for STEM] – public relations –*

schools – media, to raise its profile and stimulate interest. They contribute to lifting the bar for STEM interest and engagement through supporting *annual science expos for feeder primary school students to motivate the students from an early age* (TS2) or establishing a *primary school extension program* (WP5).

System leaders can empower *local schools – using school data to identify needs* (TS15) for STEM enhancement, and through their structures: *Teacher development schools* (WP5). Participants felt that school systems can build capacity systematically through establishing *support networks, cluster models* (T3) and *network meetings amongst other primary schools and high school* (W3) to enable inter-school support and the development of professional learning communities. One participant highlighted that some STEM areas are more in need of strategic and targeted support than others: *Physics workshop for high school teachers in Australian curriculum topics* (TS8) and principals can build capacity by instigating *workshops for high school curriculum leaders, e.g., new Australian curriculum areas, after school, free* (TS11). Participants recognised the usefulness of *school and system content experts working with beginner teachers* (TS11), with the former receiving *recognition of [their] skills – fast track reward those that can* (TS3). It was also suggested that students would benefit from having *good teachers teaching lower down the school* (TS11).

Availability of quality resources and resourcing: Quality resources (including IT infrastructure and access) and appropriate resourcing of and support for teachers (including professional learning and mentoring) were highlighted as essential for quality STEM teaching and learning.

Throughout their practice, teachers are *continuously looking for engaging resources* (TS7), an *effective, easy and cheap resource to engage students, e.g., physics* (TS7) and *use interesting/attention grabbing resources* (TS10) to interest students in STEM learning. One participant indicated that s/he often uses *resources that I borrow from STEM department at “university”* (TS6) and *include(s) as many hands-on activities as I can*. Whichever resources they choose, participants emphasised the importance of catering for student diversity and sharing good quality resources.

Participants commented that the problem with lack of time and sufficiently qualified STEM teachers in RRR schools could be ameliorated through the provision of suitable *resource packages supported by demos and regular PL* (TS2). The increased *availability of resources especially the kits and lesson plans to go along with them...with workshops on how to run lesson using those kits and plans* (TS6) was perceived to free up RRR teacher time and enhance the quality of their teaching. The usefulness of such *units of work already prepared that just pick up and go with at various levels* (TS8) was reiterated by another participant, while a third saw the availability of a *reliable and successful resource...as a beginning point for teachers to build their own knowledge and practice on* (TP14).

Participants felt that both isolation and teacher capacity could be addressed through the building of *networks that ACTUALLY* [emphasis in participant response] *work – someone paid to do the coordinating (we see this as a great idea, but no-one has the time)* (WS2); creating supportive network clusters between local primary and high schools and *linking less experienced teachers with more experienced/confident teachers* (WP5). Technology (if available and reliable) was perceived as assisting in the creation and maintenance of these networks. It could provide teachers with access to regular webinars to discuss issues and to provide assistance and support, and online forums linking RRR teachers with experts and city schools. Teachers could also access online mentors, view videoed lessons of good practice, and be participants in “beam in a class”. Technology is also essential to facilitating the participation of dispersed teachers in meetings via Skype (or similar) and providing access to library resources. The new technologies available in some RRR schools were considered key to the development of students’ technological skills as they are tools for *integrating* [technology] *into all areas of the curriculum* (WS14).

Information communication technology (ICT) resources were noted by some participants as being key to their practice, and to developing students' subject-specific skills: *used IT resources such as Mangahigh and Khan Academy to give students time to work at their level in maths* (TP14). ICT resources can be expensive, and participants recognised that to build up a sufficiently effective resources requires targeted funding: *gaining funding for more technology* (WP4) to ensure *ICT support, building ICT resources (iPad, computers, apple tv)* (WS14). The importance of applying for targeted *grants/funding* (WP5) *from community grants* (WP13) as well, was raised by several participants from Western Australia. Another participant described a strategic approach to building ICT capacity, interest and resourcing: *very persistent in trying to get other staff on-board, formed ICT committee to assist in making those decisions; reviving computer lab to increase engagement* (WP15).

While technology was perceived as being useful in reducing isolation and building capacity, one participant suggested that face-to-face contact is also important, and that the system should *have experts go out to them* (TS13). Mentoring was a commonly expressed strategy: *across schools for small schools* (TS11) and/or *whether school or area based or online/distance* (TS10). Again, funding and leadership in support of professional learning was seen as key: *principals should ensure that their teachers are appropriately mentored, with teachers from other schools if necessary. Build in visits to other schools, see sessions being modelled* (TS11). For less experienced STEM teachers, *give these people changes to shadow...see the good operators* (TS3), and bring the professional learning to them, for example, *further training made available in the Pilbara region* (WS14). While moderation was identified as being difficult in RRR areas, one participant suggested that a good use of funding would be to *bring rural teachers to the moderation session to meet with the city teachers* (TS13).

School relationship with the wider community: To increase student interest in STEM, participants highlighted the importance of parental, community and industry engagement and the teacher/school role in enabling this engagement as well as enhanced understanding of the relevance and importance of both STEM and STEM education.

There is often expertise within communities that has the potential to contribute to school plans for and enactment of STEM education. As noted: *Community involvement – parents on P&F* [parents and friends association] *are scientists so keen to make science a priority* (WP15) in the school and for their children. Not only should the schools engage with the community, but teachers should *contextualise the curriculum* [in order to] – *connect to the community* (TS8). At least one participant said that the curriculum is sufficiently flexible to enable teachers to *link curriculum to their* [the students'] *chosen careers (mostly farming)* (WS2) and to address the perception in the community that STEM subjects are not important. This same participant was keen to *work with students + parents to see the need for an education past basic reading, writing & numeracy*, to contribute to positive aspirations for further education and future careers.

As suggested previously, exposing students to industries where STEM subjects are essential was deemed effective for motivating students to study these subjects and to realise their importance to future careers, for example, through taking children on excursions to local industries. Inviting people, including parents who are scientists for example, or involved in STEM careers, was identified as another strategy for enhancing student motivation and/or aspirations in STEM: *I have invited young scientists, CSIRO STEM department people to run sessions at our School* (TS6).

Finally, support for STEM teaching and learning was perceived to exist in the community as well, and participants felt it was important for RRR teachers in particular to *seek external help from the community* (WP13) and ensuring that teachers raise community awareness and acceptance of *project based learning....as valuable* (WP5) and secure their involvement by getting *the narrative right – linking STEM to community* (TS10).

Discussion

The responses of participants to the four questions posed to them prior to participating in the STEMCrAfT project revealed close synergies with the literature in STEM education and within the RRR education context. In addition, participants suggested strategies they believed would address the issues teachers face and enhance the quality of STEM teaching and learning, particularly in their own contexts. Their strategies encompassed both ‘tried and true’ tactics which had helped them, and those that both they and other teachers in RRR contexts would benefit from. Importantly, at the heart of these strategies was the school principal who was seen to be the best placed to build both structures and processes for enhancing teacher quality and minimising and/or compensating for teacher isolation (Du Plessis, Carroll & Gillies, 2014). While recommendations from the TEMAG report (2014) identified strategies for improving teacher practices, including a focus on strategic recruitment of staff with a commitment to people and place, the importance of such systemic and systematic approach to recruiting, supporting and retaining STEM teachers to teach in RRR contexts was not evident in the strategies suggested by participants. Rather the participants focussed more on what they perceived would assist them in improving their own practice, on a day to day basis.

The key issues that arose from the data related to the quality and availability of support and resources for teachers (Robinson, Hohepa & Lloyd, 2009) teaching STEM subjects; the time available for teachers (Merritt, 2017) to focus on their own and their colleagues’ capacity to teach STEM effectively (Hobbs, 2013); and student and community/parental engagement and understanding of the importance of STEM education (Education Council, 2015). The solutions to almost all of these issues were perceived as being within the purview of the school principal and school leadership (Halsey, 2018). This is contrary to other research that found that teachers tended to locate the source of students’ problems outside of the influence of the school – a tendency that Beswick et al. (2019) connected with teachers’ lack of efficacy in relation to effecting change. The fact that the teachers in this study located responsibility for the issues they perceived within the school, albeit with the leadership rather than with themselves as teachers, provides some reason for optimism. It points to teachers being cognisant of ways in which issues affecting STEM teaching and learning can be addressed at the school level.

Leadership (for example, principal and discipline leader) within the school was perceived as being pivotal to addressing the issues related to STEM teaching. As Halsey (2018) summarized previously, participants’ responses indicated that effective leaders are able to assist, enable and/or lead staffing and timetabling arrangements to allow collaborative planning and mentoring. As evident in the literature, the role of leaders in recognising the importance of ongoing professional learning and supporting and resourcing staff attendance was recognised by participants as essential for RRR contexts (Handal et al., 2013). This is of key importance due to the nature of the teachers currently staffing such schools which often includes staff who need support and/or upskilling of their STEM expertise (Hobbs, 2013).

In order to enthuse and engage students in STEM learning, participants highlighted the need for schools to be staffed with teachers who are themselves enthused and engaged, appropriately qualified and capable of teaching STEM subjects (Hobbs et al., 2018). They confirmed that there is a dearth of teachers with experience and expertise to teach STEM in RRR contexts, while there is a high proportion of less experienced, first-year out and/or out-of-field teachers. Such teachers require support as they become familiar with the curriculum (both content knowledge and pedagogical content knowledge), the school and being part of the profession. Aligned with advice provided by Timms et al. (2018), participants noted that any strategies aimed at building teacher capacity in the teaching of STEM should promote structured and collaborative planning at the local level, have an inter and intra-school focus straddling primary through to secondary, and have targeted professional

learning formally timetabled into school planning. STEM teachers (science, mathematics, digital/design technologies) deserve appropriate ongoing support in the form of time (to plan, participate in PL, work collaboratively, etc.), mentoring and opportunities to network. Without such systematic support, teachers are unlikely to develop the confidence, capacity and enthusiasm to teach these subjects well, thereby impacting upon their students' learning and interest in continuing to study STEM subjects.

As teachers' professional isolation in some RRR contexts impacts upon them developing the capacity to teach effectively, leaders need to create ways to minimise and/or compensate for this isolation. Suggested solutions to compensate for such seclusion are resource intensive – either regularly enabling teachers to meet physically (bring the teacher to the learning centre or vice versa) or invest in effective information and communication technologies (ICT) that promote collaboration. There was a proviso to the ICT solutions suggested, as teachers in very remote locations suffer from a lack of robustness/reliability of the infrastructure (hardware, software, internet access, etc.) (Halsey, 2018) and potentially teacher capability to use them.

Students' earlier experiences of learning and poorly developed literacy and numeracy skills were perceived to limit their ability to understand later quite complex concepts in STEM. If this "diversity of readiness of students" (Sullivan, 2011, p. 40) across grade levels remains unattended to, participants emphasised that students will be ill-equipped with the knowledge that forms the basis for future mathematics and science understanding. As a result they may well disengage and not continue with higher levels of study. Participants in this research felt that because of the earlier inadequacies in many of their students' education, teachers were unable to achieve what McCarthy et al. (2018) suggested is essential, that is to challenge or extend their learning. Interestingly, contrary to previous research (e.g., Cuervo & Acquaro, 2018; Sullivan, 2011; Watson et al., 2017), none of the participants made any suggestion that teachers in RRR schools held lower expectations of their students than they may have of urban-educated students.

The importance of shared understandings amongst the school and broader community in supporting STEM initiatives and student learning in STEM subjects, was emphasised in participant responses, confirming arguments posed previously by Steyn and du Plessis (2007). Participants highlighted the need to improve the profile of STEM and awareness of the importance and relevance of STEM education within RRR communities (Roberts, 2018; Timms et al., 2018). They suggested that the community did not understand the nature of, or the importance of STEM learning to modern rural industries or future needs. As argued previously by Roberts (2014) and Timms et al. (2018), participants noted that one of their roles was to better contextualise the curriculum and engage with the community to leverage support for STEM pedagogies such as project-based learning.

Knowledge of or preference for farther-reaching strategies focussing on systemic educational or societal responses for addressing the issues relevant to STEM education in RRR contexts was not evident in the participants' responses. Rather, participants tended to focus on what they saw as within the influence of the teacher, the students, and the school within which they taught. None of the participants referred to any national narrative around STEM learning (e.g., OCS, 2010, 2012) or identified any national or state-based policies or initiatives driven by their education system (e.g., financial incentives; desirable placement [Reid et al., 2010]) that might be potentially useful for driving STEM learning or quality teaching or addressing entrenched issues such as students' disengagement and/or preparedness. This speaks to a disconnect between the practice or profession of teaching and the emerging research and/or policy position of Australia more widely.

Another interesting absence in the responses was any reference to STEM education being anything more than quality teaching and effective learning within individual STEM disciplines (e.g., science; mathematics). As discussed, effective learning of any of the individual STEM curriculum

areas is perceived to be underpinned by two things. First an interdisciplinary and applied approach to teaching, that is the integration of one or more of the disciplines (Honey et al., 2014), and secondly, the application of the knowledge and skills learned through study of these areas. Given that the participants focussed on the inadequacy of the teaching of individual subjects, it can be assumed that any suggestion of extending the remit of these teachers into such problem and inquiry-based areas as advocated by Hobbs et al. (2018) is moot.

Conclusion

In conclusion, the study both confirmed and extended the research relating to STEM education in RRR contexts. While it confirmed that teachers of STEM subjects in RRR schools are very often inexperienced and/or teaching out of field, it has also provided us with a greater understanding of the strategies that teachers in RRR contexts implement in the light of such constraints. Participants recognised that students' needs and their capacity as teachers to address them, were significant hurdles to their ability to teach STEM subjects effectively. Student-centred and flexible pedagogies emerged as key to ameliorating these issues in RRR schools.

Teachers were identified as responsible for ensuring that their STEM subjects were both engaging for students and that they had the capacity to study these disciplines. They achieved this through providing appropriate learning support and engaging, relevant and challenging lessons. In addition, participants associated teacher engagement with student engagement; both being essential to effective STEM learning. Enthusiastic teachers who draw upon their own passions and interests in STEM to inform their teaching generate students who are motivated and engaged in STEM learning. These outcomes speak to the importance of targeted professional learning and ongoing mentoring of teachers.

The role of the principal was confirmed as being significant in enabling teachers to teach in these ways. In summary, it is their support and advocacy which facilitates teachers to develop their capability to teach STEM subjects through the provision of ongoing professional learning, mentoring and networking opportunities. Of equal importance is their role in providing appropriate resources including structural (timetabling) and infrastructure (information and communication technologies) in support of teacher learning and practice.

A significant contribution to the literature is the extent to which teachers perceived the school community as contributing to effective STEM learning. Participants highlighted the importance of incorporating teaching and learning approaches that are relevant to context and conducive to future learning and employment. Related to this is the necessity for teachers to view the Australian Curriculum as a guide which can be modified and enhanced to cater for community contexts, needs, interests and expertise. Constructing opportunities for involving community members in the learning process and schooling more broadly was identified as important. Drawing upon existing community expertise and networks in STEM to contribute to enhanced understandings of the importance of STEM for the future of the whole community, was viewed as critical for effective STEM learning.

The research highlighted the need for further research in two areas. Firstly, there is a need to identify ways in which teachers can work with the curriculum to effectively contextualise STEM learning for RRR settings. A second focus is the exploration of ways in which schools can engage the community authentically in both curriculum development and STEM education. In addition, how these partnerships could contribute to increasing teachers' capability to teach STEM effectively and with relevance and passion, irrespective of their experience and qualifications.

Finally, the participants who responded to the four questions that are the focus of this paper, subsequently participated in the STEMCrAfT project. Through their participation in the project,

teachers with expertise and experience in teaching STEM subjects (science and mathematics in particular) contributed to the development of a resource that was then enhanced through the contributions of non-expert teachers of STEM. The resultant framework aimed to assist non-expert teachers in RR context through contributing to their ability to plan and select resources appropriate to their teaching context and their students' needs. It also mitigates against the impact of teachers of STEM who are time-poor, who may themselves be inexperienced or unqualified to teach STEM and without access to mentors on site. The framework that eventuated was experienced by those who developed, subsequently reviewed and/or used it, as very useful in capturing the expertise of STEM teachers. As such it enables out-of-field teachers, teaching in RRR contexts access to important teacher knowledge and skills, expertise that our participants indicated is often lacking in those areas.

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